Understanding Middle Palaeolithic asymmetric stone tool design and use: use-wear analysis and controlled experiments to assess Neanderthal technology

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Lisa Schunk
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Volume 1

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1. Introduction

Lithic artefacts represent a crucial source of information in the archaeological record, serving as a window into the study of the evolution of human technological and ecological adaptations (Ambrose, 2001; Bar-Yosef and Kuhn, 1999; Eerkens and Lipo, 2007; Goodale and Andrefsky, 2015; Iovita, 2010; Klein, 2000; Lycett, 2015; Whiten et al., 2009). In the Middle Palaeolithic record, samples for lithic analyses are provided by categories such as blank production, retouched tools or debris presented within archaeological lithic assemblages. In this context, Middle Palaeolithic retouched tools are found intentionally worked unifacially as well as bifacially. Both cases commonly result in characteristic sharp active edges (Iovita, 2010; Iovita and McPherron, 2011; Retzek et al., 2019). Asymmetric tools as bifacial backed knives (hereafter *Keilmesser*) or *'Prądnik scrapers'* (hereafter *Prądnik scraper*) illustrate no exception in this technological characterisation. These asymmetric tools characterise the so-called *'Keilmessergruppen'* (KMG) (Mania, 1990; Veil et al., 1994; Jöris, 2004, 2006, 2012) and are known from Central and Eastern European archaeological sites dating from late OIS 5 until mid OIS 3 (Jöris, 2004, 2006). In KMG assemblages, *Keilmesser* usually occur together with a spectrum of tools, for example hand axes, foliate pieces, scrapers and points of different shapes (Bosinski, 1967; Jöris, 2004). Within this spectrum, *Keilmesser* as well as *Prądnik scrapers* offer a unique opportunity to study several aspects, for instance tool standardisation and design, tool function and curation. Furthermore, *Keilmesser* represent an archive for tracing certain behavioural phenomena of Neanderthals such as learning strategies, the formation of tool making tradition and knowledge transfer across generations. One reason for that is their morphology.

Keilmesser can be described as tools with a sophisticated morphology and design, which is reflected by a combination of a single active edge opposed by a natural or roughly worked back (Krukowski, 1939; Bosinski, 1967; Jöris, 2001, 2012). Numerous technological studies demonstrate that the manufacturing of the tools seems to follow an underlying concept, highlighting a high degree of tool standardisation (Veil et al., 1994; Jöris, 1994, 2001, 2012; Richter, 1997). Long reduction sequences have repeatedly been documented, allowing for detailed morpho-technological reconstructions of their use-life histories, including repeated phases of production, resharpening and reworking (in the sense of shape transformation) (Jöris, 1994, 2001, 2006; Richter, 1997; Pastoors, 2001; Migal and Urbanowski, 2006; Iovita, 2014; Jöris and Uomini, 2019). This has been argued as a technological strategy requiring the application of comparable production concepts and elaborated resharpening strategies. While these aspects concern tool standardisation, they also account for tool design. Tool design includes a multitude of aspects and goes beyond the overall tool shape. Design also involves the producer's anticipation of the envisaged tool function and its interaction with the user. Thereby, design can be reflected by more obvious aspects such as tool morphology and handling but also includes details like a specific edge retouch.

Within asymmetric tools, such as *Keilmesser* and *Prądnik scraper*, the active edge is seen as being the most characteristic part of the tool. *Keilmesser* mostly display a bifacially worked, acute active edge. Frequently, this edge is altered by the application of the so-called '*Prądnik method*' (hereafter *Prądnik method*) (Jöris, 1992, 2006; Frick et al., 2017; Frick and Herkert, 2019; Frick; 2020a). Here, the *Prądnik method* describes a special type of lateral edge removal from the distal part of the tool (Bosinski, 1969; Jöris, 2001; Jöris and Uomini, 2019). This modification detaches an elongated spall running from the tool's tip along the active lateral edge. This method is used to produce a stable and straight active edge (Jöris, 2006; Frick et al. 2017; Frick and Herkert, 2019). At the same time, it divides the active edge into two parts. Compared to the proximal part of the tool, the distal part seems frequently sharper due to a more acute edge angle. Given this observation, the interpretation of *Keilmesser* as a tool with a multifunctional morphology arose (Jöris, 2001, 2006, 2012; Rots, 2009; Golovanova et al., 2017). However, this assumption has not been experimentally tested yet. Some tools testify a sequential application of the *Prądnik method*, leading researchers to the conclusion that this strategy is embedded within 'resharpening cycles' on tool production, use and maintenance (Jöris, 2001; Frick and Herkert, 2019; Jöris and Uomini, 2019). The implications of the *Prądnik method* are not conclusively clear. For instance, improvement of the edge angle in the sense of increasing sharpness has not been investigated in detail. A further question is also, which influence(s) the modification of the active edge has on tool efficiency and durability during a performed task.

Moreover, the possible influence(s) of the raw material has rarely been discussed. Although *Keilmesser* seem to be standardised in several aspects, the raw material used for the production of these tools has not always been the same (e.g. flint, silicified schist). This variability likely reflects intentional choices based on the availability and the characteristics of the individual raw materials. Raw material properties are known to have a significant impact on tool production and use (Odell, 1981; Eren et al., 2014; Dogandžić et al., 2020; Key, Proffitt and de la Torre, 2020). The effects of the raw material properties on the *Keilmesser* production, use and maintenance still need to be tested experimentally.

As previously mentioned, tool design also includes aspects such as tool handling and function. Since the back of a *Keilmesser* normally forms the thickest part of the tool and the lower surface is usually flatter compared to the more strongly curved upper surface (Jöris, 2012; Weiss, 2018; Wiśniewski et al., 2020), the morphological design supports the idea of a *Keilmesser* as a handheld tool (Jöris, 2001; Frick et al., 2017; Jöris and Uomini, 2019). Moreover, the tools can be distinguished into left-lateral and right-lateral specimens (Jöris and Uomini, 2019). This distinction is based on the length-axial tool asymmetry. It has been argued that tool lateralisation reflects hand preferences and thus can serve as a proxy for human handedness. While techno-typological analyses have been conducted extensively (e.g. Krukowski, 1939; Richter, 1997; Jöris, 2001; Pastoors, 2001; Frick, 2016a, 2016b), the same does not apply to other types of analysis, for instance use-wear studies (Rots, 2009) or experimental approaches (Migal and Urbanowski, 2006). This PhD thesis targets at filling this gap. Asymmetric tools such as *Keilmesser* and *Prądnik scraper* are highly suitable for this endeavour due to their special morphology. Already the fact that *Keilmesser* as well as *Prądnik scrapers* have only one active edge compared to other tools, such as hand axes, simplifies the analysis. It does not reduce the work, but leads instead to less complex and more reliable results when the spacial assignment (active edge VS back etc.) of the use-wear traces is given.

The aim of this study is to obtain a more precise picture about Late Middle Palaeolithic *Keilmesser* and *Prądnik scrapers*. Thus, the overarching research question is to gain a better understanding of the tools by combining data concerning the techno-typology as well as data regarding functionality and tool use. In order to test generally accepted models about *Keilmesser*, the approach chosen for this research moves beyond conventional technological and typological studies. The multidisciplinary approach also includes the analysis of 3D data, qualitative and quantitative use-wear analysis and controlled experiments. To capture tool design in more detail, high resolution 3D data, next to quantitative metric measurements and qualitative attributes, offer the possibility for testing these models. Within these analyses, a special focus lies on the detailed morphology of the tool's edge. In order to address tool use directly, use-wear analysis aims to combine qualitative and quantitative data. Additionally, controlled experiments add data to aspects such as tool use, performance, efficiency and durability. At the same time, the experiments are designed to test the possible functionality of *Keilmesser* by executing different movements such as cutting and carving. The influencing factor of the different raw materials involved – silicified schist and flint - and their properties, will be tested throughout the experiments.

Taken together, the proposed approach has two main goals. The first goal is to gain new data about *Keilmesser* focussing on tool design, function and use. This data aims to be predominantly quantitative over qualitative and thus, also statistically evaluable. The second goal of this study is to test given interpretations or accepted models about *Keilmesser*. The only way to do so is by applying 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 can lead to a more holistic view on *Keilmesser*. Investigating and understanding aspects as the underlying tool concept and design, as well as tool function and use is conditional upon tracing certain behavioural phenomena of Neanderthals such as learning strategies, knowledge transmission and the formation of rules and regulations that can be approached from such a perspective. The study of these asymmetric tools may contribute to answering such questions and may allow us to gain new insights into Late Middle Palaeolithic technological choices.

Three selected Middle Palaeolithic assemblages from Central Europe, namely Buhlen (Bosinski, 1969; Bosinski and Kulick, 1973; Jöris, 2001), Balver Höhle (Andree, 1928; Bahnschulte, 1940; Günther, 1964, 1988) and Ramioul (Vandebosch, 1921, 1929; Ulrix-Closset, 1975) serve as a case study. The Upper Site of Buhlen is a collapsed rock-shelter in northern Hesse, while Balver Höhle is a large cave in North Rhine-Westphalia, both are in Germany. Ramioul represents a cave located in Belgium. All three sites have been excavated mainly in the beginning of the 20th century or in the case of Buhlen in the beginning of the second half of the 20th century.

In order to address the research question, this study is structured as follows: **Chapter 2** provides a 'State-of-the-art' for the topics: 1) Middle Palaeolithic asymmetric tools and 2) Tool design. These are the topics building the foundation for this research. Based on this, a discussion of the research questions including all objectives and aim will follow. **Chapter 3** (materials) refers to the archaeological sites, which serve as case studies. The chapter provides basic information about the archaeological sites selected for this research, including short excavation histories and the samples used in this study. The applied methods are outlined in **Chapter 4** (methods). Here, the methodological workflow of this study can be summarised in its main approaches: 1) Raw material characterisation, 2) Techno-typological analysis 3) Quantification of edge design, 4) Qualitative and quantitative use-wear analysis and lastly 6) Controlled experiments. The results of all these methods are presented in the subsequent **Chapter 5**. **Chapter 6**, the 'discussion' chapter, refers to the major interpretations and implications resulting from the newly presented data. Aspects such as tool standardisation and design, the influence of the raw material properties in terms of tool modification, performance and efficiency and the edge design are part of the discussion. Also addressed are topics such as the tool lateralisation and the lateralisation as a proxy for human handedness, tool function and use. The following **Chapter 7** (conclusion) combines the aforementioned topics and aims to provide a more distinct and holistic view on *Keilmesser*. The chapter also addresses the role of *Keilmesser* in Late Middle Palaeolithic assemblages and the interpretations and inferences on Neanderthal behaviour, which can be made. Additionally, it also points out the limitations experienced within this research and elaborates further on existing unclear aspects. Finally, this PhD project highlights the necessary work, which could enhance specific future research.

Furthermore, images of all the use-wear traces documented on the archaeological artefacts as well as on the experimental samples can be found in the appendix (III. and IV.). The same applies to all scripts used in the open-source software R to perform the data analysis (appendix V.).

2. State-of-the-art

2.1 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 and 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 and Roebroeks, 1999; Hovers and 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 and 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 and 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; Delpiano and Uthmeier 2020), Klausennische (Mania and Toepfer, 1973; Picin, 2016) and Bockstein (Wetzel, 1958; Bosinski, 1969; Bosinski and Wetzel, 1969) in the South, Lichtenberg (Veil et al. 1994; Weiss, 2020) in the North and Balver Höhle (Andree, 1928; Bahnschulte, 1940; Günther, 1964, 1988) and Buhlen (Bosinski and Kulick, 1973; Bosinski, 1969; Jöris 2001) in Central Germany. The site of Grotte de la Verpilliere (Frick, 2016a, 2016b; Frick and 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.

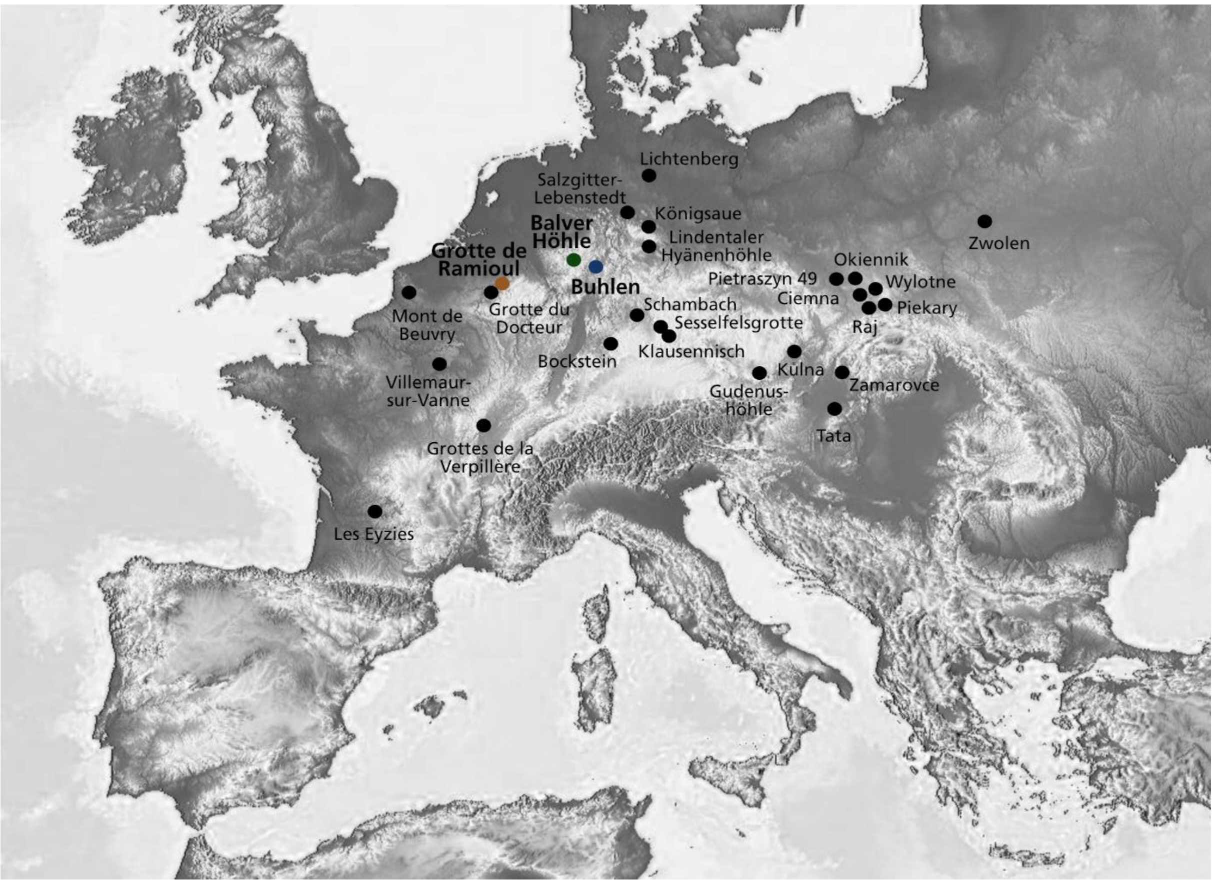


Fig. 1 Distribution of the major *Keilmessergruppen* sites in Central Europe. The sites of Buhlen (blue point), Balver Höhle (green dot), both in Germany and La Grotte de Ramioul, in Belgium (orange dot) are highlighted (the map is adapted from Jöris and Uomini, 2019).

2.1.1 *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 and 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 and Floss, 2017; Frick and 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 and Uomini, 2019). Evidence for hafting is rare, if not absent (Rots, 2009).

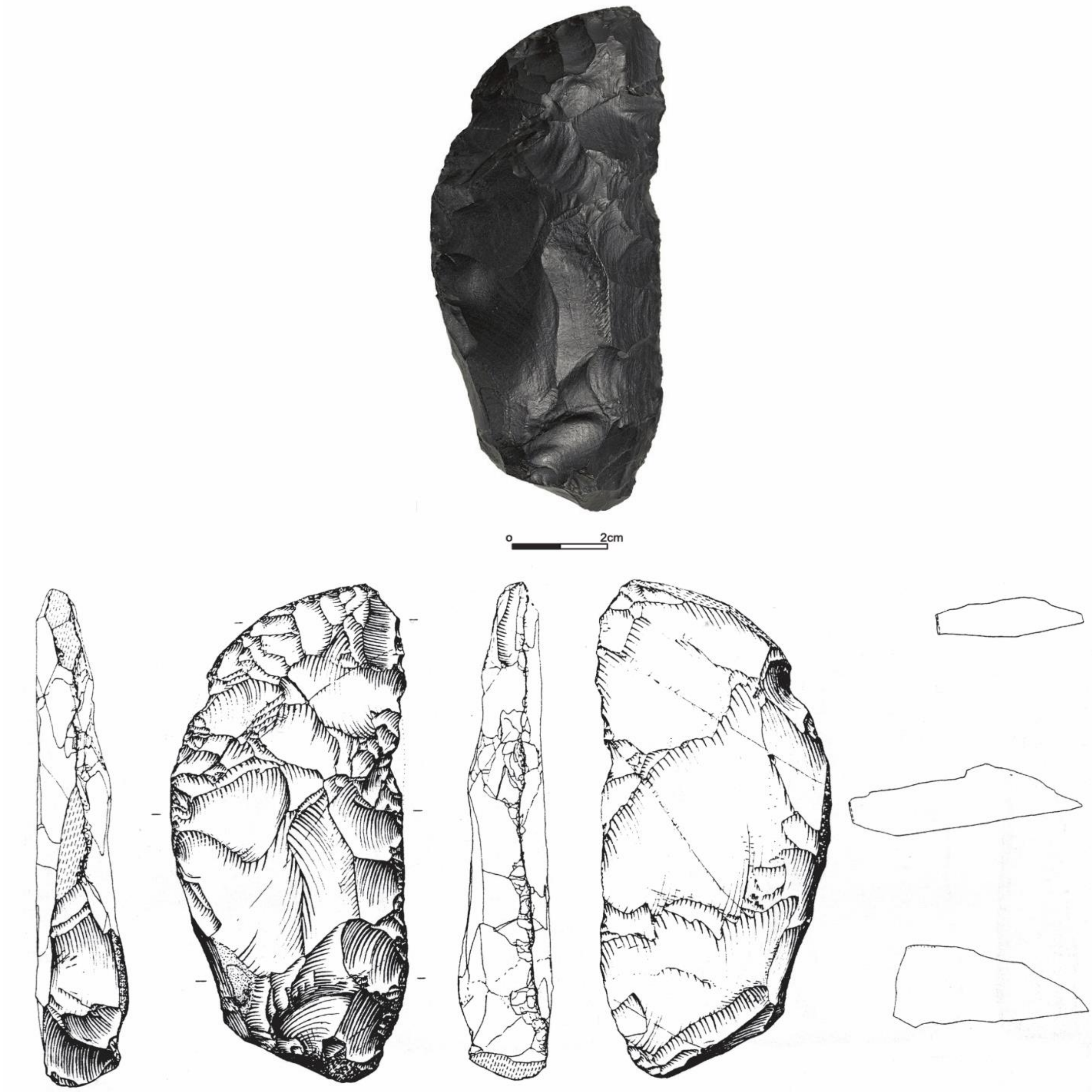


Fig. 2 *Keilmesser* from Buhlen (ID BU-163) (Photo: Sabine Steidl; Illustration: Olaf Jöris (Jöris, 2001)).

2.1.2 *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 and 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 and 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.

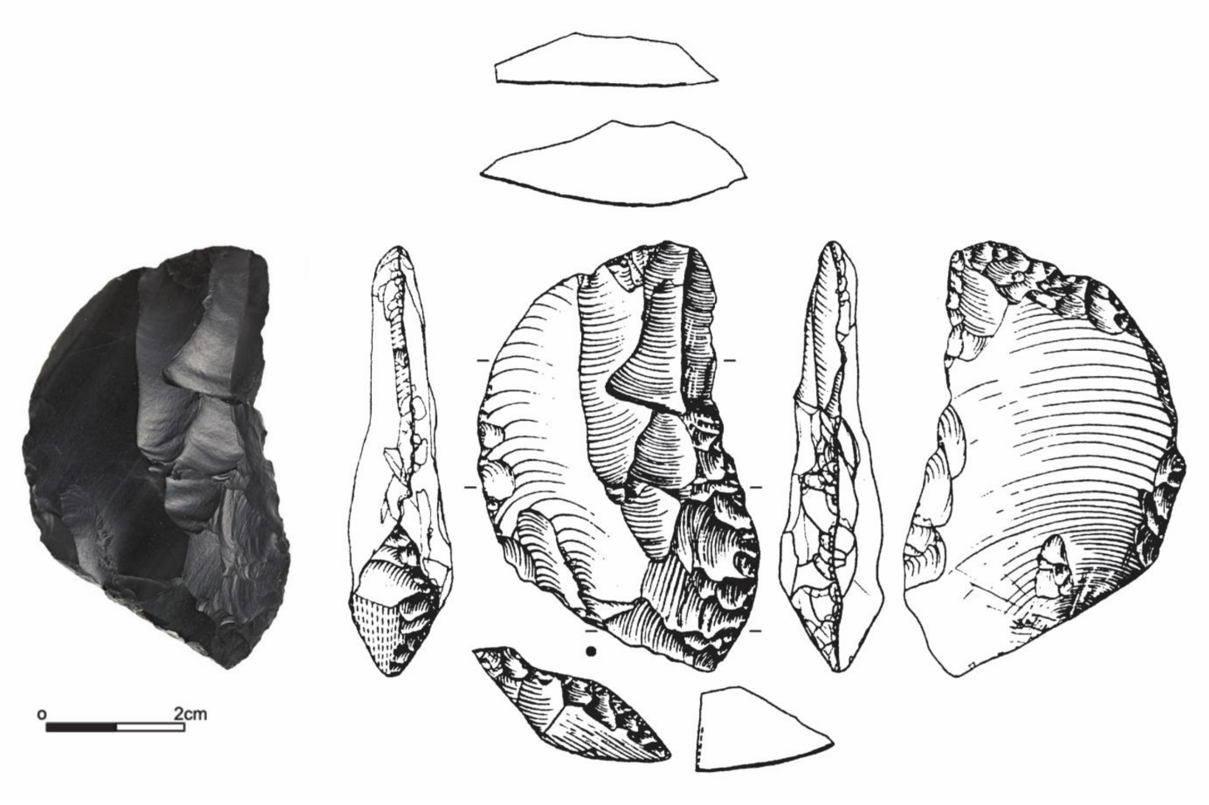


Fig. 3 *Prądnik scraper* from Buhlen (ID BU-194) (Photo: Sabine Steidl; Illustration: Olaf Jöris (Jöris, 2001)).

2.1.3 *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 and 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 and 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 and Grosman, 2015; Frick et al., 2017; Frick, 2020a; Prévost, Centi and 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 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).

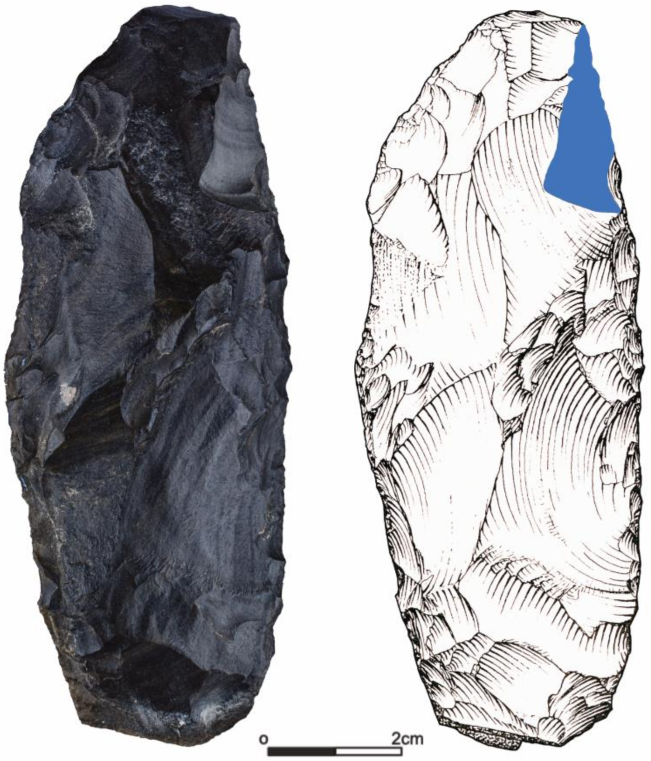


Fig. 4 *Keilmesser* from Balver Höhle (ID SM-003) modified by the application of the *Prądnik method*. Blue coloured area indicates the scar resulting from the *Prądnik spall* removal (Photo: Michael Baales; Illustration: Olaf Jöris (Jöris, 1992)).

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 and Herkert, 2019; Jöris and 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 and Herkert, 2019). Hence, the removal of a *Prądnik spalls* can also been seen as tool finishing (Frick and Herkert, 2019; Jöris and 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 and 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 and Herkert, 2019).

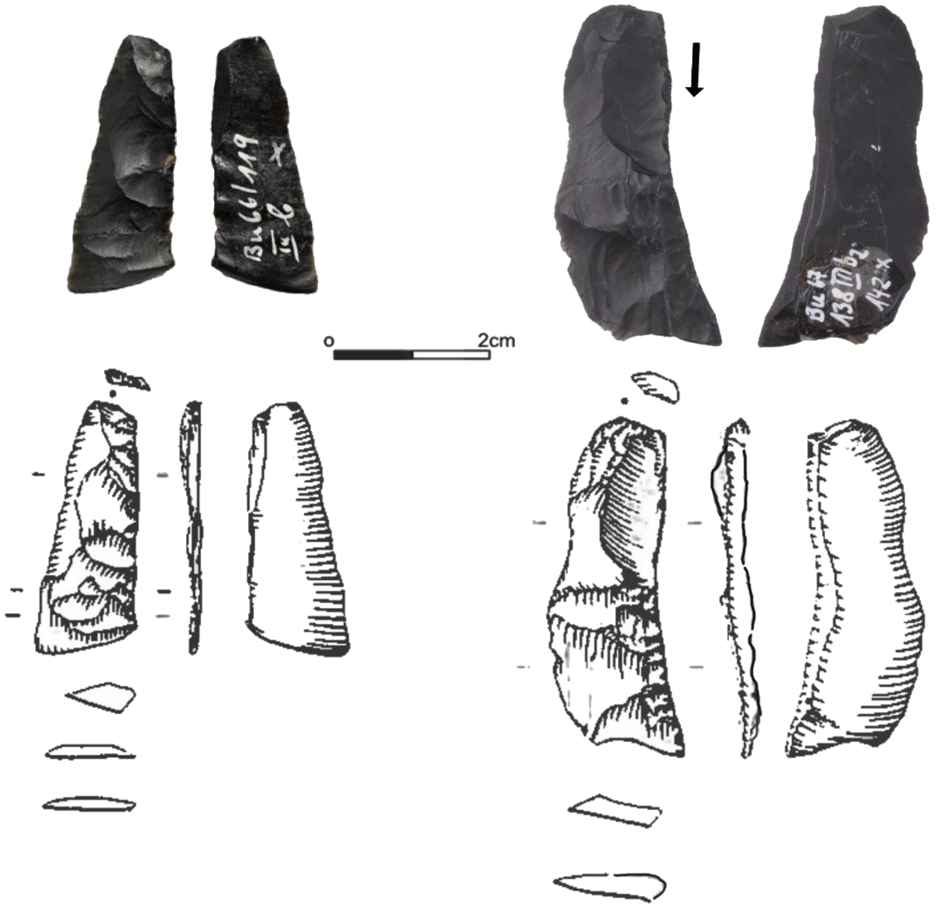


Fig. 5 *Prądnik spalls* from Buhlen (left, ID BU-155, right ID BU-136) (Photo left: Sabine Steidl; Illustration: Olaf Jöris (Jöris, 2001)). The artefact on the left side illustrates a primary, the on the right side a secondary *Prądnik spall*. The black arrow indicates the direction of the applied *Prądnik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

2.2 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 and 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 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).

2.2.1 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; 2001, 2012; Richter, 1997). The overall tool concept seems to be present from the first step of the tool production onwards (Jöris, 2001, 2012; Migal and Urbaowski, 2006). 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; 2001, 2006; Pastoors, 2001; Richter, 1997; Migal and Urbanowski, 2006; Jöris and 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, 2006; Pastoors, 2001). 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 and Schäfer, 1999; Jöris, 2001, 2006; Pastoors, 2001). At the same time, the tool shape in relation seems to change isometrically (Iovita, 2010). This required the application of consistent production 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, 2016) were able to demonstrate the entire *chaînes opératoire* of *Keilmesser* production, including rejuvenation processes.

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 and Floss, 2017; Wiśnie-wski 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 and Urbaowski, 2006; Frick and 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 and Uomini, 2019; Frick and 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 and Herkert, 2019; Jöris	**quantification edge design**: edge angle along the edge

			and Uomini, 2019; Weiss, 2020	**use-wear analysis**: do the traces differ in the distal and proximal part of the active edge?
				controlled experiments: edge angle functionality
shape diversity	different *Keilmesser* shapes exist as chronological sequence	variety of *Keilmesser* shapes	Bosinski, 1967; Bosinski, 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 and 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 and 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 and Herkert, 2019, Jöris and 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
tool biographies	long life-histories	negatives/ scars on tools	Richter, 1997; Pastoors and Schäfer, 1999; Pastoors, 2001; Jöris, 2001, 2006	**controlled experiments**: when is resharpening 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 and 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 and Herkert, 2019; Jöris and 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 and Herkert, 2019	**quantification edge design**
				controlled experiments: testing tool performance based on edge angle

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.

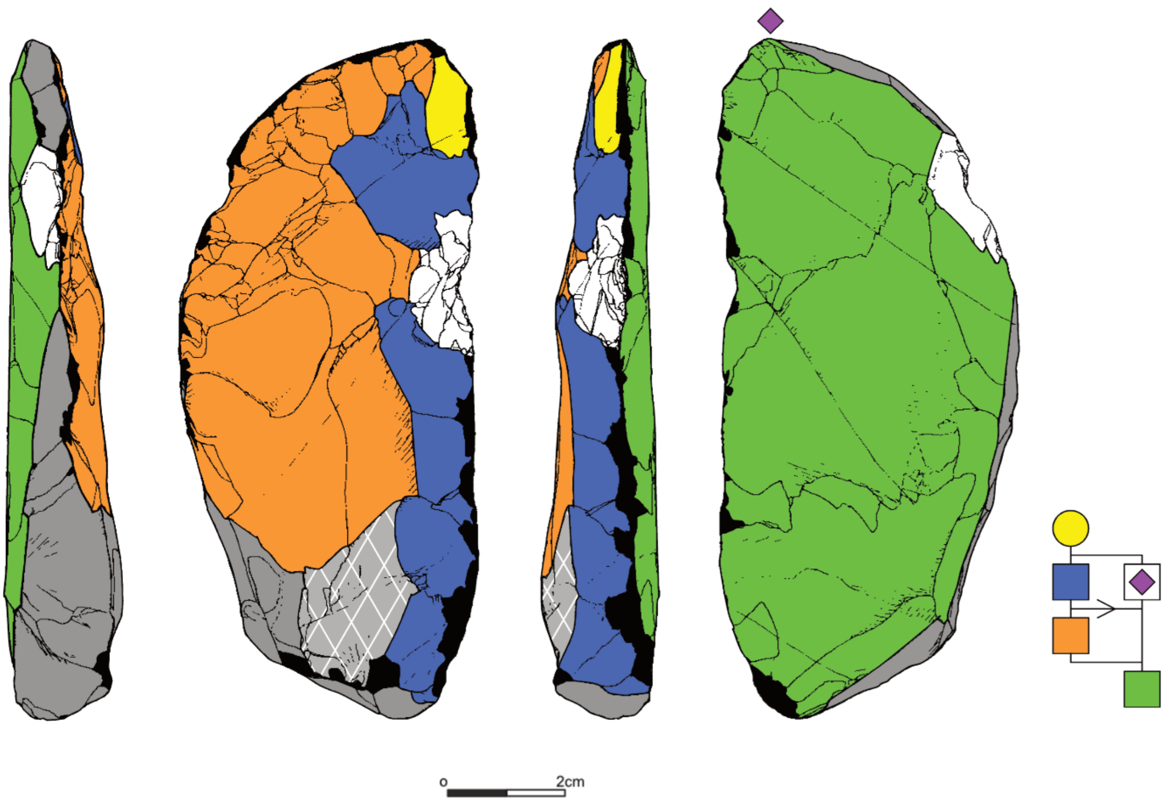


Fig. 6 *Keilmesser* from Buhlen (ID BU-163). The colours correlate with the Harris diagram on the right, indicating the order of individual retouch sequences from bottom to top. The yellow circle indicates the removal of a *Prądnik spall*, the purple diamond indicates the preparation of a striking platform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

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 and Toepfer, 1973), 'Lichtenberger *Keilmesser*' (Veil et al., 1994), 'Bockstein-' (Wetzel and Bosinski, 1969), '*Prądnik-*' (Wetzel and Bosinski, 1969 or '*Klausennische-*' (Wetzel and Bosinski, 1969), '*Messer*' 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, 2004; Pastoors, 2001; Migal and Urbanowski, 2006). The reasons for this outline shape variability, is most likely due to reduction and reworking processes (Jöris, 2001, 2004; Pastoors, 2001; Migal and Urbanowski, 2006; Weiss, 2020).

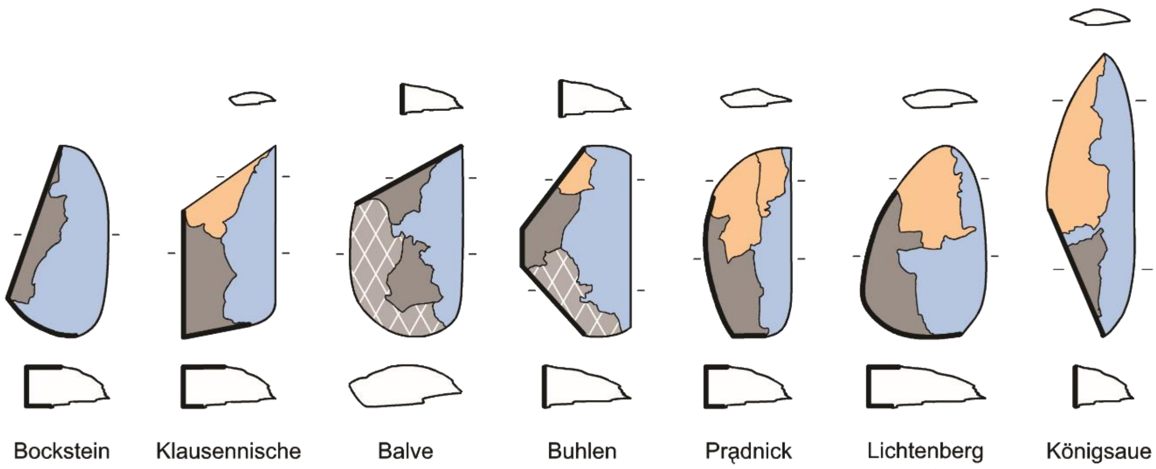


Fig. 7 Half-schematic illustration of the range of different shapes of *Keilmesser*. The thick black line indicates the back and the base as one perimeter section. The colours relate to unworked parts or thinning retouch orientated from the back and the base (grey), thinning of the distal posterior part (orange) and flat surface retouch of the active edge (light blue) (after Jöris and Uomini, 2019).

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.

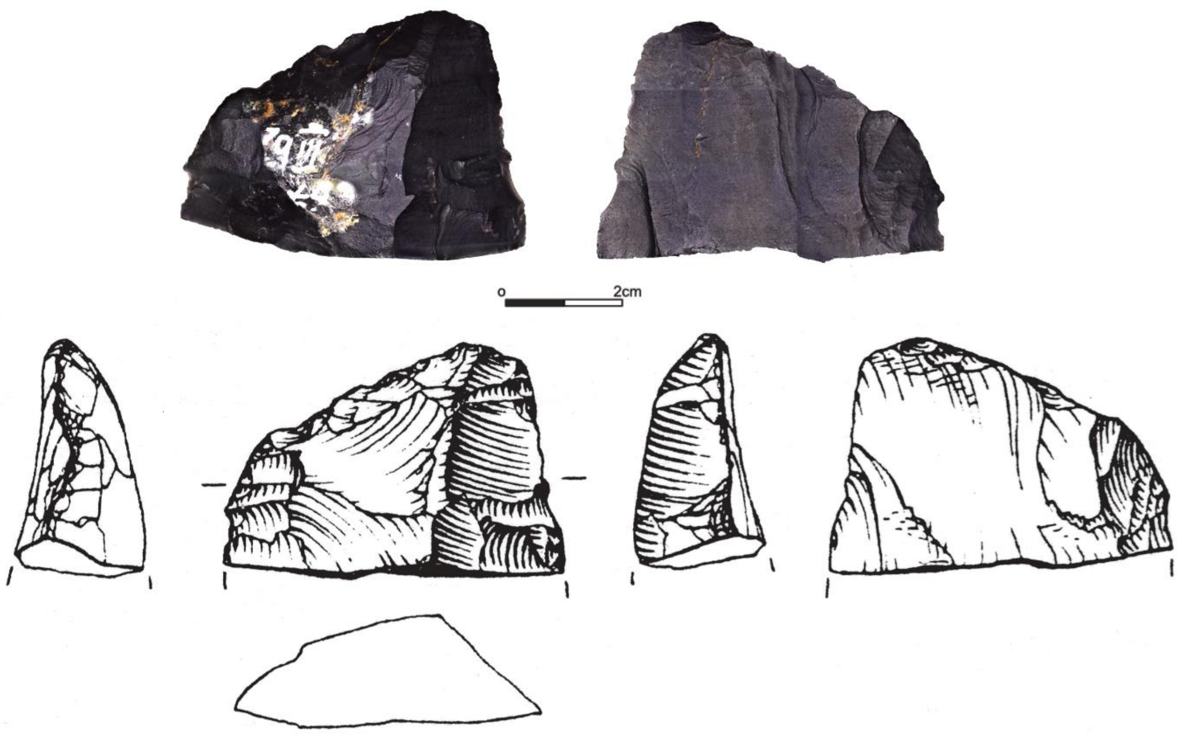


Fig. 8 *Keilmesser* tip from Buhlen (ID BU-086) (Illustration: Olaf Jöris (Jöris, 2001)).

2.2.2 Handedness and skills

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.

Based on the overall tool asymmetry, it is possible to distinguish left-lateral from right-lateral tools (Jöris and 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 et al., 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 and Uomini, 2019). Unlike apes, humans have a species-level bias towards one hand preference (McGrew and Marchant, 1997; Cashmore et al., 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 and 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 and Lawson, 2017; Uomini and 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.

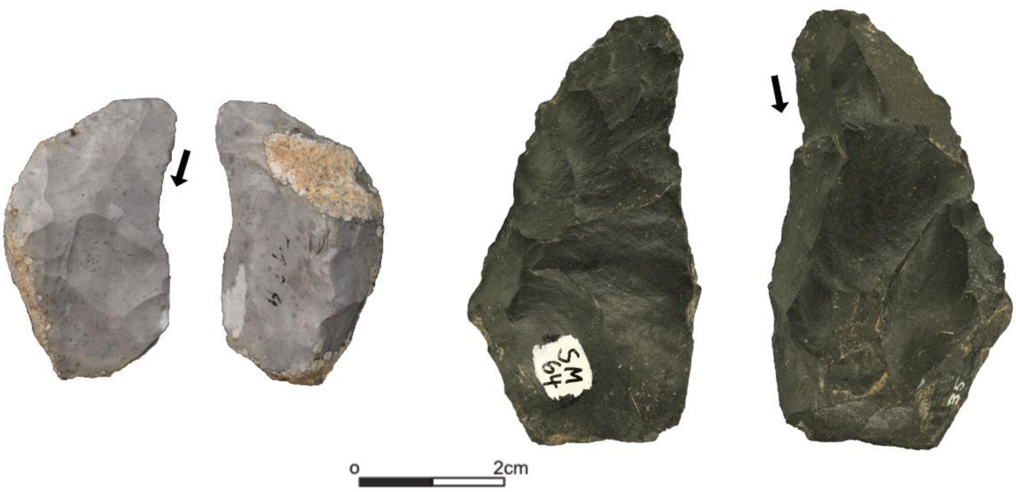


Fig. 9 Left-lateral *Keilmesser* (left) from Ramioul (ID R-002) and right-lateral *Keilmesser* (right) from Balver Höhle (ID MU-280). The black arrows indicate the direction of the applied *Prądnik method* visible as negative of the removal.

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).

2.2.3 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, 2006, 2012; Rots, 2009; Golovanova et al., 2017; Frick and 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 and Uomini, 2019).

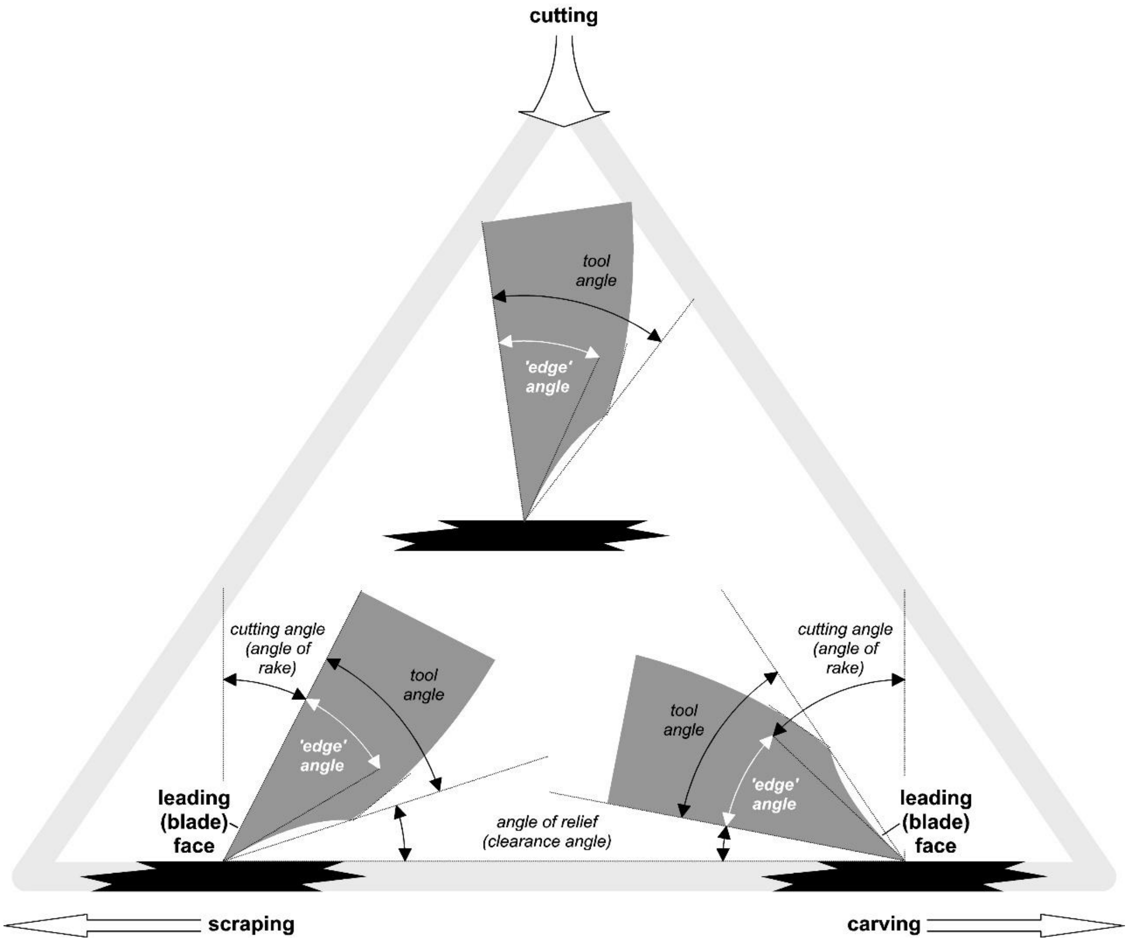


Fig. 11 Cross section of an idealised right-sided *Keilmesser* performing cutting, carving and scraping. Depending of the performed movement, the angle of relief has to be adapted (after Jöris and Uomini, 2019).

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 and 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 and Lycett, 2014; Key, Fisch and Eren, 2018; Key and 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 effectiveness 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) in order 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.

2.3 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 and Ruck, 2018; Jöris and 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, 2012; Rots, 2009; Golovanova et al., 2017, Frick and 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 and 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.

2.4 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 analysis 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 [figure xx]. 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.

In order 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 in order 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 in order 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 et al. 2017; *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 in order 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.

3. Materials

The research within this PhD project is built on the study of the lithic assemblages from three Late Middle Palaeolithic sites, namely the Upper site of Buhlen, Balver Höhle, both in Germany, and the Belgian site of Ramioul (**fig. 12**). The data will be obtained from selected samples of the associated lithic assemblages. The selection of asymmetric tools – more precisely *Keilmesser* and *Prądnik scrapers* – and *Prądnik spalls* as candidates for specific artefact categories and elements from the reduction sequence are a result of the topic itself and the formulated research questions.

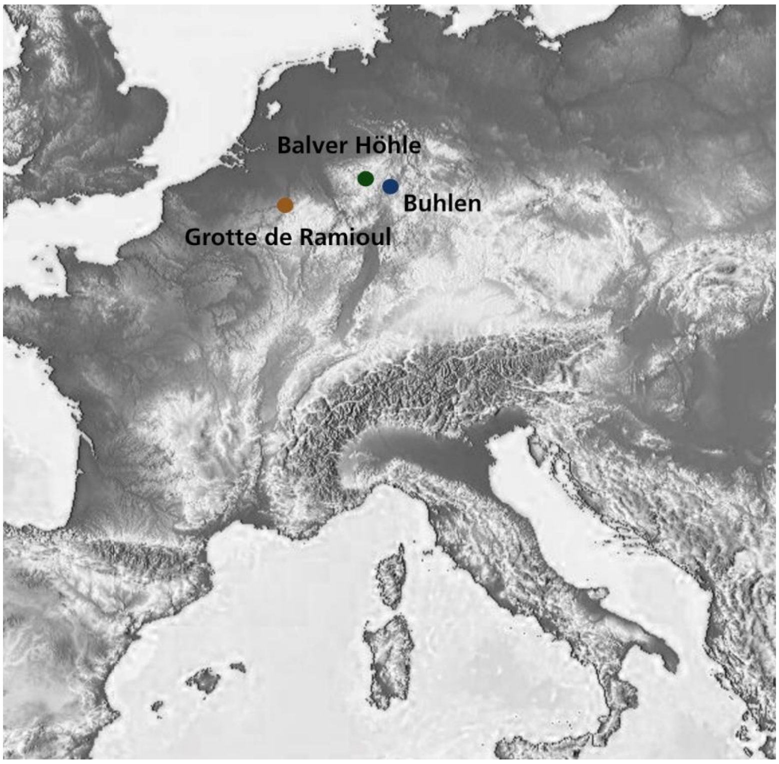


Fig. 12 Location of the three Middle Palaeolithic sites Buhlen (blue dot), Balver Höhle (green dot) and Ramioul (orange dot).

As explained in the 'State-of-the-art', *Prądnik scrapers* share certain technological and typological similarities with *Keilmesser* (Jöris, 2001, 2004; **fig. 13**). The main discriminating feature is thereby the application of the *Prądnik method*, which also differentiates these *Prądnik scrapers* from other scrapers. The typological categorisation is based on an attribute analysis, explained hereafter.

Fig. 13 *Keilmesser* from Buhlen (ID BU-172) and *Prądnik scraper* from Balver Höhle (ID MU-290) in comparison (Photo Buhlen: João Marreiros).

Keilmesser are usually made from cores, rarely from flakes. They display in general a bifacially worked active edge. The retouch is applied sequentially, surface after surface (alternating unifacial edge regularization; see Bosinski, 1967). The opposing back is natural (often with the presence of cortex) or roughly worked and builds mostly the thickest part of the tool. *Keilmesser* are in their morphology clearly asymmetric with a wedge-shaped cross section. Their lower surface is commonly flatter compared to the more strongly curved upper surface. *Keilmesser* are usually characterised by sequences of flat, standardised surface retouch, leading to the aforementioned typical shape. The complex pattern of scars on the surface often indicates numerous stages and phases of resharpening or modification. The application of the *Prądnik method* appears frequently not as a single event, judged by the overlying negatives of the removed *Prądnik spalls*.

Prądnik scrapers, on the contrary, are commonly made from flakes, not from cores. They display one unifacial or semi-bifacial retouched active edge. The back, opposed to the active edge, is either natural or modified with a clear, intentional blunting. Thus, also *Prądnik scrapers* show a distinct asymmetry. Usually, retouch extension over the surface is far scarcer, which leads to a less obvious surface curvature. *Prądnik scrapers* are characterised by at least one negative scar, resulting from the application of the *Prądnik method*. Although *Keilmesser* and *Prądnik scrapers* share morphological attributes, *Prądnik scrapers* appear technologically less complex.

Sometimes, a distinction between the two artefact categories is not clear cut. However, based on these attributes, the artefacts can be analysed and categorised as either *Keilmesser* or *Prądnik scrapers.*

In general, all available artefacts belonging to one of these three categories – *Keilmesser*, *Prądnik scrapers* and *Prądnik spalls* - have been chosen for the study. The *Prądnik spalls* from the site Buhlen form a sole exception. In this case, only some representative pieces have been sampled out. Additionally, a small number of scrapers and flakes are part of the study. Within the analysis they form an outgroup. With the outgroup the possibility will be given to put the results of the other studied artefact categories in relation.

Brief information about the sites, their research history and the number of selected artefacts from the lithic assemblages will follow in this chapter. An extended version and a detailed description can be found in earlier published literature concerning the sites Buhlen (Bosinski, 1969; Bosinski and Kulick, 1973; Jöris, 2001), Balver Höhle (Günther, 1964; Kindler, 2007) and Ramioul (Vandebosch, 1921).

3.1 Selection of the sites

Although the three sites, Buhlen, Balver Höhle and Ramioul are not dated radiometrically and not all finds are stratified, the classification of the material as Late Middle Palaeolithic assemblages is unquestioned. In fact, according to the research question, a refined chronological dating is not of major relevance for this study. Buhlen represents one of the richest *Keilmesser* assemblages and especially the huge quantity of lateral sharpening spalls is unique. In fact, the inventories of the Balver Höhle can be described as forming one of the largest *Keilmesser* assemblages in central Europe and are therefore especially suitable for the analysis of the artefact category itself, the main goal of the presented project. The assemblages from Buhlen and Balver Höhle thus allow an in-depth study of the selected artefact categories concerning metric as well as qualitative aspects. Based on the numerous samples a statistic evaluation of the analysis is possible. Ramioul displays, in contrast to Buhlen and Balver Höhle, a small *Keilmesser* assemblage only. The reason to include the site is based on the technology concerning the tool manufacturing. All three sites attest similar technological sequences including the application of the *Prądnik method*. From a technological point of view, the sites are much alike and display a high inter-comparability. Additionally, the artefacts are so similar that an analogous function can be assumed. Also important to mention is that the raw materials used in order to produce the tools is the same in the three sites, silicified schist and flint (**tab. 2**). Buhlen, Balver Höhle and Ramioul are perfectly suitable for an inter-site comparison.

site		raw material			
		silicified schist	flint	other	total
Buhlen	n	195	2	1	**198**
	%	98.5	1.0	0.5	100.0
Balve	n	337	10	0	**347**
	%	97.1	2.9	0.0	100.0
Ramioul	n	2	18	0	**20**
	%	10.0	90.0	0.0	100.0
total	n	**534**	**30**	**1**	**565**
	%	94.5	5.3	0.2	100.0

Table 2 Distribution of the raw materials used for the production of the studied artefacts from Buhlen, Balver Höhle and Ramioul. For Buhlen, other refers to carnelian.

3.2 Buhlen

3.2.1 Site location and excavations

The archaeological site of Buhlen is located in northern Hesse, Germany, roughly 200 meters north-northeast of the village Buhlen in the district Waldeck-Fankenberg/ Nordhessen. The site consists of two units – the Lower Site of Buhlen at the banks of the Netze river and the Buhlen Upper Site, a small collapsed rock-shelter (Bosinski, 1969; Bosinski and Kulick, 1973; Jöris, 2001; **fig. 14**). In this PhD project, only the material from the Upper site is addressed.

Fig.14 The site Buhlen seen from the East. The loess quarry is visible between the trees on the right of the picture (Photo: Gerhard Bosinski).

Buhlen has been known as a paleontological site in a loess quarry since 1840. At the beginning of the 1960ies, a small Dolomitic limestone ridge was partly removed by road construction, during which Pleistocene animal bones became exposed. In the context of geological mapping work, two geologists, M. Horn and J. Kulick revisited the outcrop in 1963. Within the Upper Pleistocene loess sequence of the site, they found animal bones and the first lithic artefacts. As a consequence, Kulick started the first test trenches. After contacting Gerhard Bosinski at Cologne University, the site was excavated in 1966 to 1967 and in 1969, starting with the Lower Site and finally uncovering the Upper Site with the collapsed rock-shelter and its small terrace. Excavation standards also included wet-screening of the entire sediment. Thus, a high amount of artefacts belonging to smallest fraction is part of the excavated material. In cooperation with the Hessische Landesamt für Bodenforschung in Wiesbaden and the Institute for Palaeontology at the University of Mainz, Bosinski's excavation covered almost the entire spatial extent of the Upper Site (Bosinski and Kulick, 1973; Jöris, 2001). In total, the site yielded over a surface of less than 80 m² an extremely rich assemblage of around 200.000 lithic artefacts and 150.000 animal bones (Jöris, 2001). The material is stored and also partly on display in the Hessisches Landesmuseum in Kassel. The majority of the artefacts relevant for this PhD project derive from one find complex: Bu-III. Based on sedimentological and biostratigraphical arguments, this find complex most likely dates to the transition from late OIS 5 into early OIS 4 (Jöris, 2001, 2004).

3.2.2 Buhlen lithic assemblage

The lithics selected for this project are almost all associated with the basal find complex of the Upper Site of Buhlen, BU-III (**tab. 3, 4**). However, in the periphery of the rock shelter, the material seems to have been mixed up with the succeeding complex, BU-II (Jöris, 2001). Thus, single artefacts have to be ascribed to BU-II instead of BU-III. In the case of the selected lithics here n = 9 artefacts originate from BU-I, n = 22 artefacts from BU-II, while n = 155 artefacts are associated with BU-III. N = 13 artefacts cannot be ascribed to a specific find complex due to missing labels.

artefacts	n
Keilmesser	115
Keilmesser tip	15
Prądnik scraper	24
Prądnik spall	42
scraper	2
total	198

Table 3 Categories of the selected and studied artefacts from Buhlen.

layer	artefacts [n]					
	Keilmesser	*Keilmesser* tip	*Prądnik scraper*	*Prądnik spall*	scraper	total
I	3	2	2	1	1	9
II	15	0	2	2	0	19
II b	2	0	0	1	0	3
III a	3	0	0	3	0	6
III b	77	9	17	26	1	130
III c	6	3	2	5	0	16
III d	1	0	1	1	0	3
unknown	8	1	0	3	0	12
total	115	15	24	42	2	198

Table 4 Stratigraphic attribution of the artefacts from Buhlen. A small amount of n = 13 artefacts could not be ascribed to a layer.

The artefacts from the Upper Site of Buhlen are with a few exceptions made of local silicified schist. On a rare occasion Baltic flint or carnelian have been used as raw material. Although the *Keilmesser* assemblage, as demonstrated by Jöris (2001) is known to be bigger than selected for this project, the accessibility of the material was a limiting factor. The present study refers therefore to n = 130 *Keilmesser* and n = 24 *Prądnik scrapers*. N = 42 *Prądnik spalls* were selected next to n = 2 scrapers as outgroup.

3.3. Balver Höhle

3.3.1 Site location and excavations

The Balver Höhle describes a karst cave within the Rhenish Slate Massif in North Rhine-Westphalia, Germany (**fig. 15**). The cave is situated in the Hönne valley, one of the most important karst areas in the region, north of the city Balve in the district Märkischer Kreis. The Balver Höhle represents the largest archaeological cave in Germany (Andree, 1939) and is used nowadays as a cultural venue. The cave system is composed of a main cave of circa 54 meter length, the major distributary and two lateral distributaries, each about 20 meter long (**fig. 16**). These latter are named after Heinrich von Dechen and Rudolf Virchow, scientists who were both responsible for early excavations at the site (Günther, 1964).

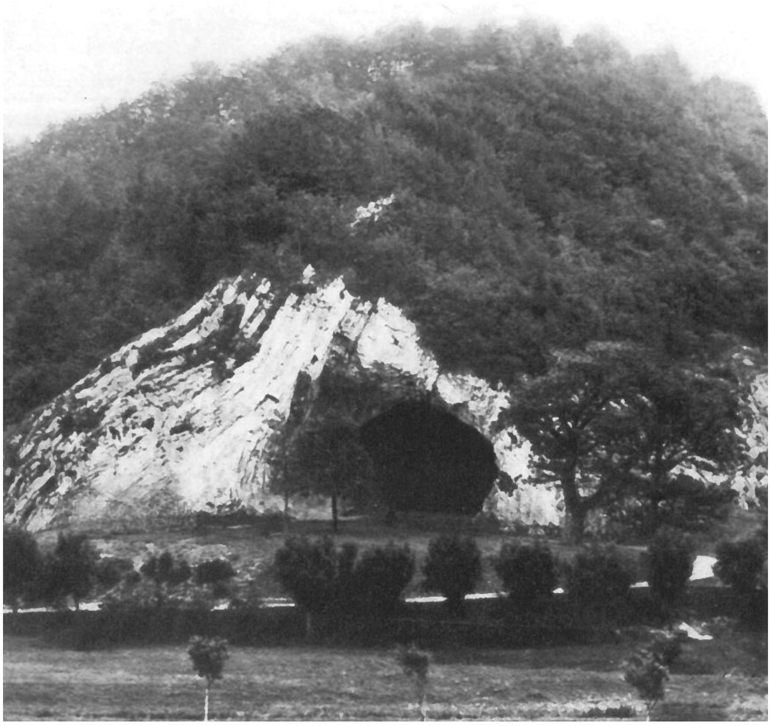


Fig. 15 Balver Höhle in North Rhine-Westphalia, Germany (after Günther, 1964).

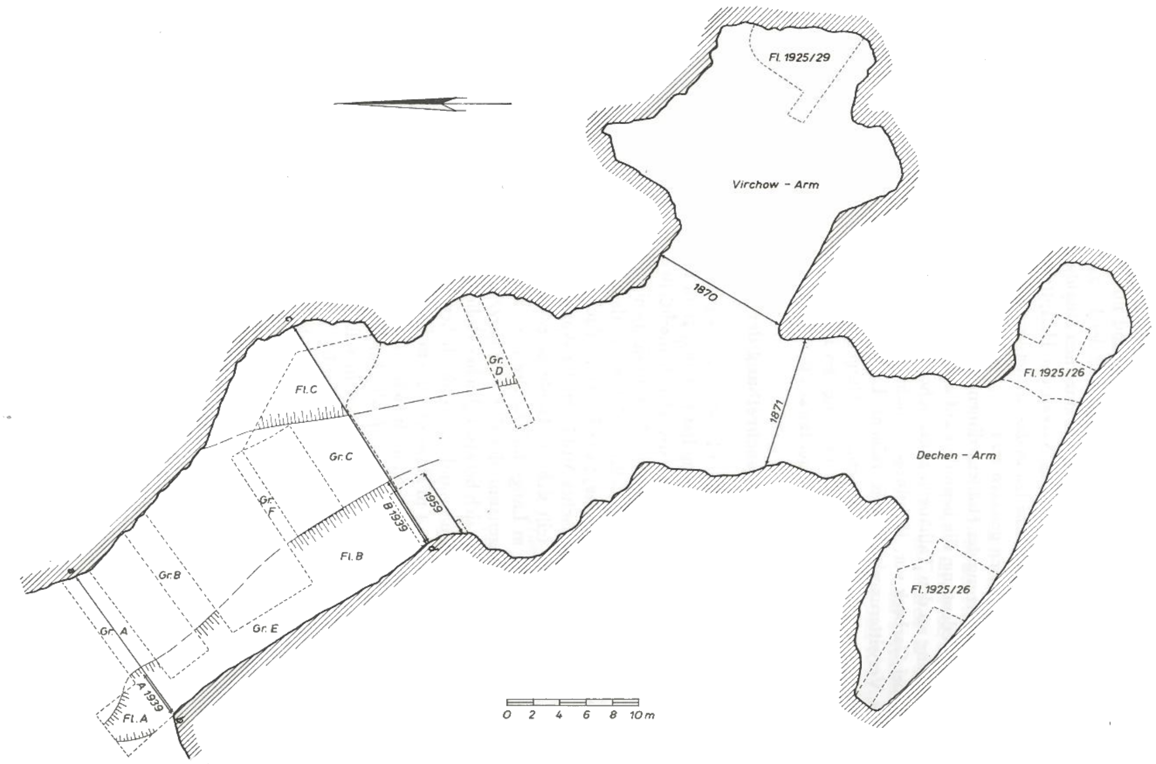


Fig. 16 Cave plan of the Balver Höhle in North Rhine-Westphalia, Germany (after Günther, 1964).

Research history started early in the middle of the 19th century with the exploitation of phosphate-rich cave sediments, which were used as a fertilizer for the surrounding fields. The majority of the excavations took place at the end of the 19th century and the beginning of the 20th century (Bahnschulte, 1940; Günther, 1964). The excavations opened an up to 7 meter long stratigraphic sequence, covering large parts of the Upper Pleistocene and Holocene.

With the first reported findings of lithic artefacts in 1843 archaeologists became aware of the site. During the succeeding decades archaeological interest into the cave sequence intensified, resulting in a series of field campaigns that emptied large parts of the cave's interior and also examined the terrace in front of the cave's entrance (Andree, 1928; Bahnschulte, 1940; Günther, 1988, 1964). Nevertheless, it was not until 1939 that major systematic excavations at different localities near the entrance and within the cave were conducted by Bernhard Bahnschulte (1940). Since the topmost layers, including Upper Palaeolithic sediments, had already been removed during earlier years, Bahnschulte's work concentrated on remnant sediments in lower fissures of the cave floor. Thereby, he excavated thousands of artefacts from a surface of several m^2 and from almost all sedimentary layers (I-V from bottom to top). The vast majority of these finds as well as the associated fauna are ascribed to the Late Middle Palaeolithic. In 1959, in order to gain new geoscientific data for an improved understanding of the site's stratigraphy, geochronology and site formation, Klaus Günther added small trenches immediately near to those of Bahnschulte. Most recently, in 2009, Michael Baales aimed at re-opening the

site to obtain samples for OSL-dating, but unfortunately did not succeed in finding undisturbed horizons (Baales, 2013). Due to the long and intensive research history at the site and later constructions in order to use the cave as a public cultural venue, no remaining *in situ* deposits could be detected. The majority of the material attributed to the Balver Höhle is today stored in the Amt für Archäologie und Denkmalpflege in Münster, the Landesmuseum für Archäologie in Herne and – until recently - in the Sauerlandmuseum in Arnsberg. The material derives mainly from Bahnschulte's excavations, to lesser degree from other archaeological fieldwork at the site, but also from several private collections. In total, the entire lithic inventory adds up to 40.600 artefacts, although only 9.100 artefacts are stratified and a substantial loss of material over time can be assumed (Günther, 1964). This includes for example small chips, which have not been kept in the course of the excavations, except for those from Günther's 1959 sondages. The sediment removal in order to fertilize the surrounding fields has not spared the artefacts from being removed, either. As a result, artefacts can be found on the surrounding fields, which originate from the cave deposits. As mentioned before, the inventory represents a broad range of different Middle Palaeolithic artefact types, characterised by a particularly high amount of bifacial tools.
In particular, the material from archaeological horizon (AH) II up to AH V has been attributed to the Micoquian (Bosinski, 1967; Günther, 1964) and later referred to as KMG (Jöris, 2004). Based on the results from Olaf Jöris (1992, 2004, 2006) and Lutz Kindler (2007), the sequence of Middle Palaeolithic layers in the Balver Höhle spans from late OIS 5 to early OIS 3 (Jöris, 2004, 2006). The settlement in the Balver Höhle is characterised by recurrent Neanderthal presence (Kinder, 2007).

3.1.2 Balver Höhle lithic assemblage

The selected assemblage from the Balver Höhle represents artefacts from the entire stratigraphic sequence (**tab. 5, 6**). The stratigraphic correlation of the results from the various excavations is complicated and leads sometimes to an ambiguous attribution of the artefacts (Pastoors and Tafelmaier, 2010). In total, the sequence extends from the lowest layer AH I to the uppermost layer with archaeological artefacts, layer AH VI (Günther, 1964).

artefacts	n
Keilmesser	170
Keilmesser tip	21
Prądnik scraper	27
Prądnik spall	117
scraper	12
total	347

Table 5 Categories of the selected and studied artefacts from Balver Höhle.

layer (AH)	artefacts [n]					
	Keilmesser	*Keilmesser tip*	*Prądnik scraper*	*Prądnik spall*	scraper	total
IV	4	2	2	7	0	15
sterile	2	0	0	0	0	2
III	10	1	3	4	5	23
II + III	2	0	0	14	0	16
II	27	5	0	4	0	36
I	2	0	0	0	0	2
unknown	123	13	22	88	7	253
total	170	21	27	117	12	347

Table 6 Stratigraphic attribution of the artefacts from Balver Höhle. Out of the n = 347 studied artefacts, only n = 94 artefacts can be ascribed to one of the archaeological layers (AH = archaeological horizon).

For the production of the tools the local silicified schist served as a raw material. Although the entire lithic assemblage from the Balve cave is characterised by the use of this specific raw material, Baltic flint was also used in a few exceptional cases.
The material consists of n = 189 *Keilmesser* and n = 27 *Prądnik scrapers*. The amount of corresponding *Prądnik spalls* is n = 117. Additionally, n = 12 scrapers were selected for an outgroup comparison. From these 347 artefacts, only 94 samples can be attributed to a stratigraphic horizon. The majority originates thereby from layer AH II, followed by layer AH III. Due to missing labels the other three-quarters of the selected assemblages cannot be associated with a specific layer.

3.4 Ramioul

3.4.1 Site location and excavations

La Grotte de Ramioul, short Ramioul (sometimes also Ramioulle) belongs to a karstic system on the right riverside of the Meuse, near Liege, in the municipal Flémalle, Belgium (Vandebosch, 1921; Ulrix-Closset, 1975; **fig. 17**). It is located between two quarries, Abime Martel to the West and Caverne à végétations to the East. The cave is separated in three vertical levels (**fig. 18**): the upper section ('*superieure*'), the mid section ('*moyenne*') and the lower section ('*inférieur*' or '*réseau actif*'). The levels are connected through a shaft and linked to a main chamber ('*salle*'). Additionally, there is an open air area with a small rock shelter associated with the cave ('*terrasse*') (Vandebosch, 1921; Quinif et al., 2011).

Fig. 17 Entrance portal of the Grotte de Ramioul, Belgium (after Ulrix-Closset, 1975).

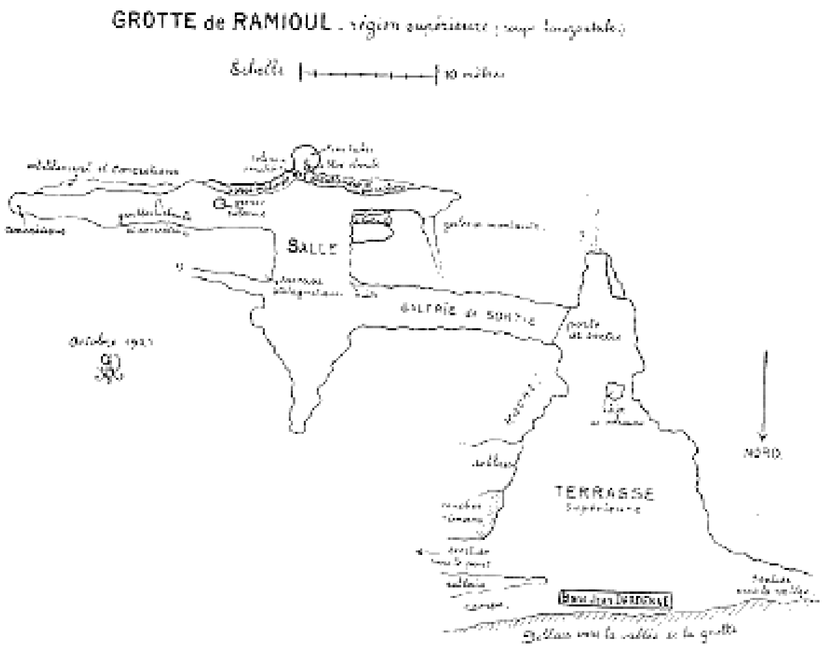


Fig. 18 Cave plan of the Grotte de Ramioul, Belgium (after Vandebosch, 1921).

In 1908, a group called '*Les Chercheurs de la Wallonie'* discovered two prehistoric burials (Vandebosch, 1921, 1929; Ulrix-Closset, 1975). The burials contained bones, but no further artefacts, which would have allowed for a more precise age estimation. By continuing the research within the cave, a total of seven child burials have been found. Additionally, lithic tools, ceramics and fauna have been unveiled. Together, these finds could be attributed to the Neolithic. This marks the beginning of the research in Ramioul. Back then, sediment layers reached a depth of 5.5 meters. In total five different layers could be distinguished (layer 1 to 5, from top to bottom, whereas layer 5 is connected to the bedrock). Based on the initial finds, a second excavation was initiated in 1911. During this excavation, Palaeolithic artefacts of undetermined age were found. Among them, numerous lithics (circa 200 pieces) mainly made of flint and glacial fauna. Most of these finds have been found in front of the cave ('terrasse'), rather than inside. However, the excavated layers of the terrace could be correlated with the cave's stratigraphy from the cave. In general, not all finds are stratified, since parts of the layers seemed somewhat disturbed. In the years 1914 and 1915, research has been continued further, unearthing the lowest level ('*inférieur*' or *'réseau actif'*) that contains no archaeological finds (Vandebosch, 1921, 1957; Quinif et al., 2011).
Based on the finds and especially the lithic assemblage form the fourth layer, which contains a high percentage of bifaces, Levallois tools, scrapers and leaf-points (or leaf-point-like artefacts), the Ramioul assemblage has been associated with the "Mousterian" (Ulrix-Closset, 1975). The entire occupation of the cave starts at the Late Middle Palaeolithic and spans into the Holocene.
Since 1994, the Préhistomuseum (before Préhistosite de Ramioul), is located near *La Grotte de Ramioul.* The finds from Ramioul are stored and partly displayed in the very same museum.

3.4.2 Ramioul assemblage

The material consists of n = 9 *Keilmesser* and n = 3 *Prądnik scrapers* (**tab. 7**). Unfortunately, *Prądnik spalls* could not be sampled, due to the fact, that all artefacts which have not been categorised as tools were stored together with material from a nearby located site. An identification of material clearly belonging to the site Ramioul is therefore impossible. N = 6 scrapers and n = 2 flakes were selected additionally. The stratigraphic or spatial assignment for these 20 samples is undetermined. Unfortunately, the assemblage is poorly published (Ulrix-Closset, 1975, cf. Jöris, 1992).

artefacts	n
Keilmesser	9
Prądnik scraper	3
scraper	6
flake	2
total	20

Table 7 Categories of the selected and studied artefacts from Ramioul. For none of these artefacts a stratigraphic attribution is possible.

Concerning the raw material, the situation in Ramioul is different than in Buhlen or Balver Höhle. The predominantly used raw material is flint. In a few exceptions, silicified schist served as a raw material too.

4. Methods

This chapter focuses on the methods and techniques applied within this project. It is organised according to the different steps of the research and types of analysis. The project is trying to follow an integrative and multidisciplinary approach in order to gain a more holistic view on asymmetric tools from the Late Middle Palaeolithic. At the same time, a standardised analytical workflow is aimed for. Irrespective of the applied method or pieces of equipment used, following standards and protocols were sought. Used settings, programs and software were reported as transparently as possible. The scripts and templates used to analyse the data are saved and stored on GitHub, a distributed version-control system for tracking changes [https://github.com/lschunk]. The same applies to all involved data, including the raw data.
The first subchapter describes the raw material characterisation, followed by the techno-typological analysis, and a subchapter on the quantification of the edge design. The next two subchapters addressing the use-wear analysis are separated into a qualitative and a quantitative analysis. The last part of this chapter is dedicated to the controlled experiments. All methods are targeted at gaining information about the archaeological assemblages and producing data, which in most cases is statistically evaluable. Although it goes beyond the scope of a method chapter, an introduction to some of the methods are given. This is the case for the chapters addressing raw material characterisation, use-wear analysis, edge design and experiments. Thereby, the introductions focus on the perspective of lithic analysis. Additionally, the advantages, disadvantages and limitations of these methods are discussed.

4.1 Raw material characterisation

Early humans had to select suitable raw material for the production of tools. Whether this process was a conscious decision or not was also presumably dependent on the raw material availability and variability. Research on the raw material variability present in archaeological assemblages has already been established for many decades (Dibble, 1985; Féblot-Augustins, 1993, 1997, 2008; Floss, 1994; Andrefsky, 2009; Meignen et al., 2009). The reasons for studying the raw material can differ. The most obvious one is the classification of the raw material and identification of the possible source, which can provide information about movement patterns of early hominids (Andrefsky, 1994; Féblot-Augustins, 1997; Brantingham, 2003). Alongside raw material procurement, the raw material properties themselves are another aspect which can be analysed. The properties of raw material, for instance the size and shape of the original blocks or nodules as well as density and hardness, have a critical influence on the ability to knap a tool (Kuhn, 1992; Braun et al., 2009; Dogandzic et al., 2020). Moreover, the tool design correlated with the used raw material can provide information about intentional selection. Therefore, raw material properties are assumed to affect not only tool production, but also technical choices in general and tool use specifically (Odell, 1981; Delgado-Raack et al., 2009; Key, Proffitt and de la Torre, 2020; Nonaka et al. 2010). By the analysis of their characteristics, it is possible to say whether, for example, physical properties have been manipulated through heat treatment (Brown et al., 2009; Schmidt and Mackay, 2016; Key, Pargeter and Schmidt, 2020). Features such as surface roughness are also recognised as a determining factor in the development and the characteristics of use-wear traces (Lerner, 2014). As demonstrated by several studies, the nature and the properties of the contact material can be associated with specific use-wear traces (Stemp and Stemp, 2003; Lerner 2007, 2014). The rate at which use-wear forms on a given tool surface, is dependent on the surface hardness and roughness of both the tool and the contact material. This means that raw material properties are known to affect the development and the characteristics of use-wear traces, for instance polish (Lerner, 2007, 2014; Lerner et al., 2014). Analysing the material properties of a given raw material is therefore a prerequisite to understand the formation of use-wear traces and their interpretation, respectively. To go into more detail, raw material properties are an influencing factor not only for tool morphology, but also for tool efficiency and durability. As demonstrated recently, early hominins might have actively chosen certain raw materials for specific functional performances (Agam and Zupancich, 2020; Key, Proffitt and de la Torre, 2020). Consequently, analysing raw material properties should be part of each lithic study.

Thus, the first aspect of this study addresses the raw material used to produce the tools. In the case of the three examined sites, only two types of raw material are involved in the analysis: silicified schist and cretaceous ('Baltic') flint (Vandebosch, 1921; Günther, 1964; Bosinski, 1969; Jöris, 2001). For the petrographic analysis, only optical factors such as the colour, the nature of the cortex and the translucency of the raw material were of relevance. The raw material from the archaeological sites was compared with the lithic raw material collection at MONREPOS Archaeological Research Centre and Museum for Human Behavioural Evolution, RGZM as a reference (https://monrepos.rgzm.de/en/ausstattung/#Sml). This collection contains siliceous rock samples from different sources used to manufacture tools in western Central Europe during the Palaeolithic and Mesolithic (Floss, 1994).

The properties of the raw materials, for instance hardness, can be measured in order to evaluate the possible influence of the raw material itself on tool morphology and also to predict potential efficiency and durability during the use-life of the tool (Key and Lycett, 2017; Key, Proffitt and de la Torre, 2020; Key, Pargeter and Schmidt, 2020). Relatively common is the use of a Schmidt hammer to estimate mechanical properties of rock material (Yilmaz and Sendir, 2002; Yasar and Erdogan, 2004; Braun et al., 2009). The Schmidt hammer is a device that works with a rebound hammer in order to test surface hardness and penetration resistance based on elastic properties and the strength of rock. An alternative method has been provided recently using a Leeb rebound hardness tester. The hardness test was originally developed for metals but has been correlated for rocks (Braun et al., 2009; Rodríguez-Rellán, 2016; Corkum et al., 2018; Kovler et al., 2018). The measurements can be carried out rapidly and non-destructively. Micro surface roughness of knapped surfaces as another parameter, can be measured for example with a 3D

confocal laser scanning microscope. Even though important, the material properties of the raw materials present in archaeological assemblages have been rarely tested. Although highly relevant in experimental design, they are often neglected (Evans, 2014). The reason for this might be the costly equipment needed to calculate some of the properties or maybe an underestimation of their relevance.
Here, the material properties of the raw material were tested using the Leeb rebound hardness tester (Proceq Equotip 550, Leeb C probe; **fig. 19**). Two types of raw material were involved in the analysis: silicified schist and Baltic flint. The advantage of the hardness test conducted with the Leeb rebound is that the measurements can be carried out rapidly and are non-destructive. The disadvantages are the required flat surface and mandatory maximum size of the object. For the knapped archaeological tools, it was not possible to measure the hardness with the Leeb rebound. Based on their morphology it is impossible to position the tools entirely flat, so that one face is in contact over its total surface with the stable supporting base (here a flat rock slab of about 20 kg). Additionally, the other tool surface must be flat as well in order to conduct the measurements. However, one semi-finished tool from Balve (ID MU-278) fulfilled these requirements. While this approach was used only once for the archaeological samples, it was always applied for the experimental samples (see chapter 4.6). With the hardness tester, to insure and test intra-variability in each sample, ten measurements per sample were taken. The number of measurements not only ensures the inclusion of the raw material variability within the result but also identifies potential outliers. When the samples did not fulfil minimum sample size requirements, an additional coupling paste was used to connect the sample with a massive support plate.

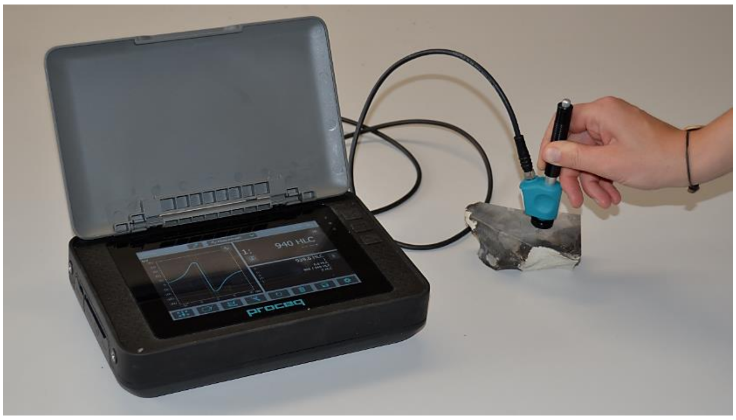


Fig. 19 Hardness measurements taken on a flint sample using the Leeb rebound hardness tester with the Leeb C probe (Proceq Equotip 550).

4.2 Techno-typological analysis

Initial information for all assemblages from the three different archaeological sites was acquired through traditional lithic analysis methods (Hahn, 1993; Debénath and Dibble, 1994; Andrefsky, 1998; Odell, 2014). This technological and typological analysis was

based on two different but complementary methods. While one approach produced qualitative data related to several descriptive attributes, e.g. tool morphology, the shape and character of the back or the application of the *Prądnik method*, the second method generated quantitative results obtained by standard calliper-based morphometric data (e.g. length, width and thickness). *Keilmesser* as well as *Prądnik scrapers* were analysed in the exact same way. The approach described here is therefore identical for both artefact categories respectively. Mentionable exceptions are the *Prądnik spalls*, the *Keilmesser tips*, scrapers and simple flakes, which are treated differently in some respects. These artefact categories were analysed in the same way but certain steps of the analysis (e.g. definition *Keilmesser* shapes, perimeter sections) were not of relevance and have therefore been omitted. Concerning the '*Keilmesser tips*', it needs to be noted that these tools are notably shorter than a complete *Keilmesser*. Thus, their metric values are not directly comparable with those of the remaining artefacts.
The database for the techno-typological analysis was done by using E4 for Microsoft Windows 10 (Old Stone Age, S. McPherron), as a data entry program. In order to use E4, a script with all variables was entered and their type (e.g. text, numeric) was configured. Since E4 offers the possibility, to create conditional statements, variables can be skipped based on values entered for previous variables. The script was written in the open-source software R (version 4.0.2 through RStudio version 1.3.1073, RStudio Inc., Boston, USA) for Microsoft Windows 10 (appendix I.). The data was saved in MDB format.

4.2.1. Blanks and cortex

To begin with, a qualitative attribute is addressed with the determination of the blank used for the tool production. The tools can be manufactured on different blanks (Jöris, 2001). If a distinction is possible, it should be determined in this part of the analysis, whether a core or a flake was used as a blank to produce the tool. In some cases, it is not possible to identify the type of blank. Thus, the term 'undeterminable' was selected.
Another feature that can provide valuable information, for instance on manufacturing sequences or methods, is the amount of cortex left on the tool surface (Dibble et al., 2005). The first question is whether there is cortex on the artefact. If yes, the amount of cortex in percent (>25%, 25-50%, 50-75%, <75%, total) was indicated as well as the location.

4.2.2 Morphometric quantitative analyses

All metric data were recorded using a digital calliper of the brand Mitutoyo with a direct data output. The used model achieves a precision of 0.01 mm with an error margin of 0.03 mm. Dimensions were taken for complete and incomplete artefacts, the latter being recoded as such. The length measurement was determined using the active edge and not necessarily the maximal dimension of the tool (**fig. 20**). However, the maximum dimensions were applied for the measurements of width and thickness (Debénath and Dibble, 1994).

Fig. 20 *Keilmesser* from Balver Höhle (ID MU-021). The black lines indicate the length measurement of the active edge.

4.2.3 Tool back

The design of the back forms another of the criteria of the attribute analysis. Here, the relevant trait is the state of the back (Bosinski, 1967; Jöris, 2001). The design of the artefact back can inform about the extent to which the back already formed a conceptual part of the tool manufacture and influence of the morphology of the raw material blank used. For instance, the back can be characterised by unworked cortex surfaces or natural fragmentation. Moreover, clear traces of intentional retouch or minor working traces can be observed.
The thickness of the tool back was recorded identically to the dimensions described above, at its maximum extent, meaning the most pronounced section of the back.

4.2.4 Active edge retouch

In addition to the back, the design of the active edge was analysed. The interesting technological aspect was the type of retouch along the edge. The retouch was classified into either bifacial retouch, semi-bifacial retouch or unifacial retouch.

4.2.5 Lateralisation

Another feature documented as a qualitative attribute is the laterality of the artefacts. The lateralisation results from tool asymmetry (Jöris and Uomini, 2019; **fig. 9**). Tool lateralisation can be determined when the artefact is aligned with the proximal part of the tool towards the observer and the flat surface (of *Keilmesser*) or the ventral surface (of *Prądnik scrapers*). If the back is then on the left side and the active edge on the right side, the artefact counts as *dextrolateral* (dex.). If the back is to the right and the active edge at the left, the tool is recorded as *sinistrolateral* (sin.).

4.2.6 Morphological shape variability

The artefacts were assigned to one of the seven distinct *Keilmesser* shapes respectively (**fig. 7**). However, the division was made baes only on a visual impression. The fundamental question to be asked is whether these *Keilmesser* shapes indeed exist as strictly distinguishable types or if the types merge into each other and show the result of reworking and resharpening processes. In the following, the seven *Keilmesser* shapes are described in more detail (e.g. Jöris, 2001).
The '*Bockstein knife'* is characterized by the absence of a transition between the back and the active edge. Both these tool areas, the back and the active edge, meet at an acute-angle (Wetzel and Bosinski, 1969).
The back and the active edge of the *'Klausennische Messer''* run almost parallel to each other. A bifacially worked, mostly obliquely running distal posterior part connects the back with the active edge. This distal posterior part and the active edge display an acute angle (Wetzel and Bosinski, 1969).
The *'Prądnik Messer'* is morphologically closest to given definition of a *'Klausennischen Messer*'. The back of this *Keilmesser* shape changes into a retouched, bow-shaped distal posterior part, which is more rounded and connects with the active edge at approximately right angles (Wetzel and Bosinski, 1969).
The outline of the *'Buhlener Keilmesser'* resembles a right-angled, equilateral triangle. The two catheti are formed by the back and the distal posterior part, whereas the active edge corresponds to the hypotenuse (Jöris, 2001).
Characteristic for the '*Lichtenberger Keilmesser'* is a clear convexity of the active edge. Both the base and the distal posterior part are rounded and thus the active edge is slightly elongated. The description of this *Keilmesser* shape is not narrowly defined and can vary (Veil et al.,1994).
Artefacts of the type *'Königsaue-type Keilmesser'* are also characterized by a convex active edge. The back is located at the proximal part of the tool. The biconvex distal end of the artefact resembles the morphology of a leaf point (Mania and Toepfer, 1973).

The *'Balver Keilmesser'* is defined by a crudely worked base. From the top view, the base seems rounded. The distal posterior part runs obliquely, comparable to the '*Klausennische' Keilmesser* shape (Jöris, 2001).

Following this descriptive morphology of *Keilmesser*, the outline of the artefacts can be separated into three distinct components, resulting together in the artefact's perimeter (Jöris, 2001; Frick and Herkert, 2019; **fig. 21**). Firstly, one segment is defined by the tool base and the back. The second section is described by the distal posterior part, connected directly to the back. The overall perimeter is completed by the third region made up of the active edge of the tool. The respective lengths of the different sections of the artefact's perimeter were measured. Only complete tools were suitable for this measurement.
The morphological distinction, of the *Keilmesser* shapes defined above is largely a reflection of the different length ratios of the individual perimeter sections (Jöris, 2001, 2004; Pastoors, 2001; Migal and Urbanowski, 2006). The metrical measurements can therefore as an objective control whether the different subjectively defined *Keilmesser* shapes exist as valid entities or not. If they are confirmed as valid the different *Keilmesser* shapes should cluster as such when the metrical results are plotted.

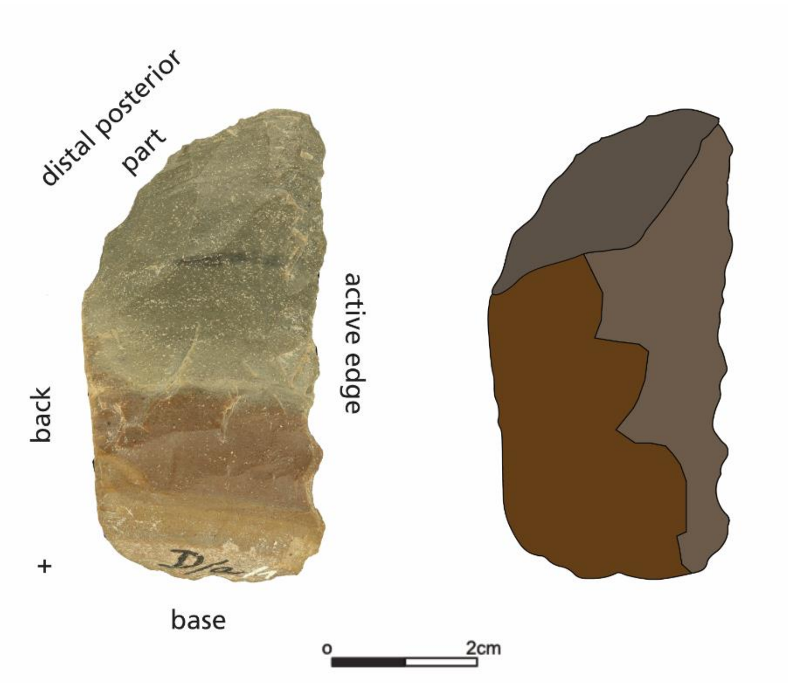


Fig. 21 Dorsal surface of a *Keilmesser* from Balver Höhle (ID MU-114) (left), indicating the different perimeter sections base and back, distal posterior part as well as active edge. The half-schematic illustration (right) displays the identical *Keilmesser*. The three perimeter sections are highlighted in colours.

4.2.7 Application of the *Prądnik method*

Use of the *Prądnik method* leaves a characteristic negative on the surface of the artefact (Jöris, 1992, 2001; Frick at al., 2017; Frick and Herkert, 2019, Frick, 2020a; **fig. 4**). The purpose of this part of the analysis is to document whether the method has been applied or not. In some cases more recent negatives overlap with negatives resulting from a previous application of the *Prądnik method.* In this case, the information was labelled as 'multiple' applications. Artefacts for which the presence of a negative is debatable are classified as 'undetermined'.

4.2.8 *Prądnik spalls*

Lateral *Prądnik spalls* emerge during the artefact modification by one or more blows to the distal part of the active edge. It is possible to distinguish primary from secondary sharpening spalls based on the pattern of scars on the dorsal face of the flake (Jöris, 1992, 2001; Frick and Herkert, 2019; **fig. 5**). The lateralisation, as described before, can also be determined for the *Prądnik spalls*. Based on the orientation of the retouch it can be defined if the spall has been removed from a left-sided or right-sided tool (Cornford, 1986; Jöris and Uomini, 2019).

4.2.9 Data analysis

All descriptive analyses (summary statistics, scatter plots and bar plots) were performed in the open-source software R version 4.0.2 through RStudio version 1.3.1073 (RStudio Inc., Boston, USA) for Microsoft Windows 10. The following packages were used openxlsx v. 4.1.5, R.utils v. 2.9.2, doBy v. 4.6.7, ggsci v. 2.9, dplyr v. 1.0.2, patchwork v. 1.0.1, ggplot2 v. 3.3.2, tidyverse v. 1.3.0, wesanderson v. 0.3.6. The analysis was done for each archaeological site individually and once for the three sites together. Reports of the analysis in HTLM format, created with knitr v. 1.29 and rmarkdown v. 2.3 are available on GitHub [https://github.com/lschunk/Lithic_analysis_archaeology]. Moreover, the raw data, the scripts and the RStudio project are saved in the same repository.

4.2.10 Sampling strategy

During the techno-typological analysis, samples of the three assemblages were selected for further examination. Artefacts were chosen for edge angle measurements as well as for the use-wear analysis.
Use-wear analysis is a time-consuming methodology, in most cases necessitating sub-sampling of the assemblage. Depending on the research question, the sampling can follow different strategies (Marreiros et al., 2020; **fig. 22**). What often happens though, is that the supposedly more important artefacts, for instance *fossiles directeurs* or retouched tools will form most of the subset. While this sampling approach would be still debatable, the following interpretation is mostly not. The results obtained for this chosen subset are then applied to the entire assemblage. Sampling based on this rather problematic strategy is frequently criticised as biased. To avoid this bias, sampling strategies should be defined by the research question and not be influenced by preconceived interpretations. The intention is to transfer the analytical results for a sub-

sample to the total assemblage. Elements of all represented technological categories should be integrated in the analysis. This includes retouched artefacts as well as unretouched specimens often ignored because believed to be unused. If the research question focusses on the use of a certain artefact type, this specific artefact type should represent the most numerous group in the analysis, but outgroups should also be selected to form part of it. Otherwise, the data do not allow for any comparison. Following this idea, lithics were sampled comprehensively to represent all the existing categories present (*Keilmesser*, *Keilmesser tips*, *Prądnik scrapers* and *Prądnik spalls*) as well as *Keilmesser* shapes from the two different raw materials. Additionally, scrapers and flakes were selected as outgroups. Crucial for the sampling was also the preservation of the artefacts.

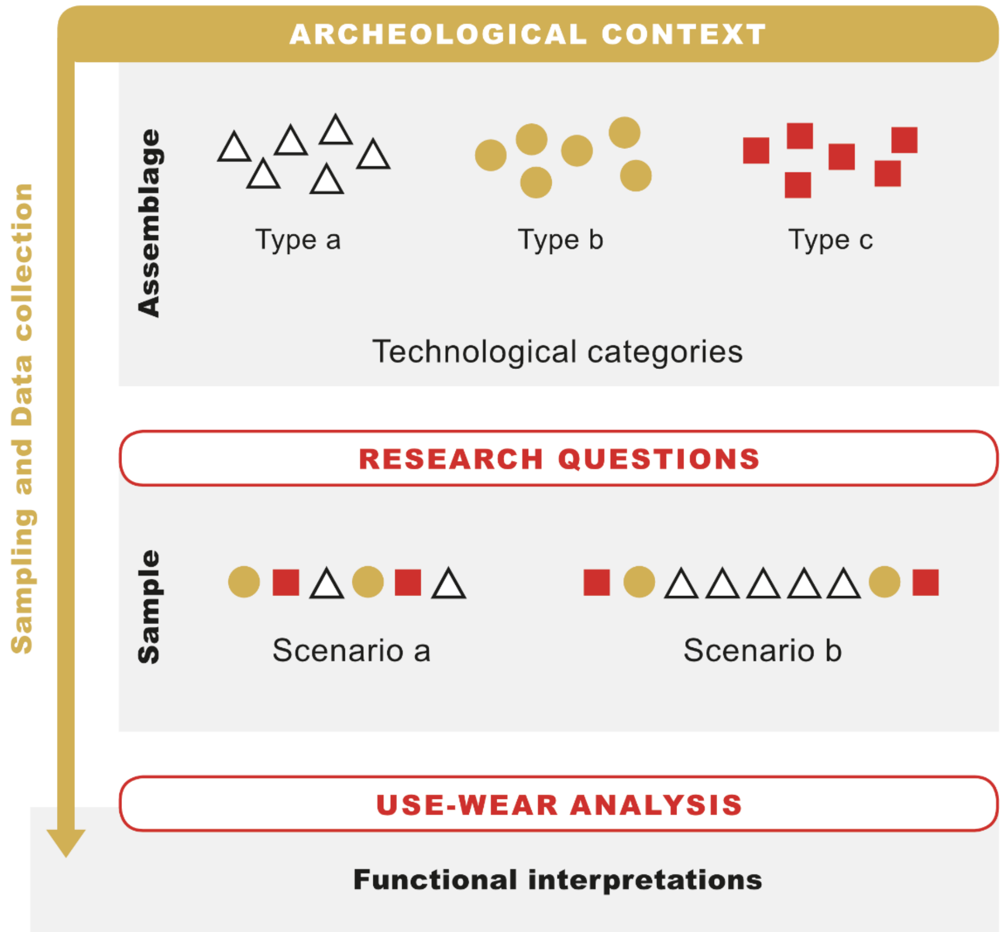


Fig. 22 Schematic representation of the different sampling and data collection strategies commonly used in functional studies. Scenario b was chosen as a sampling strategy for the presented project (after Marreiros et al., 2020).

With this sampling strategy as a prerequisite, artefacts have been selected for two purposes: firstly, for the quantification of their edge design and secondly, for the qualitative use-wear analysis. The sub-sample for calculating the edge angle consists of n = 226 artefacts (**tab. 8**). Only complete artefacts were selected. These artefacts can be divided into n = 157 *Keilmesser*, n = 18 *Keilmesser* tips, n = 20 *Prądnik scraper* and n =

21 *Prądnik spalls*. Additionally, artefacts not belonging to the selected artefact categories were samples for references as a relevant outgroup. Thus, n = 8 scrapers as well as n = 2 flakes.

site		artefact category						
		Keilmesser	***Keilmesser* tip**	***Prądnik scraper***	***Prądnik spall***	**scraper**	**flake**	**total**
Buhlen	n	83 [115]	8 [15]	16 [24]	21 [42]	2 [2]	0 [0]	**130** [198]
	%	63.9	6.2	12.3	16.2	1.5	0.0	100.0
Balve	n	65 [170]	10 [21]	3 [27]	0 [117]	0 [12]	0 [0]	**78** [347]
	%	83.3	12.8	3.9	0.0	0.0	0.0	100.0
Ramioul	n	9 [9]	0 [0]	1 [3]	0 [0]	6 [6]	2 [2]	**18** [20]
	%	50.0	0.0	5.6	0.0	33.3	11.1	100.0
total	**n**	**157** [294]	**18** [36]	**20** [54]	**21** [159]	**8** [20]	**2** [2]	**226** [565]
	%	69.2	7.9	8.8	9.3	3.9	0.90	100.0

Table 8 Number of artefacts from Buhlen, Balver Höhle and Ramioul selected for the quantification of the edge design. The numbers in the square brackets sow the total number of assemblage, respectively.

For the use-wear analysis, more than one third of the total assemblage has been sampled (**tab. 9**). Concretely, n = 200 artefacts from the three archaeological sites have been selected. With n = 129 artefacts, mainly *Keilmesser* (including n = 10 *Keilmesser* tips) have been sampled. Additionally, n = 23 *Prądnik scraper* as well as n = 39 *Prądnik spalls* have been chosen for the qualitative use-wear analysis. Also here, n = 17 scraper and n = 2 flakes build a typological outgroup within the analysis.

site		artefact category						
		Keilmesser	***Keilmesser* tip**	***Prądnik scraper***	***Prądnik spall***	**scraper**	**flake**	**total**
Buhlen	n	58 [115]	8 [15]	15 [24]	18 [42]	2 [2]	0 [0]	**101** [198]
	%	57.4	7.9	14.9	17.8	2.0	0.0	100.0
Balve	n	42 [170]	2 [21]	5 [27]	21 [117]	9 [12]	0 [0]	**79** [347]
	%	53.2	2.5	6.3	26.6	11.4	0.0	100.0
Ramiou l	n	9 [9]	0 [0]	3 [3]	0 [0]	6 [6]	2 [2]	**20** [20]
	%	45.0	0.0	15.0	0.0	30.0	10.0	100.0
total	**n**	**109** [294]	**10** [36]	**23** [54]	**39** [159]	**17** [20]	**2** [2]	**200** [565]
	%	54.5	5.0	11.5	19.5	8.5	1.00	100.0

Table 9 Number of artefacts from Buhlen, Balver Höhle and Ramioul selected for the qualitative use-wear analysis. The numbers in the square brackets sow the total number of assemblage, respectively.

4.3 Quantification of edge design

Tool design incorporates several attributes, from the overall morphology through to a specific edge retouch. Thus, design builds the bridge between tool shape on the one hand and function and handling on the other. Several methods exist to analyse different aspects of lithic tool design. Recording metric variables, for instance the tool dimensions and mass, presents the most standard of these (Kuhn, 1990; Hahn, 1993; Andrefsky, 1998; Dibble et al., 2017). Although useful, orthogonal dimensions do not capture the geometric configuration of the artefact since artefacts can in fact have similar linear measurements but possess have different morphologies (Borel, 2017). More detail can be gained through methods such as a geometric morphometrics (e.g. Lycett et al., 2010; Shott, 2010; Serwatka, 2015; Weiss et al., 2018) or elliptical Fourier analysis (e.g. Iovita, 2009, 2010; Archer et al., 2018; Wiśniewski et al., 2020). Geometric morphometrics focuses on the shape of the tool. Based on defined landmarks and semi-landmarks as well as the spatial and geometric relation between them, this approach captures morphologically distinct shape variables. Elliptical Fourier analysis follows the same main idea to capture the relation between size and shape. It was designed to describe shape by a closed outline, independent of the object's orientation. The method does not depend on landmarks, but on the elliptical Fourier coefficients. The so-called *techno-functional analysis* (Lepot, 1993; Boëda, 2001; Boëda and Auduze, 2013) tries to combine information about the tool morphology and the location of modified and unmodified tool areas. This approach aims to understand tool design including tool function.
Other analyses go further into detail and focus directly on specific areas of the artefact, for example retouched edges. Important therefore is the recognition of an artefact not as a morphological end product (Dibble, 1987, 1995; Rolland and Dibble, 1990; Iovita, 2014). Tool use as well as maintaining processes can change a tool's shape. Based on retouch intensity, assumptions about the length of the tool-life history are possible (Lin and Marreiros, 2020). Identifying these reduction dynamics (Kuhn, 1990; Morales, 2015) is important in order to make behavioural inferences based on tool design. As an integrated part of the overall tool design, the tool edge, whether modified or unmodified, can be analysed by a qualitative description (e.g. 'stepped scaler retouch', 'trapezoidal retouch') or quantified by calculating the edge angle. The performance of a given task with a tool is linked with its edge angle. (Collins, 2008; Key and Lycett, 2015; Key, Proffitt and de la Torre, 2020). This is based on the assumption that the presence of sharp active edges determines a stone tool's utility, whereas the form of a tool's edge determines its functional efficiency, effectiveness, reliability and durability (Key and Lycett, 2014; Key, Proffitt and de la Torre, 2020). Therefore, the acuteness of an edge angle often plays a role in the interpretation of a tool's function. Several techniques for the recording of measurements have been devised. Among them are manual techniques (e.g. Dibble and Bernard, 1980; Pop, 2013) or technically more advanced methods, using 3D models (Zaidner and Grosman, 2015; Archer et al., 2018; Weiss et al., 2018; Stemp et al., 2019; Porter et al., 2019; Valletta et al., 2019; Weiss, 2020; see also ISO 8442-5), all of which

being afflicted with their own levels of imprecision inherent to the applied techniques. The recent developments with the integration of script-, algorithm-based and automated analysis of 3D models are clear improvements. On the one hand, it increases the possibility to gain considerable information, and leads to reproducible results and on the other hand decreases random errors. Nevertheless, such methods often result in an overall numeric value per artefact, ignoring possible variability along the edge. In order to address and understand tool design, a mean value of the edge angle is not sufficient. With more detail, it is possible to address technical choices as well as the effects of retouch on the tool. Thus far, the recording methods are limited by the resolution and accuracy.

4.3.1 Edge angle variability and morpho-functional design

One integrated part of the overall tool design is the tool's active edge. It is common to describe the active edge in a qualitative way (e.g. sharpness, retouch) or quantified by calculating the edge angle (Dibble and Bernard, 1980; Pop, 2013; Zaidner and Grosman, 2015; Archer et al., 2018; Stemp, Macdonald and Gleason, 2019; Porter, Roussel and Soressi, 2019; Valletta et al., 2020; Weiss, 2020). The edge angle describes the angle between two intersecting planes. In the case of lithics, it means the intersection between the dorsal and the ventral surface. In order to address and understand tool design, it is a prerequisite to know the edge angle values whereby a mean value is not sufficient. With more detail, it is possible to address technological choices as well as the implications of retouch on the tool (Dibble, 1995). To acquire the data, an objective method to measure the edge angle at cross sections along the entire tool edge in defined steps as well as measurements at different distances perpendicular to the edge, was chosen. The method is applicable with a 3D model, script based and semi-automated. It provides a systematically error avoiding and reproducible approach, resulting in quantitative and statistically evaluable data.

4.3.2 3D data preparation and acquisition

The application of the method is based on the use of a 3D model. Thus, the selected samples were scanned with an AICON smartScan-HE R8 from the manufacturer Hexagon, Germany (software version OptoCat 2018R1). The S-150 FOV used has a resolution of 33µm. Identical settings were used for all scans. Approximately 20 to 27 scans per tool were needed to create a closed model – a prerequisite for the application of the method. Afterwards, the scans were exported in an STL-format.

With a complete model as a basis, some preparatory steps were necessary before calculating the edge angle. The following steps were manually done in GOM Inspect, an open source software for 3D measurement data (GOM Software 2018, Hotfix 1, Rev. 111729, build 2018-08-22). The edge of interest for calculating the edge angle needed to be defined. Since archaeological tools are variable in themselves and display a complex geometry, this is a step that has to be done manually in order to reach the intended

accuracy. Therefore, a 'surface curve' was added to each 3D model (**fig. 23 - 25**). This means, a polyline was defined, tracking the edge of the object as precisely as possible and exported in an IGES-format. This step was repeated for all tool edges. In case of *Keilmesser*, most of the time, three polylines (one for the active edge and two for the back) had to be digitalised. With this procedure, the interpretation should be kept apart from the analysis.
The next steps are script-based and also done in GOM Inspect. Based on the defined polyline the software replaces this line with a 'reference curve', which is slightly straightened by filtering the changes in direction out. It is a smoothing function, reducing the point distance to 1mm. This parameter was chosen according to the resolution of the 3D model and therefore not a universal parameter. The 'reference curve' was used for only one purpose, which is the definition of the sections. The sections are the horizontal lines originating rectangular from the 'reference curve' and following the artefact surface in a defined length. These sections are horizontal polylines compared to the vertical polylines along the edge. In case of using the 'surface curve' instead of the 'reference curve' polyline, the sections would not always be rectangular orientated because of the small changes in direction as a result of the detailed and complex artefact surface. After generating the 'sections', the 'reference curve' was no longer needed. All further steps used the previously created 'surface curve'.

4.3.3 '3-point' procedure

For calculating the edge angle in a final step, three different measuring procedures are possible (**fig. 23**). The first one, the so-called 3-point measurement, is modelled on the previously mentioned '*caliper method'* described by H. Dibble and M. Bernard in 1980. Whereas the result of the '*caliper method'* is based on a measurement taken by a special modified calliper at a known distance from the edge of the artefact by using a formula (Dibble and Bernard, 1980), the 3-point measurement is using the same topographical indexes represented by 3 points. One of the points is the intersection between the vertical polyline, the 'surface curve', and the horizontal polyline, the section. The two other points are placed on the section, each on one surface, in a defined distance away from the intersection. The edge angle can be calculated between these three points.

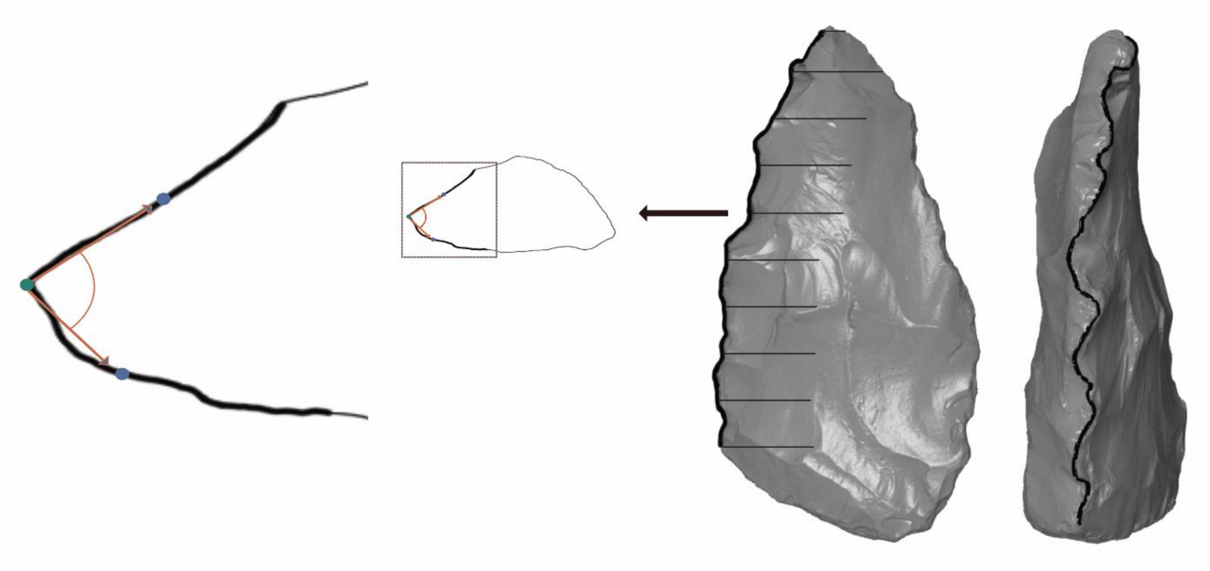


Fig. 23 3D scan of a *Keilmesser* from Ramioul (ID R-007). The scan displays the ventral surface (left) and the active edge (right). The vertical irregular black line represents the ‘surface curve’, the ten horizontal black lines the sections. The left part of the illustration shows the ‘3-point’ measurement procedure explained on the cross-section of the *Keilmesser* at the position of the fifth section. The green point indicates the intersection between the vertical ‘surface curve’ and the horizontal section. The two blue points are placed on the section in a defined distance. The edge angle measurement (orange lines) is taken based on these three points.

4.3.4 ‘2-lines’ procedure

The second measuring procedure is the so-called 2-lines measurement (**fig. 24**). This approach takes the intersection between the two polylines, as described in the first method, as one point. Beginning with this point, it follows the section on both surfaces in a given distance. Until this step, the two procedures are identical. These points on the section are used as a reference for two constructed lines. The lines have a defined length and take the points as a centre from where they spread in both directions. The calculation of the edge angle takes the two lines and the intersection into account.

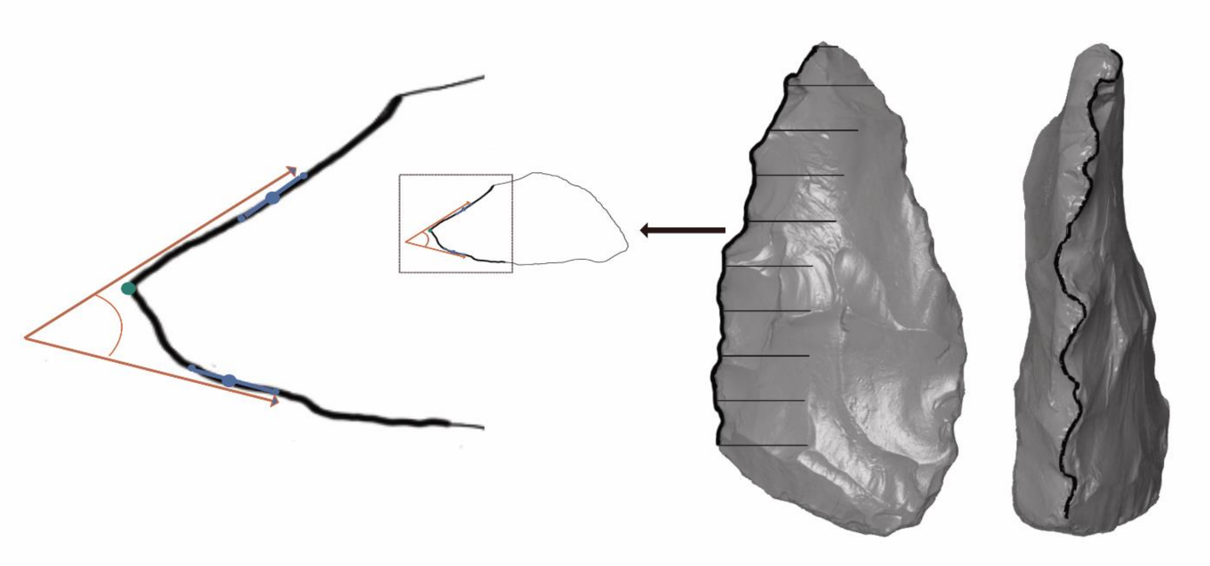


Fig. 24 3D scan of a *Keilmesser* from Ramioul (ID R-007). The scan displays the ventral surface (left) and the active edge (right). The vertical irregular black line represents the 'surface curve', the ten horizontal black lines the sections. The left part of the illustration shows the '3-point' measurement procedure explained on the cross-section of the *Keilmesser* at the position of the fifth section. The green point indicates the intersection between the vertical 'surface curve' and the horizontal section. The two blue points are placed on the section in a defined distance. They build the centre for the two lines. The edge angle measurement (orange lines) is taken based on intersection and the constructed lines.

4.3.5 'best-fit' procedure

This approach – the so-called 'best-fit' - takes the intersection between the two polylines, the vertical (surface curve) and the horizontal (section) polyline, as one point (**fig. 25**). Beginning with this point, it follows the section on both surfaces in a given distance. These points on the section are used as a reference for two constructed lines. The lines have a defined length and take the points as a centre from where they spread in both directions. The mesh points between the constructed lines were interpolated. The calculation of the edge angle takes the two lines and the intersection into account.

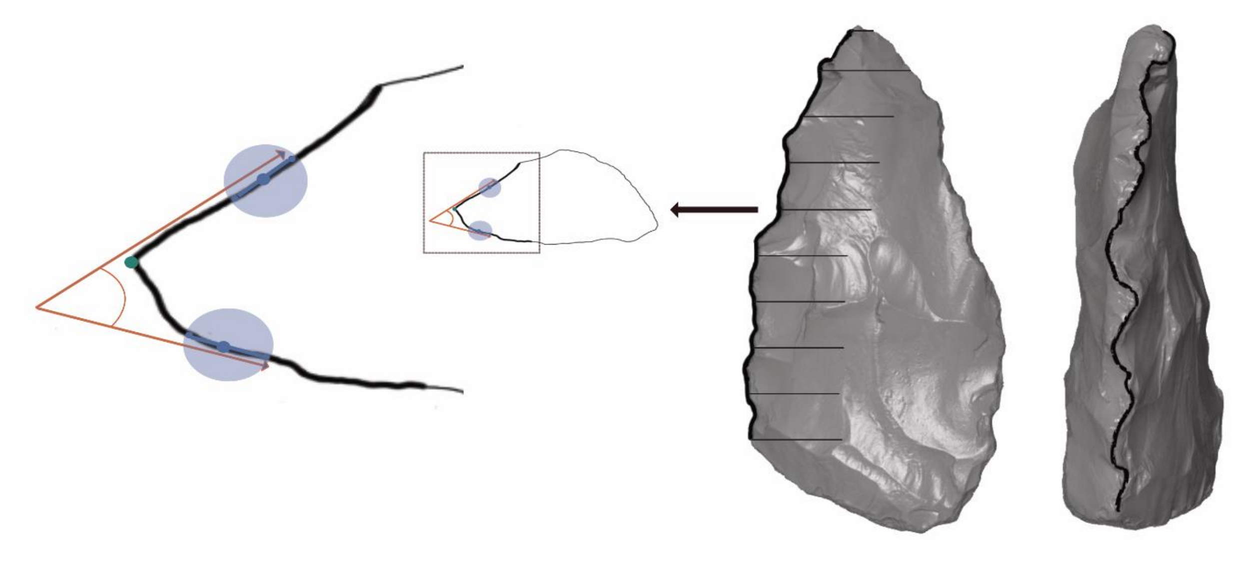


Fig. 25 3D scan of a *Keilmesser* from Ramioul (ID R-007). The scan displays the ventral surface (left) and the active edge (right). The vertical irregular black line represents the 'surface curve', the ten horizontal black lines the sections. The left part of the illustration shows the '3-point' measurement procedure explained on the cross-section of the *Keilmesser* at the position of the fifth section. The green point indicates the intersection between the vertical 'surface curve' and the horizontal section. The two blue points are placed on the section in a defined distance. They build the centre for the two lines. All mesh points of the 3D model in between the two lines are interpolated (indicated by the light-blue circles). The edge angle measurement (orange lines) is taken based on intersection and the constructed lines.

Since it seems like the 'best-fit' procedure is more precise and accurate for complex archaeological artefacts, a bit more emphasis was put on these results in the following data analysis.

4.3.6 Parameters

There are several parameters or variables, which need to be chosen in order to apply the method. One of these variables is the number of horizontal sections, represented here by ten sections per tool. The length of the lines, starting at the intersection, was defined with 12 mm. Another parameter is the distance from the edge along the sections. In the described procedures, the intersection between the vertical polyline and the horizontal section determine one crucial point, but the other two (always identical) points per measurement have to be defined numerically. Here the points were defined in 1 mm steps. The last variable is the lengths of the lines used in the '2-lines' and 'best fit' measuring procedure, which were always 2 mm.

4.3.7 Edge angle data analysis

The obtained, calculated edge angle values, were analysed. This enabled a comparison between artefacts. To do so, a statistical analysis was performed with R (version 4.0.2 through RStudio version 1.3.1073, RStudio Inc., Boston, USA). The following packages were used: writexl v. 1.3, tidyverse v.1.3.0, openxlsx v. 4.1.5, ggrepel v. 2.3, doBy v. 4.6.7, patchwork, v. 1.0.1, ggplot2 v. 3.3.2 and R.utils v. 2.9.2. Reports of the analysis in HTLM format, created with knitr v. 1.29 and rmarkdown v. 2.3 are available on GitHub as well as the raw data, the scripts and the RStudio project [https://github.com/lschunk/edge_angle_analysis]. The analysis of the data aims at illustrating possible changes for instance along the tool edges and towards the surfaces.

4.4 Use-wear analysis

Stone tools enabled past humans to access food resources like animals and plants (Lombard, 2005; McPherron et al., 2010; Wilkins et al. 2012). At the same time, they are the most commonly found physical evidence and the only continuous record to study the evolution of human behaviour (Key, Proffitt and de la Torre, 2020). Stone tools witness technological developments and innovations. Investigation how early hominins produced, used and curated their tools is thus a prerequisite for understanding the Pleistocene record. Stone tools can be observed in a great variety concerning their morphology. Nevertheless, in principle they all have something in common: they all have a certain function or combine several functions. All stone tools display the capacity to be used for a function, for instance modifying material, for movements e.g. scraping and cutting or for displaying a symbolic reason. Additionally, a tool's function can change over time or as a consequence of its use. Investigating the function of an artefact has long been part of archaeological research, either through the study of lithic typology and technology or directly through use-wear analysis. Use-wear analysis originates from the late 19th century, early 20th century (Grace, 1996). It includes the study of characteristic patterns of macroscopic and microscopic traces left on a tool, resulting from its use. Use-wear analysis is therefore the only approach providing a direct proof of a tool's utilisation (Shea 2011). Although the existence of retouch on a tool might imply tool use, solely use-wear analysis can confirm the actual use. The processes as to how use-wear forms are dependent on several aspects. For instance, the different types of use-wear traces respond to the raw material of the tool itself and the contact material, the tool morphology as well as the performed action and its duration (Kamminga 1979; Astruc et al. 2003; Lerner et al. 2007).

During the last couple of decades, use-wear analysis as a sub-discipline of archaeology passed through several changes, including methodological developments, theoretical and conceptual shifts. This process is also reflected by the given terminology. Discussions about the interchangeable character of these names and the definition of the discipline are thus the result (Marreiros et al., 2015).

Following Marreiros et al. (2020), the respective terminology – traceology, use-wear analysis and functional analysis – implies different levels of analysis and different objectives. To start with use-wear analysis, it defines the study of physical traces (microscopically and macroscopically) visible on an artefact's surface (Thomas et al., 2001; Marreiros et al., 2015). These traces are caused by human use. Traceology thereby goes a bit further. While it refers to the study of use-wear traces, it also includes traces resulting from production, non-utilitarian wear, and post-depositional traces. Ideally, use-wear analysis as well as traceology can and should be complemented with residue analysis. Functional analysis, however, combines methods such as technology, typology and use-wear analysis. Also, residue analysis can be part of functional analysis. The aim of it has to be defined in a broader sense than only to identify the use of a tool. Functional studies target the evaluation of tool design, function and utilisation.

4.4.1 Traceology, use-wear analysis & functional analysis

In the following part, the history of this sub-discipline is summarised. Giving this context is of relevance, because it illustrates and justifies the steps and methods chosen and applied within this project. It also puts some emphasis on the circumstances as to why only a combination of different scales of analysis and methods can add more – and also new – information about *Keilmesser* and *Prądnik scrapers* to our current point of view.

The beginning of traceology/use-wear analysis can be traced back until the end of the 19th century. John Evans was presumably one of the first scientists stating the fact that the use of a tool can leave corresponding traces on its surface (Tringham, 1974). Equally early is the work of William Greenwill (Hayden, 1979, Kamminga, 1979). He identified use-wear traces on Palaeolithic tools and recognized the potential of the discipline. Nevertheless, it would take decades until traceology/use-wear analysis found a broader attention. This was thanks to Sergei Semenov (Semenov, 1957, 1964), who created a methodological and systematic framework for the study of use-wear traces. For his work, Semenov is valued as the pioneer of the discipline. His publication *Prehistoric Technology* provides functional interpretations and experimental comparisons based on microscopic analysis. With his work, for the first time, experimental data has been applied as proxy for the identification of use-wear traces on archaeological samples. For his analysis, Semenov used a low magnification stereomicroscope (low-power approach) which led to a promotion of a systematic use of microscopic observations mainly on bones and lithics.
At the end of the 1960s, Semenov's work was translated and hence accessible to Western European scholars. Together with the rise of the *New Archaeology* (Binford 1962, Longacre 2010), it marked the beginning of a new period. The *New Archaeology* put the emphasis on developing scientific, hypothetic-deductive methods for the understanding of past human behaviour. The interest in for example ethnoarchaeology and the use of analogies grew. Traceology/use-wear analysis with its focus on tool function and utilisation and the microscopic approach fit the zeitgeist of the 1960s. Several researchers, for example Ruth Tringham (1974), George Odell (1975), Brian Hayden (1979) and Lawrence Keeley (1974, 1980), to mention only a few, concentrated on the new approach and tested its limitations. Consequently, the applied methods have been developed and improved, mainly by employing different microscopic magnifications. The end of the 1970s and the beginning of the 1980s are to mention as the timeframe for the introduction of the high-power approach (Keeley and Newcomer, 1977). Compared to

the low-power approach, the high-power approach is based on the use of high magnification microscopes, mostly upright metallographic microscopes. Since then, both approaches are used complementary, in the awareness of their limitations respectively. Additionally, the focus on experimental replications grew, achieving fundamental insights into the categorisation of diagnostic wear traces (Hardy and Garufi, 1998; Hayden and Vaughan, 2006). With the aid of experimental samples, it could be demonstrated that the tool's raw material influences the nature of the resulting wear pattern. A comparison between archaeological and experimental assemblages requires therefore an inclusion of the corresponding raw material (Burroni, 2002; Evans and Donahue, 2005).
The following years were characterised by improvements such as the development of more reliable and accurate methodologies by implementing more experiments and blind tests. At the same time, the limitations of a qualitative use-wear analysis became evident (Keeley, 1974; Schiffer, 1979; Grace et al., 1985; Newcomer et al., 1986, 1988; Moss, 1987; Bamforth, 1988; Hurcombe, 1988). These can be mainly summarised by the complexity of understanding use-wear traces, solely by the use of a stereomicroscope.
A new era was marked with the introduction of quantitative use-wear analysis. This significant step in the history of use-wear analysis was mainly possible due to the integration of a range of imaging equipment. The introduction of the following equipment and software is to name (Marreiros et al., 2020): the tactile profilometer (Beyries, Delamare and Quantin, 1988), the atomic force microscopy (Faulks et al., 2011; Kimball et al., 1995, 2017), the interferometry (Dumont, 1982; d'Errico and Backwell, 2009), the laser profilometry (Stemp and Stemp 2001, 2003), the confocal microscopy (Evans and Donahue, 2008; Stemp and Chung, 2011; Stemp, Lerner and Kristant, 2013; Evans, 2014; Macdonald et al., 2018), and the image analysis and surface metrology software (d'Errico and Backwell, 2009; Sahle et al., 2013; Ibáñez et al., 2018; Martisius et al., 2018, 2020; Calandra et al., 2019a,b). The aim of quantitative use-wear analysis is the identification of different use-wear traces following standardised, quantitative criteria based on 2D and 3D images and surface roughness measurements. More recently, new attempts to quantify surface textures have been made (Evans and Macdonald, 2011; Stemp et al., 2015; Martisius et al., 2018; Ibáñez et al., 2019; Pedergnana et al., 2020b; Pedergnana, Ollé and Evans, 2020). Still, criticism has been raised against a lack of reproducibility regarding the acquired data (Evans et al., 2014; Calandra et al., 2019c; Marreiros et al., 2020). While traceology/use wear analysis as a sub-discipline of archaeology is still continuously improving, scientists are aware of the current limitations of the approach. The integration of established methods from related disciplines (e.g. dental microwear) could offer great potential for further improvements (Calandra et al., 2019b).

4.4.1.1 Methods and techniques in use-wear analysis

Initial use-wear studies were characterised by the use of the low-power approach. Since the introduction of a systematic use of low magnification stereomicroscopy by Semenov, this was the state-of-the-art for use-wear analysis. This changed in the 1970s, when Keeley introduced the high-power approach. He used a reflected light microscope for his work. After years of discussion and debates about the advantages and disadvantages of both approaches, a broad agreement has been reached. Only a complementary method by the combination of low- and high-power approach can lead to a profound analysis and a reliable result. The use of the low-power approach should thereby allow the identification of macro-wear traces as for example edge damage and impact fractures. Moreover, this approach should help with identifying the areas of interest for the subsequent high-power approach. The observation under higher magnifications should allow for a detailed analysis of micro-wear traces as for instance striations and polish formations (Marreiros et al., 2015).

In general, the methods applied in use-wear analysis nowadays can be distinguished in digital microscopy, II) optical microscopy (stereomicroscopes, upright metallographic microscopes), III) scanning electron microscopy (SEM), and IV) laser scanning confocal microscopy (LSM).

When referring to the low-power approach, a stereomicroscopic analysis in the range of 4 to10 x magnification is common. Enabled by a movable light source, reflected light, the artefact can be illuminated from different angles, allowing for a shadow effect and thus an easier detection of possible traces. The implementation of the high-power approach is usually characterised by a metallographic microscope and magnifications between 50 and 400 x. An incident light serves as a light source perpendicular (90°) to the material surface. Another high magnification observation method offers the scanning electron microscopy (SEM). An SEM uses instead of a light illumination a focused beam of electrons controlled by magnetic or electric fields. The advantages of an SEM are the higher possible magnifications, resolutions, and depth of field compared to a metallographic microscope (Hay, 1977; Del Bene, 1979). The use of an SEM has also proven to lead to better results with certain raw materials, for example quartzite (Pedergnana and Ollé, 2014; Ollé et al., 2016; Pedergnana, 2017). However, the use of an SEM is also accompanied with disadvantages. Commonly, an SEM provides only a small chamber for the sample, meaning the object volume is limited. A sample preparation is typically needed, sometimes including a sample coating. Furthermore, an SEM is a costly piece of equipment and the analysis is relatively time-consuming. These aspects taken together usually lead to an analysis of a comparable small sample size. Studies have demonstrated the effectiveness of a complementary approach, the combination of optical and electron microscopy (Monnier et al., 2012; Borel et al., 2014; Ollé et al., 2016).

A quantitative use-wear analysis can be done by the means of laser scanning microscopy. The laser scanning microscopy (LSM) is an optical imaging technique. The illumination of the sample happens through a spatial pinhole system, which blocks out-of-focus light. This means, only one point on the sample at a time is illuminated. In order to acquire 2D or 3D images, the sample has to be scanned over a raster. An LSM allows observations ranging between 25-800 x magnification (e.g., Mansur, 1983; Derndarsky and Ocklind, 2001; Shanks et al., 2001; Scott et al., 2005, 2006; Debert and Sherriff, 2007; Evans and

Donahue, 2008). Laser confocal microscopy has been used mainly in archaeology for the illustration and the modelling of surface topography. Several parameters, also in accordance with ISO Norms, can be calculated on the tool's surface (e.g. amplitude parameters, spatial parameters, roughness parameters) (Calandra et al., 2019c). Based on basic roughness parameters it is possible to distinguish diagnostic use-wear traces (Giusca et al., 2012). During the last years, the LSM as well as the SEM have been used more frequently in use-wear analysis (Stemp and Stemp, 2001, 2003; Lerner et al., 2007; Evans and Donahue, 2008; Evans and Macdonald, 2011; Stemp and Chung, 2011; Giusca et al., 2012; Pedergnana et al., 2020; Pedergnana, Ollé and Evans, 2020). The likely explanation for this is the possibility to quantify micro-wear traces with both types of equipment. Unfortunately, the LSM is an expensive purchase, but the running costs are smaller and the limitations regarding the sample size are less restricting.

4.4.2 Artefact cleaning procedure

Before doing the use-wear analysis, the sampled artefacts had to be cleaned (Pedergnana et al., 2016; Pedergnana et al., 2020a). To do so, each sample was individually packed in a plastic bag filled with ~ 100 ml of demineralised water and a non-ionic detergent (BASF Plurfac LF901, 1 g/l = 1 % w/v; BASF SE, Ludwigshafen, Germany). The closed bags were put into a preheated ultrasonic bath (EMAG Emmi 20HC). The samples were left in the bath for 15 min at 40°C and 100 KHz.

Thereafter, the samples, still placed in the bags, were rinsed three times with tap water. This step is meant to remove the surfactant residues. The bags were then filled once with ~100 ml purified water and emptied after rinsing. After that, the samples were air-dried. Immediately before and during the data acquisition, the measured surface was cleaned with 2-propanol 70 % v/v.

4.4.3 Qualitative use-wear analysis

The methodological approach of use-wear analysis can be divided in a low-power and high-power approach (Keeley, 1974, 1980; Marreiros et al., 2015). While the low-power approach is equal to a macroscopic methodology, the high-power approach involves the use of optical microscopy magnification. The sampling for the use-wear analysis was done on a macroscopic observation level. When necessary, the artefacts were observed regarding their preservation with a stereomicroscope (ZEISS SteREO Discovery.V8). Only complete lithics representing all existing categories as well as *Keilmesser* shapes from the two different raw materials were sampled.

The qualitative use-wear analysis was done in a high-power approach by means of an upright light microscope (ZEISS Axio Scope.A1 MAT; **tab. 10**). The samples were studied with a 5 x, 10 x and 20 x magnification. Traces were documented as an EDF image in black and white settings.

Tool areas displaying use-wear traces were afterwards documented with a digital microscope (ZEISS Smartzoom 5) by the use of a 1.6 x objective and 34-x zoom. The combination of stitching and EDF makes a documentation of an entire tool edge in focus possible.

		LSM	upright light microscope	digital microscope	3D scanner
Microscope	Manufacturer	Carl Zeiss Microscopy GmbH	Carl Zeiss Microscopy GmbH	Carl Zeiss Microscopy GmbH	AICON, now part of Hexagon AB
	Model	Axio Imager.Z2 Vario + LSM 800 MAT	Axio Scope.A1 MAT	Smartzoom 5	smartScan-HE R8
Location	Laboratory	TraCEr, MONREPOS, Germany	TraCEr, MONREPOS, Germany	TraCEr, MONREPOS, Germany	TraCEr, MONREPOS, Germany
	Floor	basement (-1)	basement (-1)	basement (-1)	basement (-1)
	Setup	Passive anti-vibration table on solid concrete base	Standard office desk	Stable table on solid concrete base	column stand
Acquisition	Software	ZEN blue 2.3 with Shuttle&Find module	Zen core 2.7	Smartzoom software with Shuttle&Find module	OptoCat 2018R1
	Mode	LSM (laser scanning confocal microscopy)	Bright field	Bright field	Structured light
Objective	Manufacturer	Carl Zeiss Microscopy GmbH	Carl Zeiss Microscopy GmbH	Carl Zeiss Microscopy GmbH	Hexagon
	Objective	C Epiplan-Apochromat 10×/NA = 0.40/WD = 5.4 mm	EC Epiplan 5×/NA = 0.13/WD = 11.8 mm	PlanApo D 1.6×/NA = 0.1/WD = 36 mm	M-450, 108 µm point-to-point distance
		C Epiplan-Apochromat 20× /NA = 0.70/WD = 1.30 mm	EC Epiplan 10×/NA = 0.25/WD = 11.0 mm	-	S-150, 33 µm point-to-point distance
		C Epiplan-Apochromat 50×/NA = 0.95/WD = 0.22 mm	EC Epiplan 20×/NA = 0.40/WD = 3.2 mm	-	-
Illumina-tion	Source	Laser	White LED, reflected co-axial light **	White LED, reflected ringlight	Blue LED
	Wavelength	405 nm	550 nm	550 nm	-
Settings	Master Gain	245 V	-	-	-

	Scanning direction	Both ways (no correction, line step = 1)	-	-	-
	Scanning speed	8 (max)	-	-	-
	Bit depth	16 bits	-	-	-
	Pinhole diameter	54 µm (50× obj.) / 34 µm (20× obj.) (1 AU lateral optical resolution)	-	-	-
Size and **resolution**	Zoom	0.5× (50× obj.) / 0.2× (20× obj.)	-	-	-
	Step size	0.25 µm	-	-	-
	Data quality	No noise cut (0–65335 levels, post-processing)	-	-	-
	FOV	255.56 × 255.56 µm (50× obj.) / 638.9 × 638.9 µm (20× obj.)	1.70 × 1.42 mm (5× obj.) / 850.08 × 709.32 µm (10× obj.) / 425.04 × 354.66 µm (20× obj.)	10.475 7.856 mm	355 × 265 × 220 mm measuring volume (M-450) / 110 × 80 × 70 mm measuring volume (S-150)
	Frame size	1198 × 1198 pixels (50× obj.) / 3000 × 3000 pixels (20× obj.)	2464 × 2056 pixels	15875 × 3301 pixels	-
	Total on-screen magnification	1318× (50× obj,) / 527× (20× obj.)	187× (5× obj.) / 375× (10× obj.) / 750× (20× obj.)	34×	-

Table 10 Acquisition settings for the involved pieces of equipment including the objective specifications and the resulting magnifications and resolutions. NA = numerical aperture, WD = working distance, FOV = field of view.
The total on-screen magnification can be calculated as follows: objective magnification × optical zoom × camera adaptor × screen diagonal × digital zoom camera / camera sensor diagonal

4.4.3.1 Spatial pattern recognition

A scheme was developed to locate and map use-wear traces (for similar scheme see Plisson, 1985; van Gijn, 1990; Lombard, 2008; Mazzucco, 2018). The outline of the artefact was used as a grid (**fig. 26**). *Keilmesser*, *Prądnik scrapers*, scraper and flakes were separated in a grid of six areas, *Prądnik spalls* in four areas. This was done for the dorsal (A and B) as well as for the ventral (D and C) surface. The areas are numbered from 1, distal part of the tool, to 2, the medial part, and 3, the proximal part of the tool. Following this scheme, use-wear traces can easily be located and a map for all use-wear traces can be generated, allowing for statements regarding the frequency and distribution of the use-wear traces. Thus, this qualitative use-wear approach aims for pattern recognition (e.g. location of the use-wear traces on tool's surface). Included in the scheme is the type of use-wear and the orientation. Possible predefined use-wear types are polish, striations and impact marks. Here, polish refers to a modification of the tool surface caused by contact between the tool and the worked material. Polish appears as a dull, brighter or smoothed area on the surface (Keeley, 1980; Haslam et al., 2009; Rots, 2013; Evans, 2014). The term striation refers to linear scratches, furrows or grooves reflecting an abrasive action between the tool and the worked material (Keeley, 1980). Moreover, the orientation for the use-wear traces can be specified with the options perpendicular, parallel or oblique to the edge.

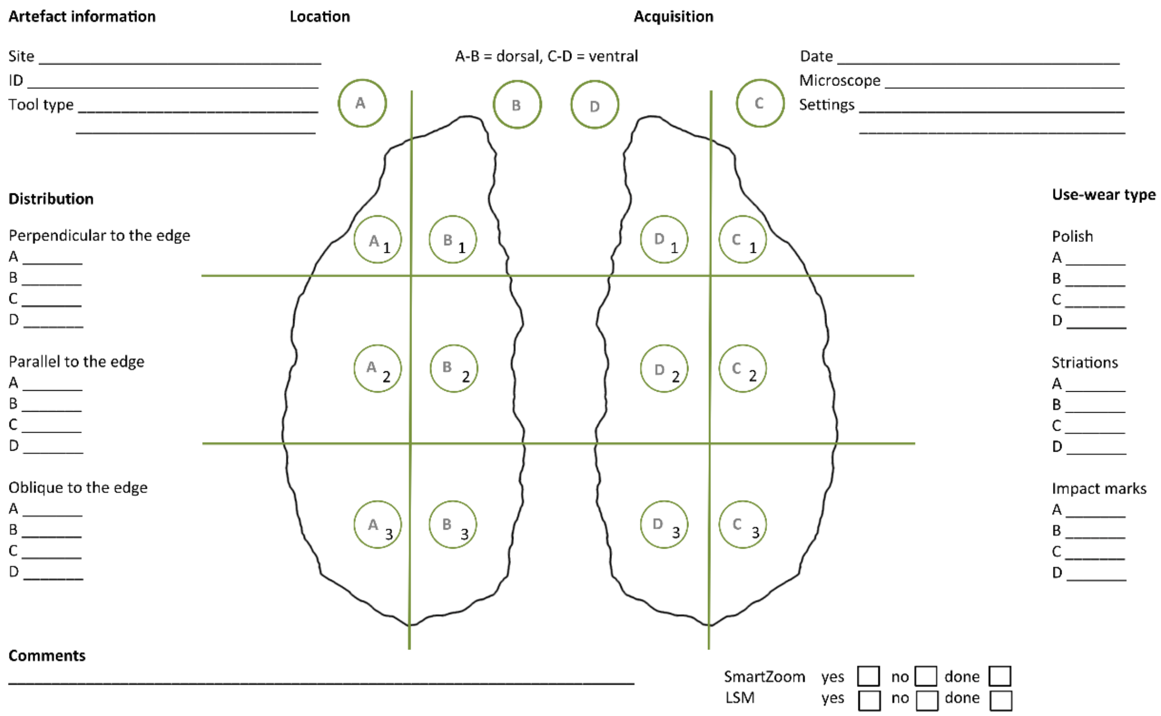


Fig. 26 Scheme used during the qualitative use-wear analysis for the documentation of the analysed tools. Here, the outline represents a *Keilmesser*. The dorsal (A and B) and ventral surfaces (D and C) are exemplarily labelled as if the tool would be a right-sided *Keilmesser*. However, the outline is different for the other artefact categories. Additionally, the scheme includes information about the analysed artefact itself, the acquisition date and settings, as well as information about the use-wear traces (location, distribution and type). The scheme also contains information, whether further acquisition or analysis are needed (SmartZoom = digital microscope images, LSM = quantitative use-wear analysis).

4.4.3.2 Description use-wear traces

The aim of use-wear analysis is to identify traces left on the tool's surface. The first step is the recognition and the characterisation of different types of traces, for example polish, impact fractures or striations. It is known that wear patterns correlate with the worked material (Keeley, 1980; Haslam et al., 2009; Rots, 2013). A further step usually seeks, especially concerning polish, a more detailed description and identification of the observed traces. In the qualitative approach, this is exclusively based on visual identification of the traces. Polish is a modified area on the tool, recognisable with an optical microscope by a brighter or smoother appearance (Keeley, 1980). It is caused by a gradual removal or deformation of the natural surface. Various names for different types of polish can be found in literature for example wavy polish, and also their functional interpretation as wood polish, bone polish, hide polish etc. Although the classification of polish and its formation is one of the fundamental questions addressed in use-wear analysis (Marreiros et al., 2015), a consensus and an agreement on the various terms and identifications is still missing (Grace et al., 1985, 1987; Evans, 2014; Van Gijn, 2014; Marreiros et al., 2020). The different types of polish are likely related to several other aspects such as the raw material, the use intensity, the performed task and not only the worked material (Buc, 2011). This means, even the same combination of tool and worked material can lead to varying traces by performing the same movement when only the duration differs. This makes it extremely difficult to assess the exact use of a tool confidentially by visual means only.

Here, documented traces were visually inspected and categorised. A subjective description of these categorised wear traces was done. With respect to the various existing definitions, nine types of use-wear traces were defined for the samples from the three analysed assemblages. Sometimes, the distinction between two types of use-wear traces was ambiguous. In these cases, the combination of two of the defined types was chosen.

4.4.3.3 Analysis use-wear data

After documenting and defining the use-wear traces on all analysed artefacts, the manually filled scheme for the use-wear pattern recognition (see section 4.4.3.1) had to be digitalised. Therefore, the initially used artefact outline templates (SVG files) were converted into DXF format using the open-source software Potrace tracing program (version 1.1.6), producing internal and external outlines as well as the grid. The DXF were modified using CAD. The resulting DXF files were then imported into QGIS (version 3.14.16) templates as vectors. QGIS is a free and open source geographic information system, which was used here to map the documented traces. Next to the described vector layers, additional point layers for each individual type of use-wear trace were created. The point layers were given a suitable colour schema. This method allows a simple and visual presentation of all use-wear traces separated per artefact type.

4.4.4 Quantitative use-wear analysis

Based on the results from the previously described qualitative use-wear analysis, samples were selected for a quantitative use-wear analysis. Thus, the quantitative use-wear analysis was done on samples displaying different types of use-wear and use-wear on the different locations. The minimum number of measurements per use-wear type was three. The 3D surface topography data was acquired with a confocal microscope. The confocal

microscope is an upright light microscope coupled with a laser-scanning confocal microscope (ZEISS Axio Imager.Z2 Vario + ZEISS LSM 800 MAT; **tab. 10**).
When time played a limiting factor, for example during a short time loan from a museum or during the execution of an experiment, moulds of the region of interest were taken. The moulds assure a possibility of a quantitative use-wear analysis at a later time, since they serve as an identical copy of the real surface. The moulds were made of Provil novo Light regular (Kulzer GmbH, Hanau, Germany), a two-component silicone impression material applied with a dispensing gun. Under regular room conditions, the moulds are fully hardened after 5 to 8 minutes.
In total 50 different use-wear spots were measured with the LSM. Six of these use-wear traces are on artefacts from Buhlen, 33 from Balver Höhle and eleven from Ramioul. Four of these 50 measurements were taken on moulds instead of the original artefact surface. Before using the LSM, the system always had to be turned on one hour in advance in order to warm up all components and to limit thermic drift. In order to assure that the artefacts cannot move and stay stable during the acquisition, a mould with a flat lower surface in the sense of a sample holder was made. The mould was made of Provil novo Putty regular set (Kulzer GmbH, Hanau, Germany). This set is a two-component silicone impression material consisting of a base paste and a matching catalyst paste. After combining these two components in a ratio 50:50, the curing time is roughly 3 to 5 minutes in room conditions. Additionally, a goniometer stage was used to position the sample with the area to measure as horizontal as possible. The LSM is equipped with a motorized revolver allowing an easy change of objectives. For the acquisition with the LSM the aim was to scan the surface under the highest magnification, respectively. Therefore, the objective C Epiplan-Apochromat 50x with the numerical apertures 0.95 was used. The field of view (FOV) was 255.6 x 255.6 µm. Sometimes the artefact surfaces were not straight enough or the artefacts could not be positioned in a way needed in order to measure the surfaces with the 50x /0.95 objective, so that the C Epiplan 50x /0.75 (for n = 9 samples) or the C Epiplan-Apochromat 20x /0.70 (for n = 1 sample) had to be used. While the 50x /0.75 has the same FOV than the other 50x objective, the 20x /0.70 objective has a FOV of 638.9 x 638.9 µm. Each use-wear trace was measured three times at nearby but non-identical spots. These scans are treated as replicas and verify (or not) the homogeneity within each trace.
Wide field images as an overview were not acquired with the LSM since EDF pictures were already taken with the upright light microscope.

4.4.4.1 Data processing

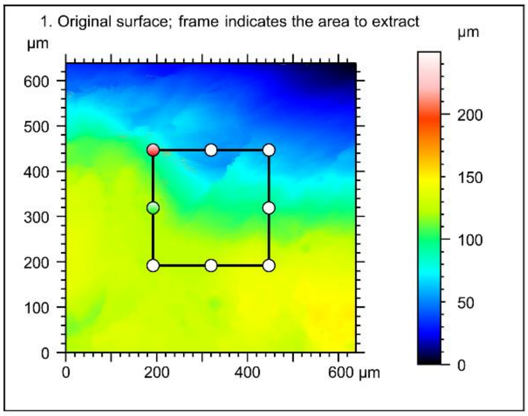
The acquired data was processed in batch for each archaeological site respectively with templates in ConfoMap (a derivative of MountainsMap Imaging Tophography developed by Digital Surf, Besançon, France; version ST 8.1.9286; for details see https://guide.digitalsurf.com/en/guide.html). In total four different templates had to be applied. The first template – the 'extracting template' - was only used for the 3D surfaces

acquired with the 20x /0.70 objective (**fig. 27 – 34**). After applying this template, all surfaces had the same size of 254.9 x 254.9 µm. The following second template, 'resampling template' was by contrast used to perform a resampling in x and y on all 150 surfaces, leading to an identical spacing. For the scans acquired on moulds, an additional third template was needed, the 'mirroring template'. Moulds always just display a mirrored version of the original surfaces. Therefore, the acquired surface needed to be mirrored in order to match the original surface again. In a final step, the data was processed with a 'processing template'. The following procedure was performed: I.) Levelling (least squares method by subtraction), II.) From removal (polynomial of degree3), III.) Outliers removal (maximum slope of 80°), IV.) Thresholding the surface between 0.1 and 99.9 % material ratio to remove the aberrant positive and negative spikes, V.) Applying a robust Gaussian low-pass S-filter (S_1 nesting index = 0.425 µm, corresponding to about 5 pixels, end effects managed) to remove noise, VI.) Filling-in the non-measured points (NMP), VII.) Analysis: Calculation of 21 ISO 25178-2 parameters, 3 furrow parameters, 3 texture direction parameters, 1 texture isotropy parameter and the scale-sensitive fractal analysis (SSFA) parameters *epLsar, NewEplsar, Asfc, Smfc, HAsfc9 and HAsfc81* (**tab. 11**).
The ConfoMap templates for each site and surface in MNT and PDF formats are available on GitHub [https://github.com/lschunk/Archaeology_use-wear]. This also includes all original and processed surfaces, as well as the results.

Quantitative use-wear analysis: Balver Höhle
Template to extract a 255 x 255 µm surface acquired with the LSM800 with the 20x/0.7 objective in order to match the FOV of the 50x0.95 and 50x0.7 objectives

This template is used for one sample with three measurements (surfaces).

A. Extracting



Identity card		
Name:	MU-232-B2-01-a_20x07_LSM_Topo	
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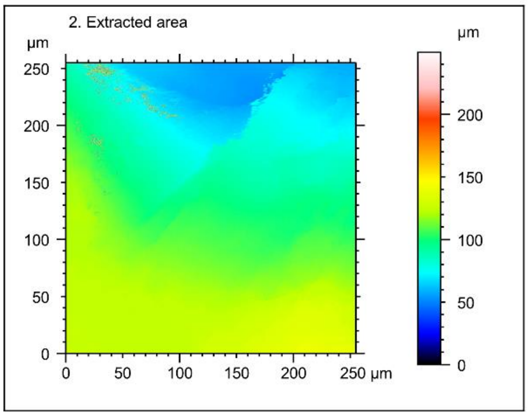
Studiable type:	Surface	
Axis:	X	
Length:	638.7	µm
Size:	3000	points
Spacing:	0.2130	µm
Axis:	Y	
Length:	638.7	µm
Size:	3000	points
Spacing:	0.2130	µm
Axis:	Z	
Layer type:	Topography	
Length:	249.7	µm
Size:	65531	digits
Spacing:	3.810	nm
NM-points ratio:	0.000 % (0 Pts)	



Identity card		
Name:	MU-232-B2-01-a_20x07..._Topo > Extracted area	
Created on:	7/7/2020 4:58:00 PM	
Studiable type:	Surface	
Axis:	X	
Length:	254.9	µm
Size:	1198	points
Spacing:	0.2130	µm
Axis:	Y	
Length:	254.9	µm
Size:	1198	points
Spacing:	0.2130	µm
Axis:	Z	
Layer type:	Topography	
Length:	249.6	µm
Size:	65505	digits
Spacing:	3.810	nm
NM-points ratio:	0.000 % (0 Pts)	

ConfoMap ST 8.1.9286

23-Jul-20

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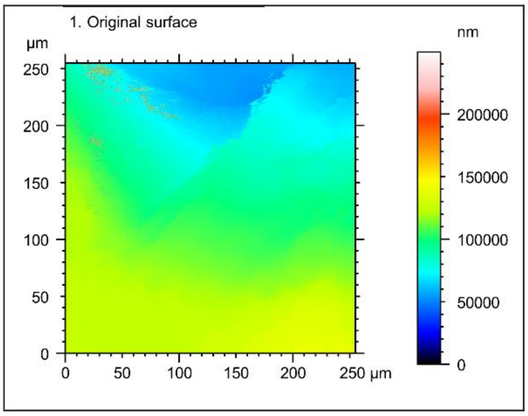
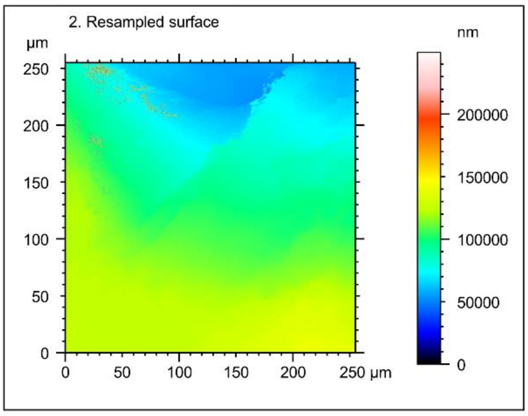
Fig. 27 'Extracting template' created in ConfoMap (a derivative of MountainsMap Imaging Topography developed by Digital Surf, Besançon, France; version ST 8.1.9286) to process the data acquired from the quantitative use-wear analysis. Here, the template was applied to a *Keilmesser* from Balver Höhle (MU-232). The template was only used for samples analysed with the 20x/0.7 objective.

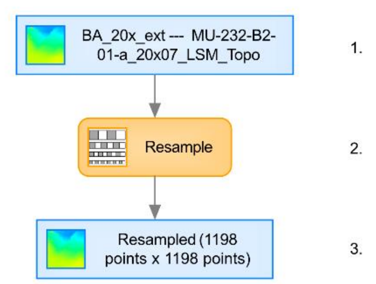
Quantitative use-wear analysis: Balver Höhle
Template to resample in x and y in order to reach an identical spacing in all with the LSM800 acquired surfaces (50x/0.7 and 50x/0.95 objectives).

This template is used for thirty-three samples with three measurements (surfaces) respectively.

B. Resampling







Identity card

Name:	BA_20x_ext --- MU-232…01-a_20x07_LSM_Topo	
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Axis:	X	
Length:	254.9	µm
Size:	1198	points
Spacing:	0.2130	µm
Axis:	Y	
Length:	254.9	µm
Size:	1198	points
Spacing:	0.2130	µm
Axis:	Z	
Layer type:	Topography	
Length:	249564	nm
Size:	65505	digits
Spacing:	3.810	nm
NM-points ratio:	0.000 % (0 Pts)	

Identity card

Name:	BA_20x_ext --- MU-232…8 points x 1198 points)	
Created on:	7/7/2020 4:58:00 PM	
Studiable type:	Surface	
Axis:	X	
Length:	254.9	µm
Size:	1198	points
Spacing:	0.2130	µm
Axis:	Y	
Length:	254.9	µm
Size:	1198	points
Spacing:	0.2130	µm
Axis:	Z	
Layer type:	Topography	
Length:	249564	nm
Size:	65505	digits
Spacing:	3.810	nm
NM-points ratio:	0.000 % (0 Pts)	

ConfoMap ST 8.1.9286

25-Aug-20

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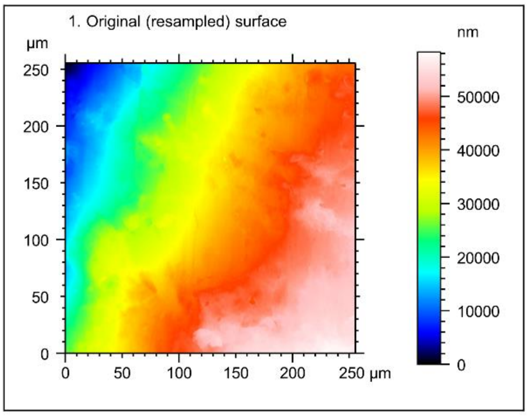
Fig. 128 'Resampling template' created in ConfoMap (a derivative of MountainsMap Imaging Topography developed by Digital Surf, Besançon, France; version ST 8.1.9286) to process the data acquired from the quantitative use-wear analysis. Here, the template was applied to a *Keilmesser* from Balver Höhle (MU-232).

Quantitative use-wear analysis: Balver Höhle
Template to mirror the surfaces in x and z that have been acquired with the LSM800 based on moulds instead of the original artefact surface.

ZEISS

This template is used for three samples with three measurements (surfaces) respectively.

C. Mirroring



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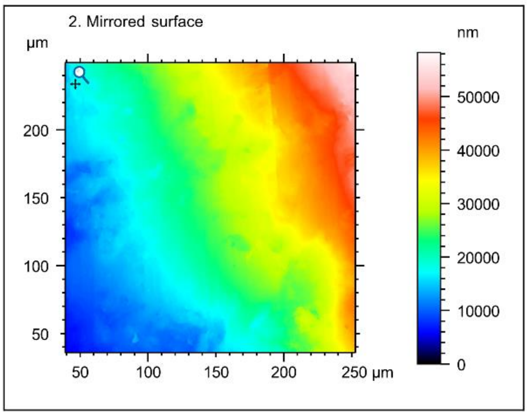
Size:	1198	points
Spacing:	0.2134	µm
Axis:	Y	
Length:	255.5	µm
Size:	1198	points
Spacing:	0.2134	µm
Axis:	Z	
Layer type:	Topography	
Length:	58262	nm
Size:	65509	digits
Spacing:	0.8894	nm
NM-points ratio:	0.000 % (0 Pts)	



Identity card		
Name:	BA_50x_res --- MU-020 …> Mirrored (in X and Z)	
Created on:	7/8/2020 4:41:00 PM	
Studiable type:	Surface	
Axis:	X	
Length:	255.5	µm
Size:	1198	points
Spacing:	0.2134	µm
Axis:	Y	
Length:	255.5	µm
Size:	1198	points
Spacing:	0.2134	µm
Axis:	Z	
Layer type:	Topography	
Length:	58262	nm
Size:	65509	digits
Spacing:	0.8894	nm
NM-points ratio:	0.000 % (0 Pts)	

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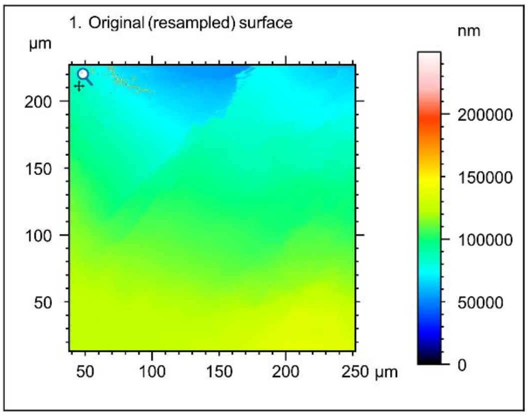
Fig. 29 'Mirroring template' created in ConfoMap (a derivative of MountainsMap Imaging Topography developed by Digital Surf, Besançon, France; version ST 8.1.9286) to process the data acquired from the quantitative use-wear analysis. Here, the template was applied to a *Keilmesser* from Balver Höhle (MU-020). This template was only used when a mould instead of the original artefact surface was analysed.

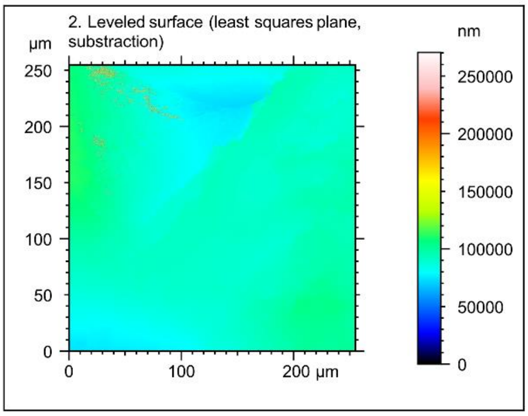
Quantitative use-wear analysis: Balver Höhle
Template to process all surfaces aquired with the LSM with the 20x/0.7, 50x/0.75 and 50x/0.95 objectives.

This template is used for thirty-three samples with three measurements (surfaces) respectively.

D. Processing



Identity card		
Name:	BA_50x_res --- BA_20x...01-a_20x07_LSM_Topo	
Created on:	7/7/2020 4:58:00 PM	
Studiable type:	Surface	
Axis:	X	
Length:	254.9	µm
Size:	1198	points
Spacing:	0.2130	µm
Axis:	Y	
Length:	254.9	µm
Size:	1198	points
Spacing:	0.2130	µm
Axis:	Z	
Layer type:	Topography	
Length:	249564	nm
Size:	65505	digits
Spacing:	3.810	nm
NM-points ratio:	0.000 % (0 Pts)	



Identity card		
Name:	BA_50x_res --- BA_20x...po> Leveled (LS-plane)	
Created on:	7/7/2020 4:58:00 PM	
Studiable type:	Surface	
Axis:	X	
Length:	254.9	µm
Size:	1198	points
Spacing:	0.2130	µm
Axis:	Y	
Length:	254.9	µm
Size:	1198	points
Spacing:	0.2130	µm
Axis:	Z	
Layer type:	Topography	
Length:	270491	nm
Size:	70998	digits
Spacing:	3.810	nm
NM-points ratio:	0.000 % (0 Pts)	

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Fig. 30 'Mirroring template' created in ConfoMap (a derivative of MountainsMap Imaging Topography developed by Digital Surf, Besançon, France; version ST 8.1.9286) to process the data acquired from the quantitative use-wear analysis. Here, the template was applied to a *Keilmesser* from Balver Höhle (MU-232). This is page 1 of 5.

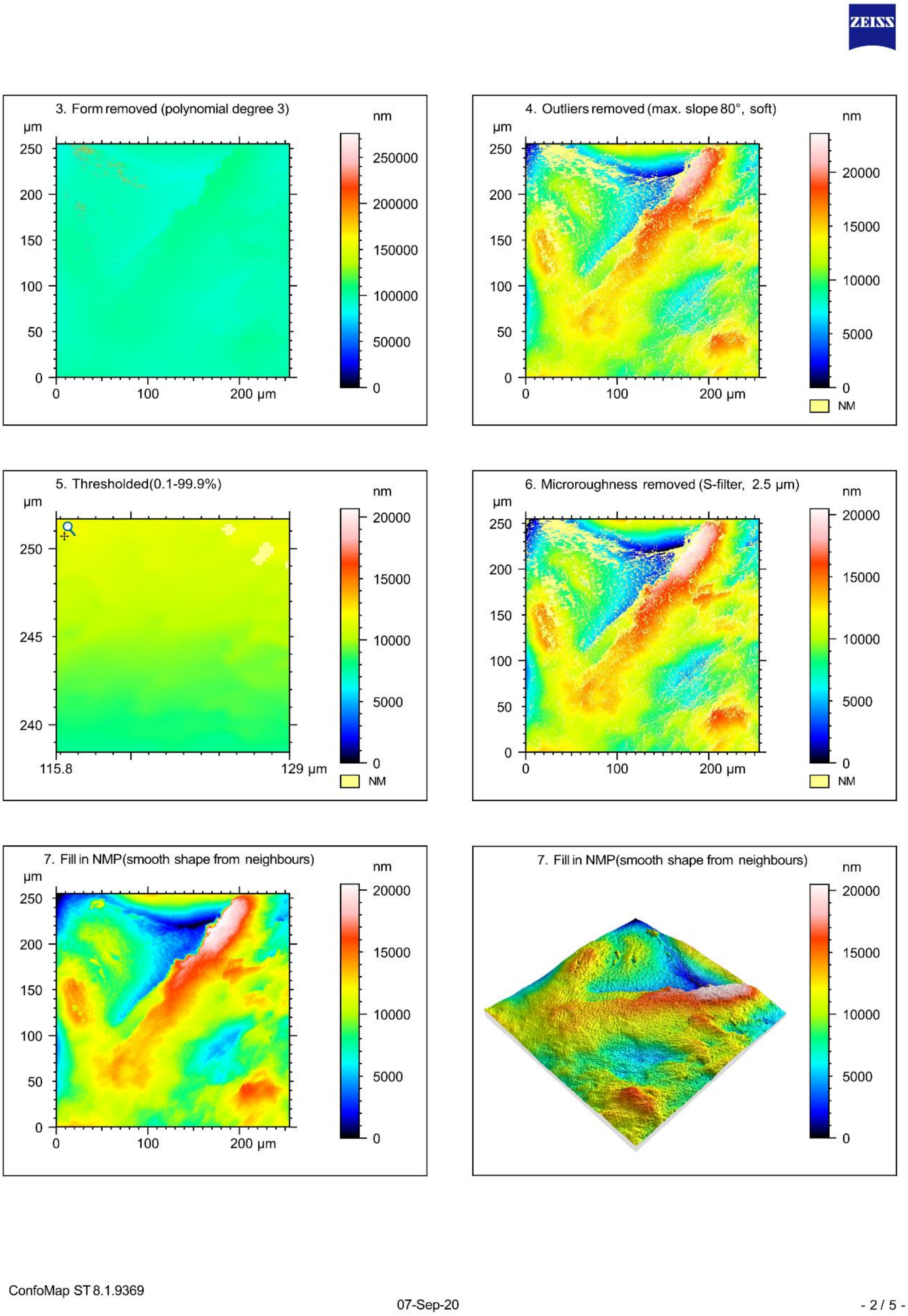
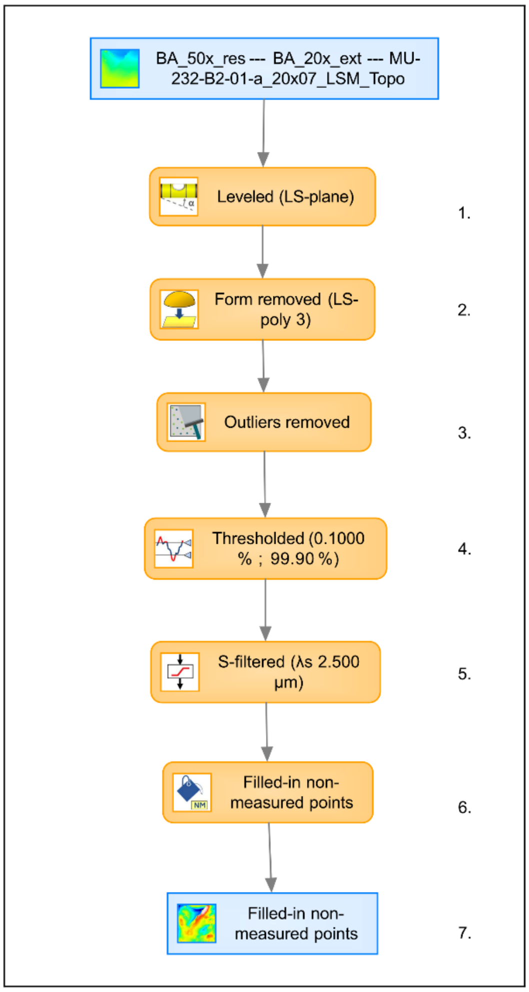


Fig. 31 ‘Mirroring template’ created in ConfoMap (a derivative of MountainsMap Imaging Topography developed by Digital Surf, Besançon, France; version ST 8.1.9286) to process the data acquired from the quantitative use-wear analysis. Here, the template was applied to a *Keilmesser* from Balver Höhle (MU-232). This is page 2 of 5.

Identity card	
Name:	BA_50x_res --- BA_20x...in non-measured points
Created on:	7/7/2020 4:58:00 PM
Studiable type:	Surface

Axis:	X	
Length:	254.9	µm
Size:	1198	points
Spacing:	0.2130	µm
Axis:	Y	
Length:	254.9	µm
Size:	1198	points
Spacing:	0.2130	µm
Axis:	Z	
Layer type:	Topography	
Length:	20482	nm
Size:	53762	digits
Spacing:	0.3810	nm
NM-points ratio:	0.000 % (0 Pts)	



C. Analyses

Analyses:

ISO 25178 8.

Furrow 9.

Texture direction 10.

Texture isotropy 11.

SSFA 12.

8. ISO 25178-2 parameters on surface #7

ISO 25178 - Primary surface		
F: [Workflow] Form removed (LS-poly 3)		
S-filter (λs): [Workflow] S-filtered (λs 2.500 µm)		
Height parameters		
Sq	3243	nm
Ssk	0.06336	
Sku	3.457	
Sp	10477	nm
Sv	10005	nm
Sz	20482	nm
Sa	2506	nm
Functional parameters		
Smr	0.5510	%
Smc	3754	nm
Sxp	6582	nm
Spatial parameters		
Sal	25.95	µm
Str	0.3211	
Std	42.50	°
Hybrid parameters		
Sdq	0.6025	
Sdr	9.994	%
Functional parameters (Volume)		
Vm	0.2094	µm³/µm²
Vv	3.963	µm³/µm²
Vmp	0.2094	µm³/µm²
Vmc	2.775	µm³/µm²
Vvc	3.559	µm³/µm²
Vvv	0.4034	µm³/µm²

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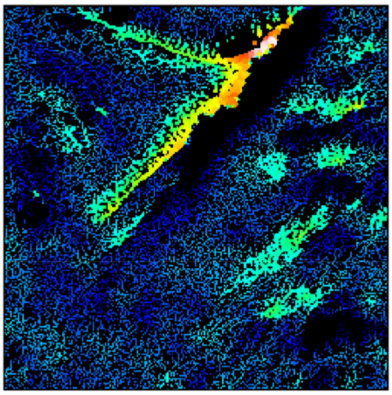
Fig. 32 'Mirroring template' created in ConfoMap (a derivative of MountainsMap Imaging Topography developed by Digital Surf, Besançon, France; version ST 8.1.9286) to process the data acquired from the quantitative use-wear analysis. Here, the template was applied to a *Keilmesser* from Balver Höhle (MU-232). This is page 3 of 5.

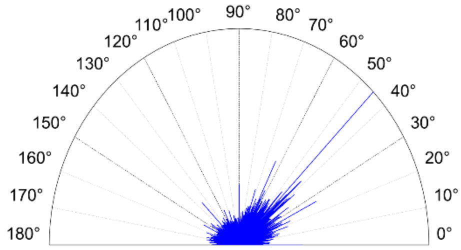
9. Furrow analysis on surface #7



All furrows are shown.

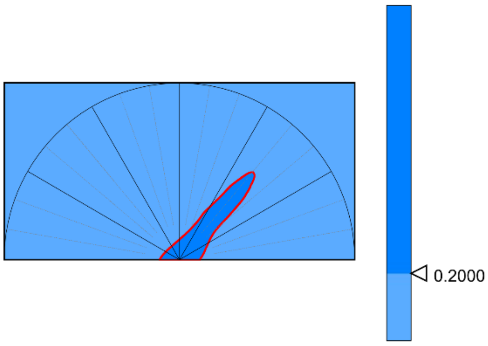
Parameters	Value	Unit
Maximum depth of furrows	12698	nm
Mean depth of furrows	2586	nm
Mean density of furrows	2987	cm/cm2

10. Texture direction on surface #7



Parameters	Value	Unit
First direction	44.98	°
Second direction	26.45	°
Third direction	63.53	°

11. Texture isotropy on surface #7



Parameters	Value	Unit
Isotropy	13.50	%

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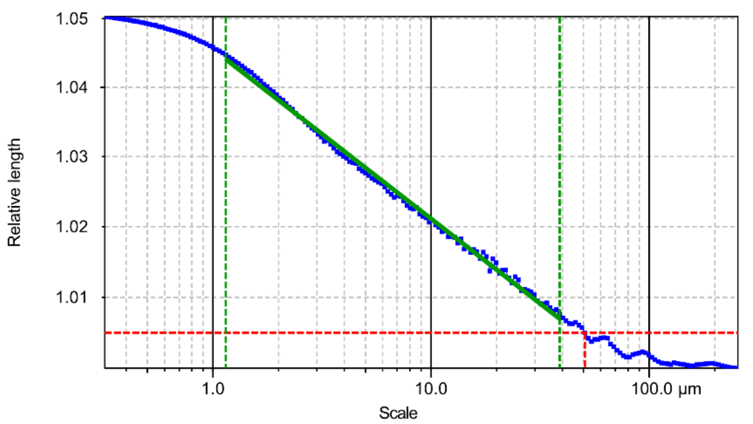
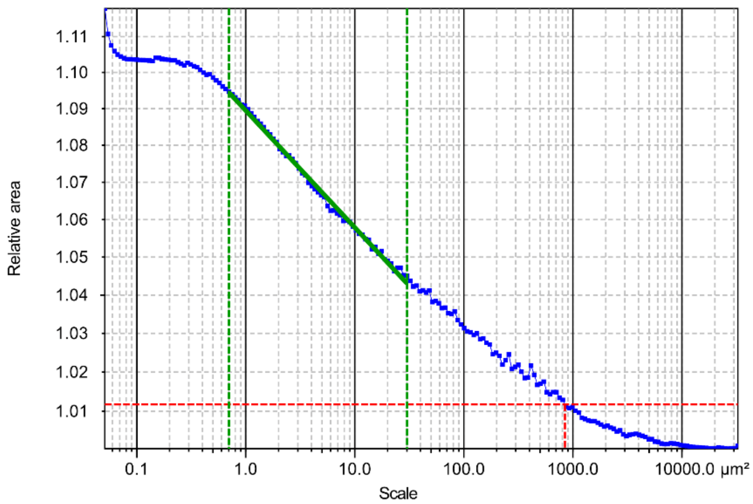
Fig. 33 'Mirroring template' created in ConfoMap (a derivative of MountainsMap Imaging Topography developed by Digital Surf, Besançon, France; version ST 8.1.9286) to process the data acquired from the quantitative use-wear analysis. Here, the template was applied to a *Keilmesser* from Balver Höhle (MU-232). This is page 4 of 5.

12. SSFAon surface #7



Information	
Method	Length-scale (rows)

Parameters	Value	Unit	Comment
epLsar	0.003683		*Length-scale anisotropy (Sfrax) (1.8 µm, 5°)*
NewEplsar	0.0181		*Length-scale anisotropy (1.8 µm, 5°)*



Information	
Method	Area-scale (four corners)

Parameters	Value	Unit	Comment
Asfc	12.80		*Fractal complexity*
Smfc	2.508	µm²	*Scale of max complexity*
HAsfc9	0.6292		*Heterogeneity of Asfc (3x3)*
HAsfc81	0.8102		*Heterogeneity of Asfc (9x9)*

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Fig. 34 'Mirroring template' created in ConfoMap (a derivative of MountainsMap Imaging Topography developed by Digital Surf, Besançon, France; version ST 8.1.9286) to process the data acquired from the quantitative use-wear analysis. Here, the template was applied to a *Keilmesser* from Balver Höhle (MU-232). This is page 5 of 5.

parameter	unit	category	subcategory	name	description
Smc (mr = 10%)	µm	Field	Functional	inverse areal material ratio of the scale-limited surface	height *c* at which a given areal material ratio (*mr*, or *p* in MountainsMap) is satisfied
Smr (c = 1µm under the highest peak)	%	Field	Functional	areal material ratio of the scale-limited surface	ratio of the area of the material at a specified height *c* to the evaluation area
Sxp (p = 50%, q = 97.5%)	µm	Field	Functional	peak extreme height	difference in height between the p and q material ratios
Sa	µm	Field	Height	arithmetical mean height of the scale limited surface	arithmetic mean of the absolute of the ordinate values within a definition area (*A*)
Sku	<no unit>	Field	Height	kurtosis of the scale-limited surface	quotient of the mean quartic value of the ordinate values and the fourth power of Sq within a definition area (*A*)
Sp	µm	Field	Height	maximum peak height of the scale limited surface	largest peak height value within a definition area
Sq	µm	Field	Height	root mean square height of the scale-limited surface	root mean square value of the ordinate values within a definition area (*A*)
Ssk	<no unit>	Field	Height	skewness of the scale-limited surface	quotient of the mean cube value of the ordinate values and the cube of Sq within a definition area (*A*)
Sv	µm	Field	Height	maximum pit height of the scale limited surface	minus the smallest pit height value within a definition area
Sz	µm	Field	Height	maximum height of the scale-limited surface	sum of the maximum peak height value and the maximum pit height value within a definition area
Sdq	<no unit>	Field	Hybrid	root mean square gradient of the scale-limited surface	root mean square of the surface gradient within the definition area (*A*) of a scale-limited surface
Sdr	%	Field	Hybrid	developed interfacial area ratio of the scale-limited surface	ratio of the increment of the interfacial area of the scale-limited surface within the definition area (*A*) over the definition area
Sal (s = 0.2)	µm	Field	Spatial	autocorrelation length	horizontal distance of the $f_{ACF}(t_x,t_y)$ which has the fastest decay to a specified value *s*, with $0 \leq s < 1$

Std (Reference angle = 0°)	°	Field	Spatial	texture direction of the scale-limited surface	angle, with respect to a specified direction ϑ, of the absolute maximum value of the angular spectrum
Str (s = 0.2)	<no unit>	Field	Spatial	texture aspect ratio	ratio of the horizontal distance of the $f_{ACF}(t_x,t_y)$ which has the fastest decay to a specified value *s* to the horizontal distance of the $f_{ACF}(t_x,t_y)$ which has the slowest decay to *s*, with $0 \leq s < 1$
Vm *(p = 10%)*	µm³/µm²	Field	Volume	material volume	volume of the material per unit area at a given material ratio calculated from the areal material ratio curve
Vmc (p = 10%, q = 80%)	µm³/µm²	Field	Volume	core material volume of the scale-limited surface	difference in material volume between the *p* and *q* material ratios
Vmp (p = 10%)	µm³/µm²	Field	Volume	peak material volume of the scale-limited surface	material volume at *p* material ratio
Vv (p = 10%)	µm³/µm²	Field	Volume	void volume	volume of the voids per unit area at a given material ratio calculated from the areal material ratio curve
Vvc (p = 10%, q = 80%)	µm³/µm²	Field	Volume	core void volume of the scale-limited surface	difference in void volume between *p* and *q* material ratios
Vvv (p = 80%)	µm³/µm²	Field	Volume	dale void volume of the scale-limited surface	dale volume at *p* material ratio
Asfc	<no unit>	SSFA		Area-scale fractal complexity	The slope of the steepest part of the curve, fit to a log-log plot of relative area over the range of scales multiplied by -1000
epLsar	<no unit>	SSFA		Exact proportion Length-scale anisotropy of relief	Radial profiles are extracted from the centre of the surface, by default every 5°, and the value of relative-length is calculated at a scale of 1.8 µm
HAsfc	<no unit>	SSFA		Heterogeneity of Area-scale fractal complexity	Calculated in a scale-sensitive manner by splitting individual scanned areas into successively smaller subregions given equal numbers of rows and columns
NewEpLsar	<no unit>	SSFA		Exact proportion Length-scale anisotropy of relief	Radial profiles are extracted from the centre of the surface, by default every 5°, and the value of relative-

					length is calculated at a scale of 1.8 µm
Smfc	µm²	SSFA		Scale of maximum complexity	The scale range over which *Asfc* is calculated (the steepest part of the relative area versus scale curve)
Isotropy	%	Texture direction		Isotropy	Identical to ISO 25178 *Str*
Tr1R	°	Texture direction		First direction	Only relevant if Isotropy ≤ 30%. Identical to ISO 25178 *Std*
Tr2R	°	Texture direction		Second direction	Only relevant if *Isotropy* ≤ 30%
Tr3R	°	Texture direction		Third direction	Only relevant if *Isotropy* ≤ 30%
madf	µm	Furrow		Maximum depth of furrows	Furrows are micro-valleys. The furrow analysis identifies the areas where points are lower than the neighbouring points on a given surface
metf	µm	Furrow		Mean depth of furrows	Furrows are micro-valleys. The furrow analysis identifies the areas where points are lower than the neighbouring points on a given surface
medf	cm/cm²	Furrow		Mean density of furrows	Furrows are micro-valleys. The furrow analysis identifies the areas where points are lower than the neighbouring points on a given surface

Table 11 3D parameters calculated within the qualitative use-wear analysis. These 3D parameters include 21 ISO 25178-2 parameters, 3 furrow parameters, 3 texture direction parameters, 1 texture isotropy parameter and 6 SSFA parameters.

4.4.4.2 Statistical procedure

All descriptive analyses (summary statistics, scatter plots, box plots, histogram plots and principal component analysis, PCA) were performed in the open-source software R version 4.0.2 through RStudio version 1.3.1073 (RStudio Inc., Boston, USA) for Microsoft Windows 10. The following packages were used openxlsx v. 4.1.5, R.utils v. 2.9.2, doBy v. 4.6.7, ggrepel v. 0.8.2, patchwork v. 1.0.1, ggplot2 v. 3.3.2, tidyverse v. 1.3.0, wesanderson v. 0.3.6. Reports of the analysis in HTLM format, created with knitr v. 1.29

and rmarkdown v. 2.3 are available on GitHub [https://github.com/lschunk/Archaeology_use-wear]. Also the raw data, the scripts and the RStudio project are saved in the same repository.

4.5 Controlled experiments

Assigning a function to Palaeolithic artefacts requires profound technological and morphological knowledge as well as suitable analogies and comparisons. While ethnographic comparisons are most likely revealing, they do not provide a one-to-one interpretation (Binford, 1968). Determining a tool's function has proven to be especially complicated in time periods, when toolkits were not highly specialised and tools used for multifunctional purposes as for example in the Middle Palaeolithic (Plisson, 1989). In order to address tool function, experiments provide an alternative possibility to test assumptions and gather new information. Experiments have played an important role in archaeology since the 1970's (Tringham et al., 1974; Coles, 1979; Odell and Odell-Vereecken, 1980; Outram, 2008). The general idea behind the conduction of experiments is to reconstruct past processes and to replicate potential past human activities. Experiments also frequently serve the purpose to produce reference collections for comparison with archaeological samples. Although different experiments follow different research questions, they all have something in common: they all test hypothesis. Hypothesis testing is used to assess the plausibility of a hypothesis (null hypothesis) by using sample data. A test can thereby only provide evidence concerning the plausibility of the hypothesis and the conclusion cannot be proven as true. A tested assumption can only be accepted as temporarily valid.

Depending on the question addressed by an experiment, different levels or types of experiments can be conducted. The distinction between *'Actualistic'*, *'Pilot'* or *'Exploratory'* on the one hand and *'Controlled'*, *'Second generation'* or *'Laboratory'* experiments on the other hand can be made (Eren et al., 2016; Marreiros, Pereira and Iovita, 2020). The first type of experiments (*'Actualistic', 'Pilot'* or *'Exploratory'*) aims mainly at replicating human actions in realistic contexts, whereas the second type focuses on testing individual variables *('Controlled', 'Second generation'* or *'Laboratory'*). These experiments often involve mechanical devices in order to limit the human bias. By isolating certain variables, their effect on the final result can be comprehended. Recently, an attempt has been made to refine this terminology (Marreiros et al., 2020). Based on this, a distinction of three generations of experiments is reasonable.

First generation experiments

First generation experiments are comparable with the prior described *'Actualistic'*, *'Pilot'* or *'Exploratory'* experiments. These experiments build the foundation for new hypothesis. *First generation experiments* often test the possibility to perform a certain action with a tool. With this, they provide information in order to help understanding past technologies.

First generation experiments are a crucial step for making preliminary observations and the identification of major variables. Nevertheless, these experiments cannot go further than delivering insights into certain aspects concerning for instance, tool performance.

Second generation experiments

Second generation experiments do not seek to answer overarching research questions, instead they are focused on basic fundamental aspects. This often concerns uniform principles for instance physical principles, operating uniformly across space and time. The identification of patterns, processes and the test of key properties should be the focus of the experiments. Therefore, the archaeological interpretations should be detached from the data interpretation. Performing a *second generation experiment* means testing individual variables. With this approach, the effect of the individual variables in the setup can be evaluated respectively. Furthermore, the aim of *second generation experiments* is to control and manipulate actions. The design of these experiments is thus more complex and involves mechanical devices. Human variability should be reduced to a minimum. By following this approach, not only the performed action is standardised through a mechanical apparatus, but also the samples and the contact material. Ideally, the samples imitating archaeological artefacts or at least certain features are standardised in order to guarantee variable control and comparability. The same applies to the contact material. *Second generation experiments* reduce subjectivity and result in information about the cause and effect of the tested variables, but at the same time, they are further away from replicating human actions and thus the results cannot directly be transferred to the archaeological record. Since *second generation experiments* are controlled and standardised, they also seek to produce repeatable and reproducible results.

Third generation experiments

Experiments from the *third generation* build on the results gained through *second generation experiments*. In this step, the human variability should again be incorporated. The recognised patterns and the generated models from the *second generation experiments* should be tested in a more naturalistic way. Mechanical devices are not needed in this type of experiment. Instead, the use of so-called multi-sensor systems for gesture recognition (Pfleging et al. 2015; Key 2016; Williams-Hatala et al., 2018) is recommended. Standard samples and replicas of archaeological tools should be employed in an identical way. This approach makes it possible to correlate the results. The *third generation experiments* allow evaluating the results from the *second generation experiment* by adding the human variability and bias. Doing so, the results can have implications on the interpretation of archaeological assemblages and can address overriding research questions.

Archaeologists have conducted experiments for decades. Since then, criticism has also accumulated. In particular *controlled* or *second generation experiments* are exposed to scepticism. As a major point of criticism, the artificial nature of these experiments has to be highlighted. The division in the three generations of experiments is trying to overcome this problem. It needs to be stressed that the different generations do not exclude each other, on the contrary; they should be seen as complementary. To go further, for designing a *second generation experiment*, several researchers require keeping the following conditions: the research question should be defined clearly, including a hypothesis as well as an alternative hypothesis which can be tested. The number of trials and samples has to be high enough in order to be statistically evaluable. This should also lead to a dominant use of quantitative over qualitative methods. The involved variables need to be identified and assigned as independent, dependent and random variables. The experimental setup has to be detailed in the explanations in corresponding publications. Together, *second generation experiments* should target at repeatability and reproducibility.

Although discussions concerning experiments, especially *second generation experiments* are becoming numerous and first improvements are visible, there are limitations. In general, sequential experiments are time consuming. Moreover, mechanical devices are expensive and their incorporation in an experimental design is most commonly unrealistic. Even if the use of a mechanical device is possible, testing, manipulating and controlling each variable related to an archaeological assemblage is extremely elaborated. The use of quantitative methods and open data in archaeological research is unfortunately not yet common practice. Thus, cooperation and data exchange in order to minimise the costs and the time investment are difficult to implement.

The controlled experiments conducted within this project belong to the so-called *second generation experiments*. These experiments aim to address basic questions and to understand the influence of specific variables within a complex system. Thus, variables need to be tested individually in order to test their effect-causation with other variables in the experiment. In *second generation experiments*, the human factor as well as subjectivity are reduced to a minimum. To do so, a mechanical device was used to perform defined actions. This mechanical device involved in the controlled experiments here is a modular material tester (SMARTTESTER®, Inotec AP GmbH, Germany). The SMARTTESTER® allows for precise movements and is sensor-controlled (Calandra, Gneisinger and Marreiros, 2020). Using the mechanical device makes the experiment itself repeatable. To further improve this aspect and to actually isolate certain variables, standard samples were used during the experiments. Raw-material intra-variability was limited by the use of as few as possible raw material nodules. The standard samples are machine cut samples with a predefined shape (**fig. 35**). Baltic flint as well as silicified schist served as raw material. The raw material, in case of the silicified schist, was collected next to the small streams in the surrounding areas of the two sites Buhlen and Balver Höhle. The silicified schist and flint nodules were cut with a rock-saw into cubes, and further cut into size-defined blanks. While the sample length could vary, the standard width (length edge) of the samples was always 3 cm. The cubes were separated into as many blanks as

possible to reduce raw material variation. In the next step, one end of the blanks was cut with a diamond band-saw (EXAKT 310 CP) in a given angle. One side of the active edge was in addition modified by a 45° chamfered edge (exception: initial experiment). The chamfered edge was meant to reduce the force applied on only one point of the sample when the contact with the worked material was initialised. The idea was, that this modification would spread the applied force on a bigger area and would therefore minimise the risk of immediate fracture. This cut was also done with the diamond band saw. Usually, the cut with the band saw left a small burr between the two adjacent surfaces – the surface of the active edge and the chamfered edge. This burr was manually removed with a mini diamond drill bit. The samples were cleaned after cutting. First the samples were rinsed with tap water and then with a preheated ultrasonic bath (EMAG Emmi 20HC). For that reason, the samples were individually packed in a plastic bag filled with ~ 100 ml of demineralised water and a non-ionic detergent (BASF Plurfac LF901, 1 g/l = 1 % w/v; BASF SE, Ludwigshafen, Germany). The samples were left in the bath for 10 min at 45°C and 100 KHz. Subsequently, the demineralised water was exchanged with tap water. This was repeated two more times. In a final step, the bags were filled with ~100 ml purified water and emptied after rinsing. Since it was crucial for the later use-wear analysis to enable the analysis of the exact same surface, a coordinate system was created directly on the sample (Calandra et al., 2019a). For this, three 100-200 µm diameter ceramic beads were adhered with epoxy resin (Epoxydharz L mixed with Härter S in a ratio 10:4 by weight) on the dorsal and ventral site of the tool.
The experiments were described with the aim to address the same overall research question. The goal is to bring the relation between tool morphology and tool function into question.

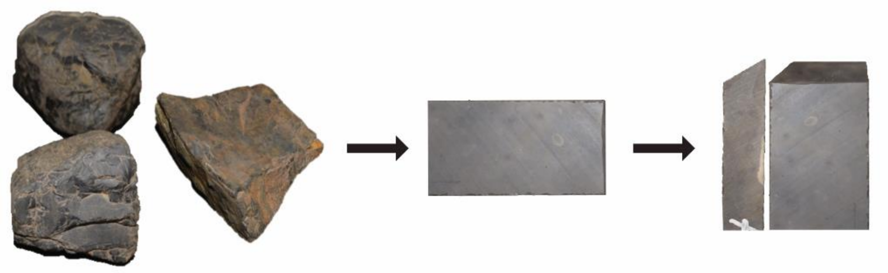

Fig. 35 Standard sample production. The raw pieces (left; here silicified schist) are cut into blanks (middle) with a rock-saw. A diamond band-saw was used to cut the blank in order to create a typical standard deign sample with a defined edge angle (right).

4.5.1 Experimental setup - Initial experiment (testing setup and sample configurations)

The initial experiment was designed to evaluate the experimental setup and to test two variables, raw material and edge angle (**fig. 36**). Silicified schist as well as Baltic flint served as raw material. The standard samples were bifacially cut as 40° and 60° degree edge angles respectively. The experiment had no demand on statistical validity. With a sample size of n = 7 (3x silicified schist 40°, 2x silicified schist 60°, 1x flint 40°, 1x flint 60°) not enough replicas were included in order to lead to statistically significant results. The electric, linear drive (z-direction) of the mechanical devise, the SMARTTESTER®, was used in order to perform a unidirectional cutting movement. As a prerequisite in order to standardise the experiment as much as possible and to test the effects of the two mentioned variables individually, the contact material was also standardised. Therefore, an artificial bone plate (PR0114) from the Swiss company SYNBONE® was used. This generic plate is a modified bone-like polyurethane with the dimensions 250 x 250 x 6 mm and a shore hardness (D) of 78 5/- 5%.

The experiment was built up as a sequential experiment. Four cycles defined by a number of cutting strokes were executed. The first cycle started from 0 to 50 strokes, the second from 51-250 strokes, the third 251-1000 strokes and the final cycle from 1001-2000 strokes. The cutting length was thereby 23 cm. Each sample had to perform the four cycles with 2000 strokes in total by always using the same cutting track. Certain factors were set up during the experiment, others were measured by sensors only. The velocity with 600.00 mm/s and the acceleration 4000.00 mm/s belong to the predetermined factors. The force of 30 N was also defined by the weight of the sample holder (~1kg) and two manually added kg. In total five sensors were activated during the entire duration of the experiment. Three sensors recorded the predetermined factors velocity, acceleration and force. The other two sensors recorded the penetration depth in mm and the friction in N. The sampling rate was in a frequency of 10 Hz. The samples were clamped straight into the sample holder in a 90° angle between sample and contact material. A template per sample was created to assure the constancy of the programmed settings as for instance the position of the sample on the x-, y- and z-axis.

To test aspects such as efficiency, performance and durability by comparing the two raw materials and the two edge angle values, the documentation of the samples needed to follow a protocol. Initially, the samples were photographed with a Nikon D610. The weight was recorded with a weighing scale, Kern PCB 3500.2, with an accuracy of 0.1g. To avoid inaccuracies, each sample was measured three times. The material properties of the raw material were tested using the Leeb rebound hardness tester (Proceq Equotip 550, Leeb C probe) by means of a coupling paste. The samples were scanned with an AICON smartScan-HE R8 from the manufacturer Hexagon. The system was always turned on one hour in advance in order to warm up all components. The S-150 FOV used has a resolution of 33µm. Identical settings were used for all scans; scans were exported afterwards in an STL-format. Three of the four surfaces per sample (one lateral and the two main surfaces) were documented with the ZEISS Smartzoom 5, a digital microscope. The 1.6x objective was used to create EDF-stitching images. Moulds were taken from the two cutting surfaces covering the edge. This protocol was not only followed before the experiment, but also after each cycle. Frequently, single cycles were video recorded.

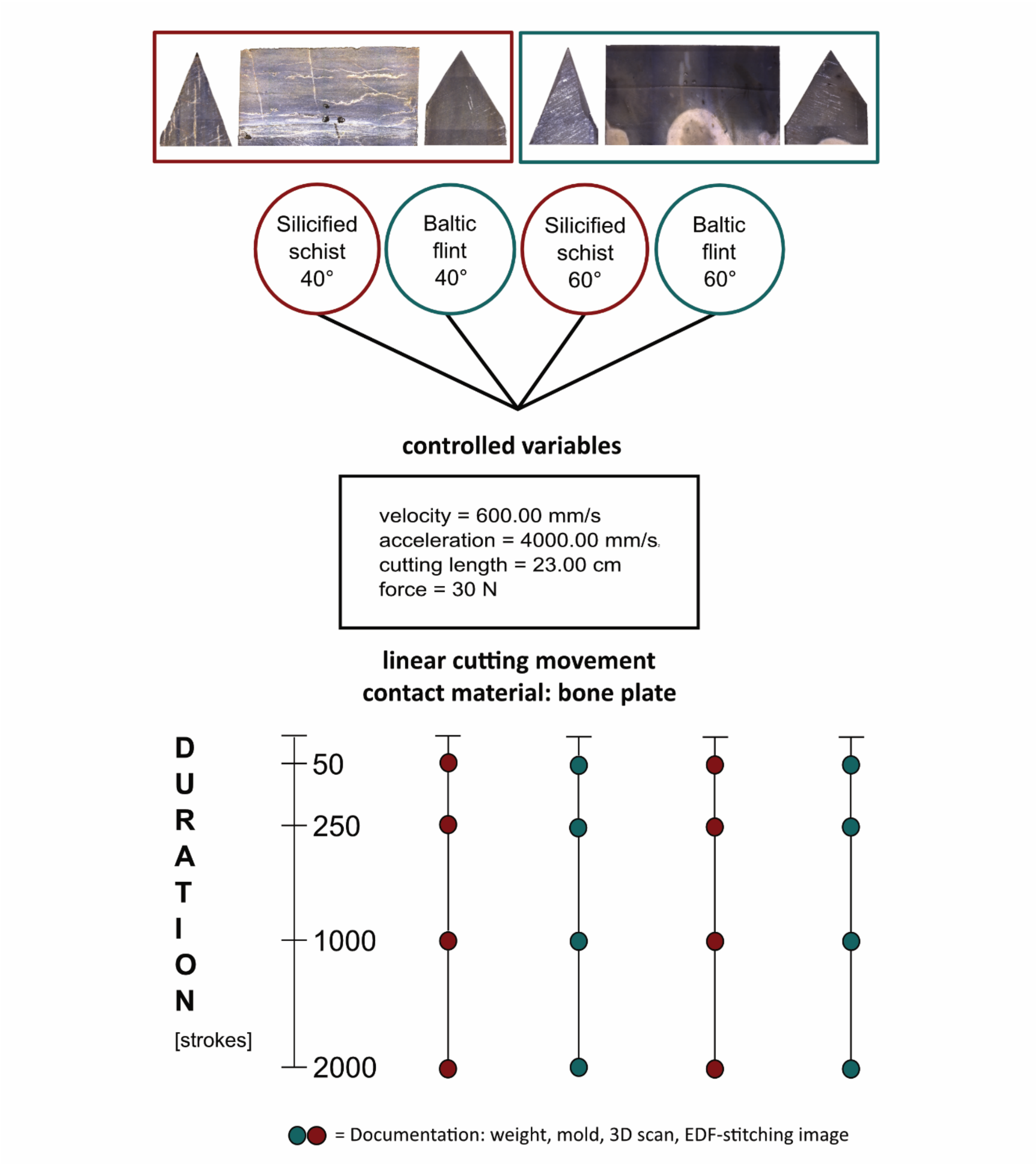

Fig. 36 Experimental design for the initial experiment.

4.5.2 Experimental setup - 'artificial VS. natural' experiment

In the sequence of experiments was the so-called 'artificial VS. natural experiment' the second one (**fig. 37**). This experiment aimed to validate the comparability of artificial with

natural contact material. Tool performance and durability as well as the produced use-wear traces served as a measure of criteria. In order to standardise the contact material during an experiment, these artificial materials are a convenient solution, but their use needs to be justified. In addition, the experiment aimed at understanding the development of use-wear traces and testing the mechanical trends behind the formations. Within this experiment, the independent variables were the raw material – silicified schist and Baltic flint – and the contact material. Four different contact materials were tested. Two belonging to the category artificial material and the other two were natural, fresh materials. An artificial bone plate coated with a rubber skin (PR0114.G) from the Swiss company SYNBONE® was used. This generic plate is a modified bone-like polyurethane with the dimensions 250 x 250 x 6 mm and a shore hardness (D) of 78 5/- 5%. The bone plate with the rubber skin layer, imitating the periosteum, was therefore an artificial equivalent to a fresh and defleshed bone. The bone in this experiment was a cow scapula (*Bos primigenius Tarurus, Angus*) provided in a fresh state by a butcher. The periosteum and small pieces of flesh were still attached. The experiment was carried out in a laboratory under ambient room temperature conditions. During the course of the experiment, the bone started to dry out but apart from desiccation no other degradation were visible. The reason to choose a cow scapula can be explained by the size and shape. The morphology of the bone offers the possibility to perform long cutting strokes on a considerably straight surface, providing better conditions for a comparison of the results between the bone plate and the bone. The second set of contact material was skin. As artificial skin a soft tissue pad with a matrix (PR1043.10) SYNBONE® was used. This skin pad is made of silicone ecoflex and has the dimensions 140 mm x 130 mm x 4.2 mm and a shore hardness 0-3A. A piece of natural pork skin was provided by a butcher by separating the skin from the flesh below. The skin was kept outside under room temperature and overnight it was kept cold in a fridge. Two pieces of skin were needed during the course of the experiment. The n = 24 samples were cut unifacailly with an edge angle of 60° and equally distributed between the four contact materials. Thus always three replicas per raw material were tested on one contact material.
The setup for this experiment was identical with the setup from the initial experiment. The same linear drive was used in order to perform unidirectional cutting strokes, the same number of strokes separated in four cycles was executed and the same sensors with identical settings were used. A few changes however, are noteworthy. For the bone plate and the natural bone a force of 60 N was applied, while the force for the artificial and natural skin was only 20 N. The cuts on the bone plate had a length of 20 cm and half of the cuts on the fresh bone, too. The other cutting strokes were 10 cm long, but the amount of strokes was doubled in these cases. The documentation followed the same protocol mentioned for the initial experiment.

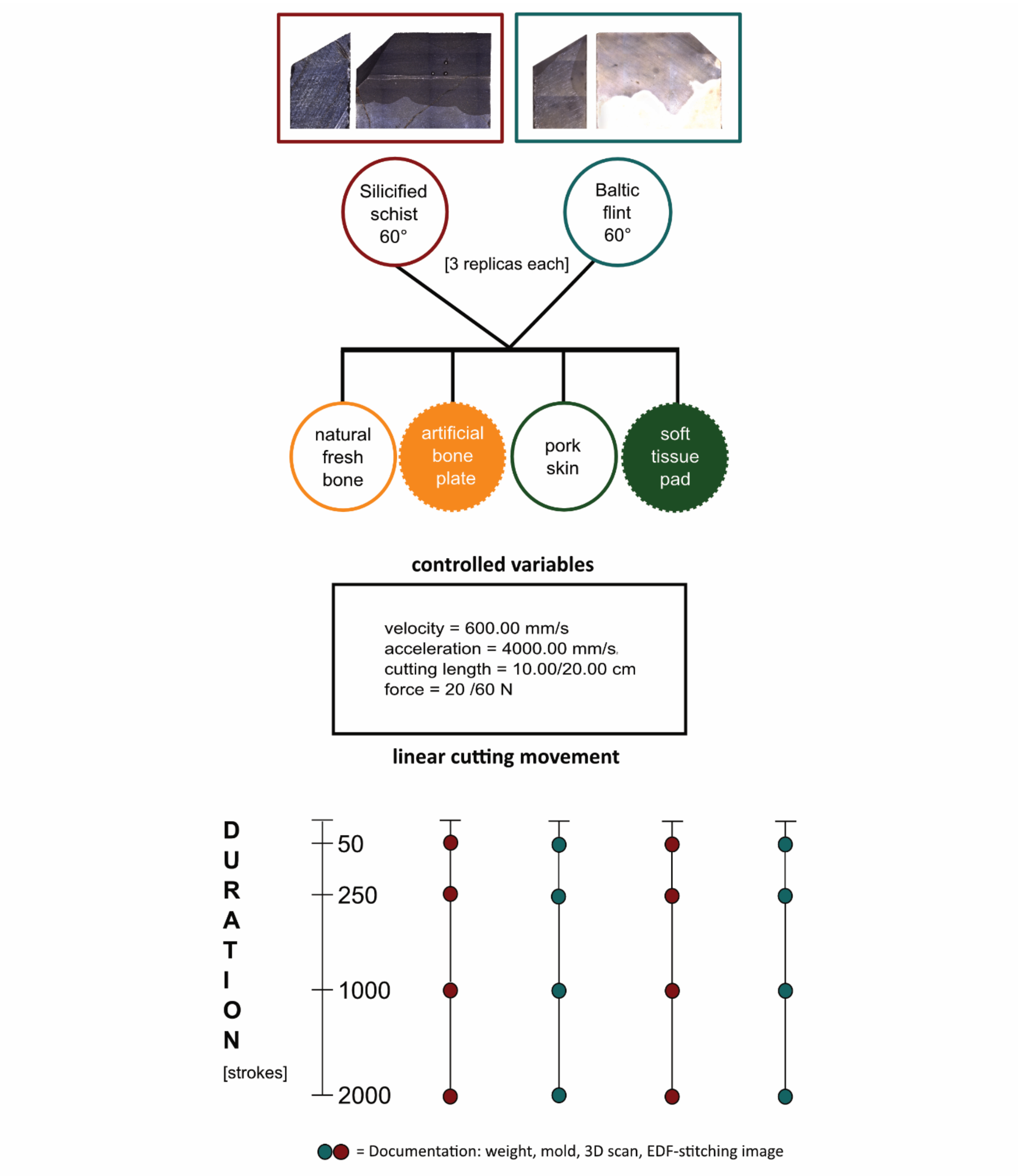

Fig. 37 Experimental design for the 'artificial VS. natural' experiment.

4.5.3 Experimental setup - tool function experiment

The third and main experiment built up on the results carried out during the other two experimental setups (**fig. 38**). The goal was again to test efficiency, durability and performance by comparing two raw materials and different edge angles on standardised contact material. To further investigate the relation between tool morphology and function, the edge angle values for the standard samples were extrapolated from the edge angle measurements (see chapter 4.3.1) from the sampled *Keilmesser*. These measurements are based on 3D scans of in total 157 *Keilmesser*. The selected tools were separated in *Keilmesser* (n = 57) and *Keilmesser* with a modification through the application of the *Prądnik method* (n = 100). From all the calculated edge angle data only the results from the '2-lines' procedure with measurements at 5 mm distance to the intersection were selected. The statistical analysis was performed with the open-source software R version 4.0.2 through RStudio version 1.3.1073 (RStudio Inc., Boston, USA) for Microsoft Windows 10. The following packages were used: writexl v. 1.3, tidyverse v.1.3.0, openxlsx v. 4.1.5. and R.utils v. 2.9.2. Reports of the analysis in HTLM format, created with knitr v. 1.29 and rmarkdown v. 2.3 are available on GitHub [https://github.com/lschunk/edge_angle_analysis] as well as the raw data, the scripts and the RStudio project. For calculating the average edge angle on the selected tools, the first and the last horizontal section (always 10 sections per tool) were excluded (**fig. 39**). This is reasoned by the fact that these sections usually display edge angle values distinct from the values of the other eight sections. These two sections are likely not representing the active edge anymore. It is possible that they are already part of the base and the arch of the tool. Based on the eight horizontal sections and the measurements at 5 mm the average per tool could be calculated. Since there was a notable change in the edge angle values in the distal and the proximal part of the tool, two instead of one average value were calculated. The first built on the results of the section two to four and the second on the results of the section five to nine. The average was calculated per classification (*Keilmesser* and *Keilmesser* with *Prądnik method*). The results for the proximal tool part were nearly identical in the two classifications (44.75° and 44.48° respectively). For the distal part of the tool the results varied slightly. While *Keilmesser* reach an average of 36.06°, *Keilmesser* modified by the *Prądnik method* show an average of about 33.50°. Therefore, the decision was made to test two different edge angle values – 45° and 35° - as a proxy for the proximal and the distal part of the tool, respectively.

In total 24 standardised samples were unifacially cut. Twelve of these 24 samples were produced out of Baltic flint nodules, the other twelve from silicified schist blocks. The linear drive was used to perform two different movements: unidirectional cutting and carving. Artificial bone plates served as contact material (PR0114), the same modified bone-like polyurethane plates as used during the initial experiment. The cutting and carving length was 17 cm each. Three samples per raw material and edge angle were tested for cutting and carving respectively. The experimental setup was identical to the ones during the first and second experiment. Thus, the tool function experiment was also designed as a sequential experiment with the same four cycles and 2000 strokes in total per sample. A force of 50 N was applied for both movements. While the samples for the cutting movement were clamped again straight into the sample holder in a 90° angle between sample and contact material, the sample was adjusted differently for the carving movement. With the flat, not angled tool surface, the samples were clamped into the sample holder in a 20° angle towards the contact material. Consequently, the carving movement was performed in a flat and unidirectional motion. The documentation followed the same protocol as mentioned for the initial and the 'artificial VS. natural' experiment.

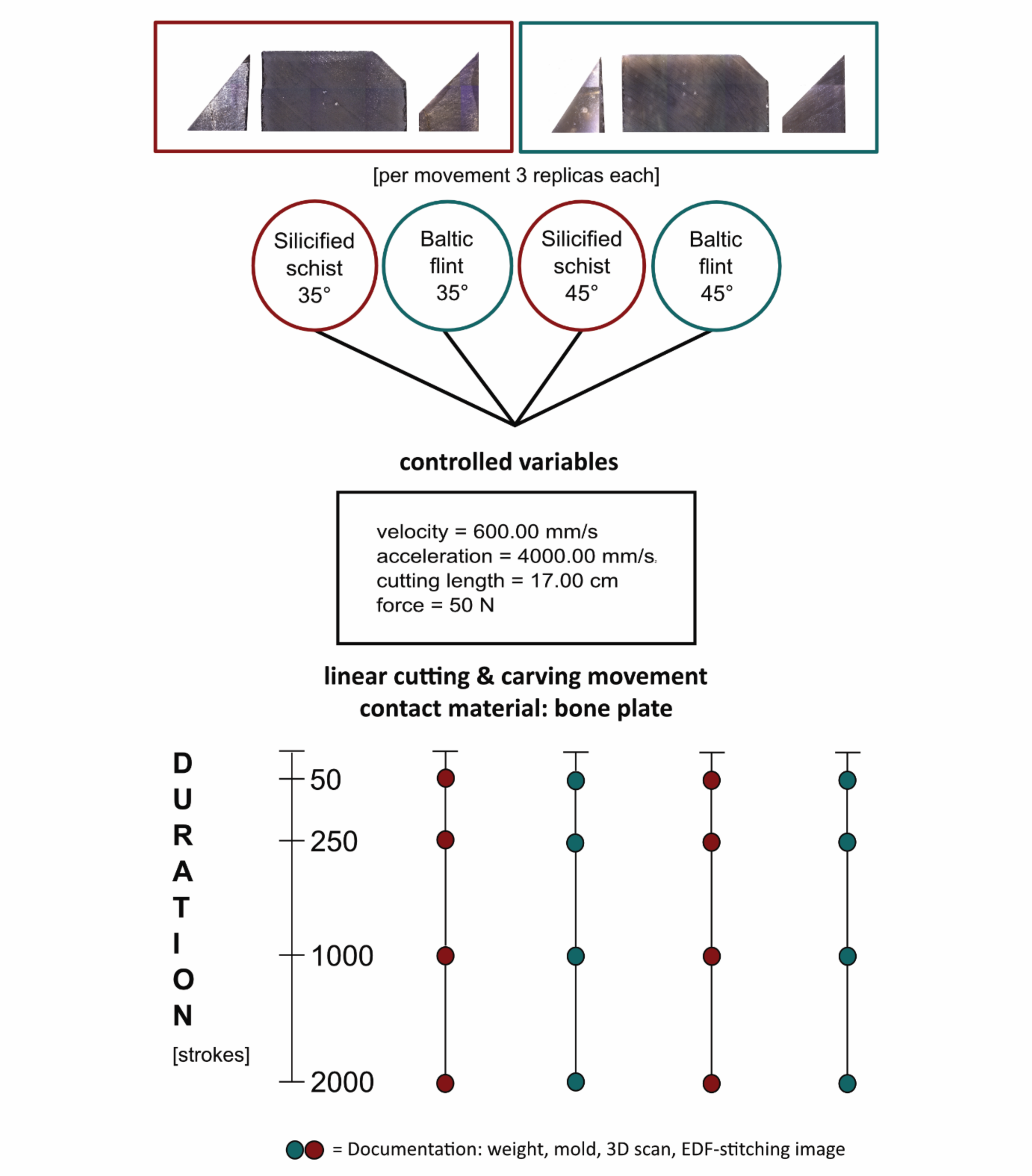

Fig. 38 Experimental design for the tool function experiment.

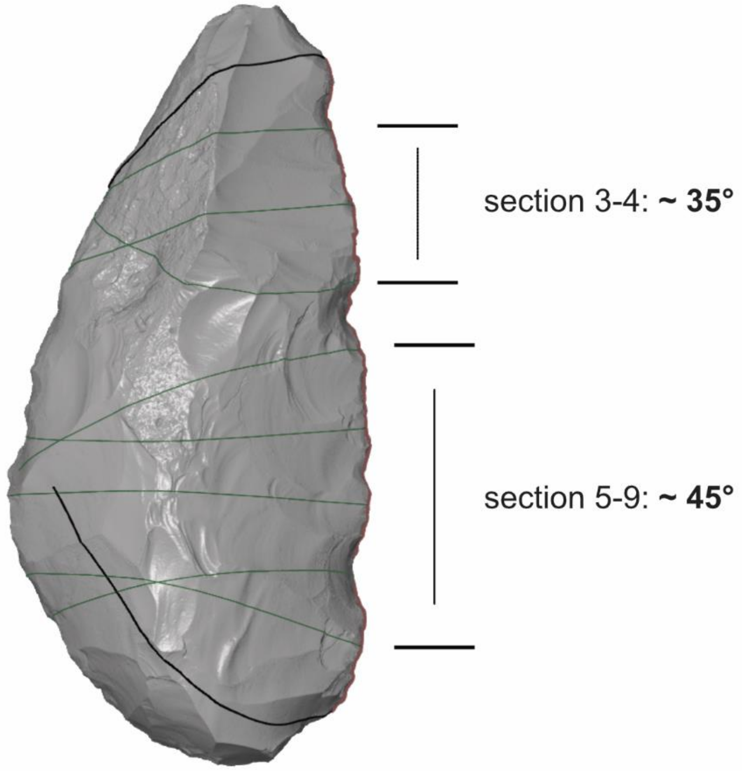

Fig. 39 Calculation of the edge angles, illustrated here on a 3D model of a *Keilmesser* from Ramioul (ID R-019). The horizontal lines are the section. The sections used to calculate the edge angels in green, in black the ones excluded for the calculation. The edge angle values have been calculated with the '2-lines'

4.5.4 Analysis of the experiments

Since the three experiments were following an identical experimental setup and protocol for the documentation, the acquired date could be evaluated similarly. Furthermore, the data could be combined. To answer questions related to tool efficiency, durability and performance, the samples were review in terms of their morphological changes. Material loss, fractures, retouch and changes in the edge angle were documented. The contact material was evaluated on the one hand concerning material loss, on the other hand the penetration depth was a valid indicator. Use-wear traces resulting from different actions and contact materials on the two different raw materials can be compared as well. Due to the sequential aspect of the experiments, also statements regarding the temporal formation and the development of the use-wear traces can be addressed.

4.5.4.1 Analysis 3D data

Part of the documentation before and after each cycle of the experiments was the 3D scanning of the samples. In order to further analyse the 3D models, a few preparatory steps were necessary. After scanning, the resulting STL file was imported in GOM Inspect,

an open source software for 3D measurement data (GOM Software 2018, Hotfix 1, Rev. 111729, build 2018-08-22). With GOM inspect, the 3D models were checked for holes in the mesh. Existing holes were closed automatically with a maximum hole size of 10.000 mm and 1000 as maximum number of edges. Mesh errors were eliminated. Depending on the number or the size of the holes, these two steps were repeatedly applied. The holes were not closed directly in one step with a higher maximum hole size value in order to avoid a change in the original morphology of the scanned sample.
Based on the closed models, the volume per sample could be computed. In this way, material loss of the samples due to the use within the experiment can be detected. At the same time, the 3D models can be inspected visually. GOM inspect allows for a comparison of 3D meshes. For this step, one of the meshes needs to be defined as CAD body (computer-aided design), while the other one can be imported as a mesh. The two models can be optically combined with a local best-fit alignment. Afterwards, a surface comparison on the CAD can be initialised. Based on a colour scale, the differences between the two 3D meshes can be optically seen and also numerically read.

4.5.4.2 Analysis edge angle

The closed 3D models also serve for the edge angle calculation (see method section 4.3). A surface curve defining the edge of each sample was added in GOM inspect. This polyline was exported in an IGES-format. All further steps were identical as described in the section 'Quantification of edge angle design' earlier in this chapter. The following parameters were chosen: The number of horizontal sections is represented by ten sections per tool. The measurements were taken in 1 mm steps starting with the intersection between the vertical and the horizontal polylines. The lengths of the lines used in the '2-lines' and 'best fit' measuring procedure, was always 2 mm. Calculating the edge angle of the experimental samples allows for a quantification of a change in the edge angle.
The statistical analysis was performed with R (version 4.0.2 through RStudio version 1.3.1073, RStudio Inc., Boston, USA). The following packages were used: writexl v. 1.3, tidyverse v.1.3.0, openxlsx v. 4.1.5, ggrepel v. 2.3, doBy v. 4.6.7, patchwork, v. 1.0.1, ggplot2 v. 3.3.2 and R.utils v. 2.9.2. Reports of the analysis in HTLM format, created with knitr v. 1.29 and rmarkdown v. 2.3 are available on GitHub as well as the raw data, the scripts and the RStudio project [https://github.com/lschunk/edge_angle_experiments].

4.5.4.3 Use-wear analysis

Use-wear analysis was not done for all experimental samples. Instead, the pieces were systematically sampled. None of the samples from the initial experiment were part of the use-wear analysis. In the case of the second experiment, the 'artificial VS. natural' experiment, eight samples were selected. These samples consist of four silicified schist and four flint samples. Each of the four samples was tested on a different contact material: bone plate, scapula, skin pad and pork skin. A further eight samples belonging to the tool

function experiment were analysed. The selection was based on the raw material of the sample, the edge angle and the movement. Thus, one tool per cutting with 35° and 45° edge angle and one tool per carving with 35° and 45° edge angle made of silicified schist and flint were sampled.
As for the archaeological material, a scheme was designed for the quantitative use-wear analysis as well (**fig. 40**). The scheme fulfilled the purpose of mapping and locating the use-wear traces consistently in an identical way. The outline of the standard samples was used as template for a grid of four areas. This was done for the dorsal (A and B) as well as for the ventral (D and C) surface. The areas are numbered from 1, as the part of the tool with the edge, to 2, the lower part of the tool.

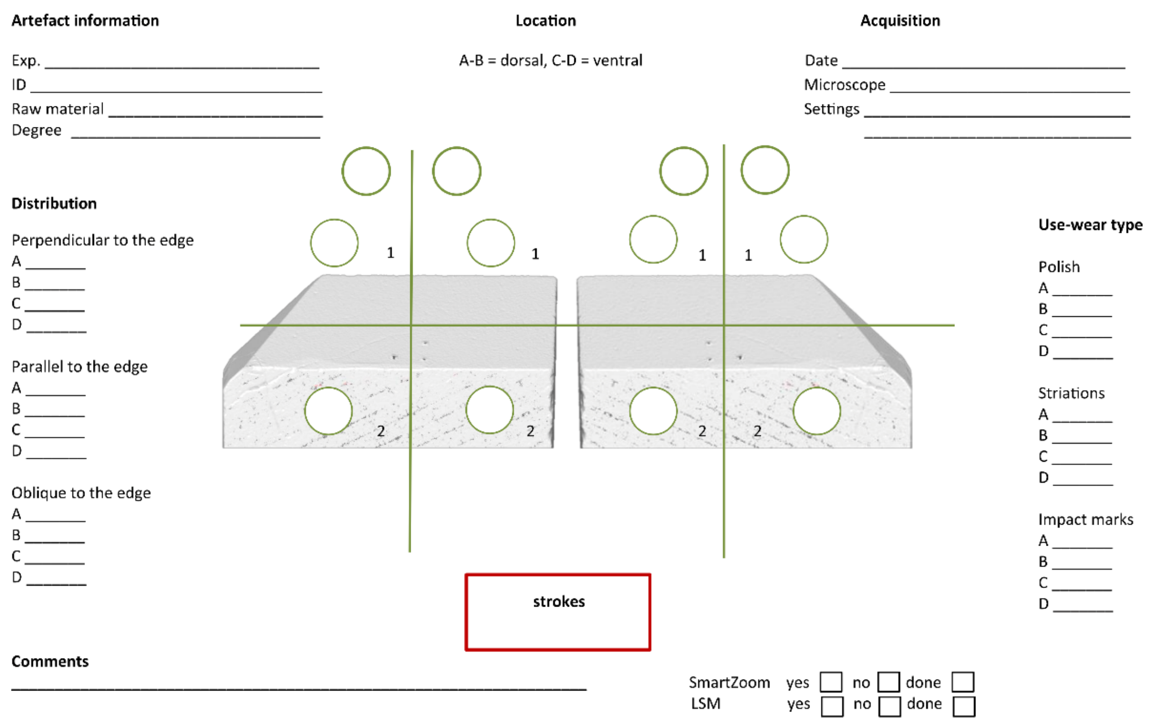

Fig. 40 Scheme used during the qualitative use-wear analysis for the documentation of the analysed standard samples from the experiments. The dorsal surface is indicated by A and B (surface with the angle) and the ventral surfaces by D and C (straight surface). Additionally, the scheme includes information about the analysed standard sample itself, the cycle within the experiment, the acquisition date and settings as well as information about the use-wear traces (location, distribution and type). The scheme also contains information about, whether further acquisition or analysis are needed (SmartZoom = digital microscope images, LSM = quantitative use-wear analysis).

The qualitative use-wear analysis was done in a high-power approach by means of an upright light microscope (ZEISS Axio Scope.A1 MAT). The samples were studied with a 5 x, 10 x and 20 x magnification. Traces were documented as an EDF image in black and white settings. While the eight samples from the 'artificial VS. natural' experiment were analysed before and after each cycle, the eight samples from the tool function experiment were only analysed before and after the last cycle with 2000 strokes.

The quantitative use-wear analysis was done on the same total 16 samples, using the laser-scanning confocal microscope (ZEISS Axio Imager.Z2 Vario + ZEISS LSM 800 MAT). The objective C Epiplan-Apochromat 50x with the numerical apertures 0.95 was generally used. In a few cases, the C Epiplan 50x /0.75 had to be used. The field of view (FOV) was 255.6 x 255.6 µm. For the quantitative analysis, measurements were taken on samples only from before and after 2000 strokes, in the case of the tool function experiment only after 2000 strokes. On each sample, one use-wear spot was measured three times at a nearby but non-identical point. Only on two samples, a second use-wear spot was measured as well. In total, 28 measurements were taken on the experimental sample times three. Since the qualitative as well as the quantitative use-wear analysis was done after the experiments were finished, the measurements were taken from the moulds. Exceptions are the samples after 2000 strokes from the tool function experiment. In these cases, the original surface not the replicated mould's surface were measured.
The reason for doing the use-wear analysis on the experimental samples was firstly to see what kind of use-wear develops within the sequential and automated experiments and also to see how the use-wear created differs depending on the contact material used. The second important aspect was to observe how use-wear develops in general and also under the application of the two tested raw materials. Therefore, each time it was important to measure the exact same spot before and after the experiments. This was possible due to the coordinate system on the samples. The use of the coordinate system should guarantee that a possible measured variability in the surfaces topography is only due to a surface alteration and not because of a positional inaccuracy. The LSM has an integrated module called Shuttle-and-Find (Calandra et al. 2019a). This module allows the relocating of a sample based on a defined coordinate system. Prior to a measurement, the coordinate system needed to be created and calibrated for each sample with the C Epiplan-Apochromat 10x /0.40. Firstly, the surface of the sample after 2000 strokes was analysed. This way, the spot with the use-wear trace could be defined and measured. Afterwards, the sample was exchanged with the corresponding sample from before the experiment. Based on the previously calibrated coordinate system, the software could automatically relocate the same spot on the surface with a horizontal positional repeatability of approximately 14% of the FOV.
The acquired data was processed identically to the data form the quantitative use-wear analysis of the archaeological material (see chapter 4.5.4.1). The data of the two experiments was individually processed with templates in ConfoMap (a derivative of MountainsMap Imaging Tophography developed by Digital Surf, Besançon, France; version ST 8.1.9286). The maximum of two templates had to be applied. The first template, the 'resampling template', was used to perform a resampling in x and y on all 108 surfaces, leading to an identical spacing. In the second and final template, that data was processed ('processing template'). The following procedure was performed: I.) Levelling (least squares method by subtraction), II.) From removal (polynomial of degree3), III.) Outliers removal (maximum slope of 80°), IV.) Thresholding the surface between 0.1 and 99.9 % material ratio to remove the aberrant positive and negative spikes, V.)

Applying a robust Gaussian low-pass S-filter (S_1 nesting index = 0.425 µm, corresponding to about 5 pixels, end effects managed) to remove noise, VI.) Filling-in the non-measured points (NMP), VII.) Analysis: Calculation of 21 ISO 25178-2 parameters, 3 furrow parameters, 3 texture direction parameters, 1 texture isotropy parameter and the SSFA parameters *epLsar, Asfc, Smfc, HAsfc9 and HAsfc81*.
The ConfoMap templates for both experiments in MNT and PDF formats are available on GitHub, including all original and processed surfaces, as well as the results.

Again, the open-source software R (version 4.0.2 through RStudio version 1.3.1073, RStudio Inc., Boston, USA) was used to perform all descriptive analyses. This includes the summary statistics, the scatter plots and PCA's. As packages openxlsx v. 4.1.5, R.utils v. 2.9.2, doBy v. 4.6.7, ggsci v. 2.9, patchwork v. 1.0.1, ggplot2 v. 3.3.2, tidyverse v. 1.3.0, wesanderson v. 0.3.6 were used. Reports of the analysis in HTLM format, created with knitr v. 1.29 and rmarkdown v. 2.3 are available on GitHub [https://github.com/lschunk/artificial_VS_natural-experiment; https://github.com/lschunk/tool_function-experiment]. Also the raw data, the scripts and the RStudio project are saved in the same repository.

4.5.4.4 Analysis sensor data

The sensor data recorded throughout the experiments with the SMARTTESTER® can be analysed. Three of the five sensors were predetermined factors: velocity, acceleration and force. This means, the sensors have to be seen as a controlling mechanism. The analysis of these sensor data shows how controlled the experiments were in the sense of permanently repeating actions. The other two sensors recorded the penetration depth in mm and the friction in N. While the friction is a topic for itself and goes into the direction of physics and mechanics and was therefore excluded from further analysis, the penetration depth was analysed. The penetration depth is of interest because it directly relates to aspects of tool efficiency and performance. During the experiment, the sensor data is saved per strokes and per sensor individually as TXT files.
By means of R (version 4.0.2 through RStudio version 1.3.1073, RStudio Inc., Boston, USA) the data from the 'artificial VS. natural' experiment as well as the data from the tool function experiment was combined in one data frame respectively and exported as a XLSX file. The data was then statistically analysed and plotted. The following packages were used openxlsx v. 4.1.5, R.utils v. 2.9.2, doBy v. 4.6.7, ggrepel v. 0.8.2, patchwork v. 1.0.1, ggplot2 v. 3.3.2, tidyverse v. 1.3.0 were used. Reports of the analysis created with knitr v. 1.29 and rmarkdown v. 2.3 in HTLM format are available on GitHub [https://github.com/ivan-paleo/Smarttester-data]. In the same repository the data, the scripts and the RStudio project can be found.

5. Results

Within this chapter, the collected data resulting from applying the aforementioned methods and techniques is presented. First, the results from the raw material characterisation (chapter 5.1) are addressed, followed by the results from the techno-typological analysis (chapter 5.2). For the techno-typological analysis, the data from the three archaeological sites are not separated but instead, addressed sequentially within each artefact category. This allows for direct inter-comparability of the artefacts. The results from the Upper site of Buhlen are always mentioned first, then the ones from Balver Höhle and at lastly the data concerning Ramioul. Within this structure, the results concerning the two artefact categories, *Keilmesser* and *Prądnik scraper* are addressed sequentially. *Prądnik spalls* as a third artefact category, are separately treated and thus mentioned after the data regarding *Keilmesser* and *Prądnik scrapers*. After this subchapter, the results regarding the quantification of the edge design (chapter 5.3), the use-wear analysis (chapter 5.4) and the controlled experiments (chapter 5.5) are mentioned. Scrapers and flakes – as outgroup – are not addressed in all chapters. The results concerning the scrapers and flakes are only of relevance in the chapters 'Quantification of edge design' and 'Use-wear analysis'.

For the analyses, in total n = 330 *Keilmesser* were studied (**tab. 3, 5, 7**). The selected assemblage from Buhlen yielded n = 130 *Keilmesser*, Balve n = 191 and n = 9 artefacts are from Ramioul. Not all of the *Keilmesser* are complete artefacts. Some of these pieces can be described as distal *Keilmesser* tips, some as fragmented or semi-finished tools. Whenever only complete *Keilmesser* have been involved in an analysis, it is mentioned within the text. *Prądnik scrapers* were analysed identically to *Keilmesser.* For the analyses, n = 54 *Prądnik scrapers* were studied in total. This assemblage is composed of n = 24 *Prądnik scrapers* from Buhlen, n = 27 from Balver Höhle and n = 3 from Ramioul. These n = 54 *Prądnik scrapers* are without exception complete tools.

5.1 Raw material characterisation

The sampled *Keilmesser* from Buhlen are with a clear majority (n = 128, 98.5%) made of black silicified schist (**fig. 41**, **tab. 2**). The silicified schist appears locally within the wider region in Pleistocene terraces and immediately next to the site in and near the small riverbed. One artefact is made of a more greenish, less dark silicified schist. The only other raw materials from the studied Buhlen assemblage are items made of Baltic flint (n = 1 piece) and reddish yellow carnelian (n = 1 piece).

A similar picture as in Buhlen is becoming evident for Balve (**fig. 42**, **tab. 2**). The significant majority with 95.3% (n = 182) of the *Keilmesser* was produced from the local silicified schist. Analogues to Buhlen, the silicified schist can be found in the small river stream next to the site. A few pieces (n = 10) are made of Baltic flint. The nearest source for flint is approximately a distance of 20 km to the north of the cave (Andree, 1928;

Günther, 1988). The silicified schist within the Balve assemblage is not always as dark black as in Buhlen and tends to be more often light-black, greyish or green greyish.
The distribution of the raw material in Ramioul is different though (**fig. 43**, **tab. 2**). The sampled artefacts are mainly made of a local light-coloured flint. With n = 18 pieces this counts for 90.0% of the assemblage. The other two artefacts are made of black silicified schist. The silicified schist, too, can be found in the local surroundings of the cave site.
The *Keilmesser* from the three archaeological sites taken together result in a clear picture regarding the raw material. Nearly 94.2% (n = 311) of the studied *Keilmesser* are silicified schist artefacts, 5.5% (n = 18) are made of flint (**fig. 44**). The other one piece is made of carnelian.

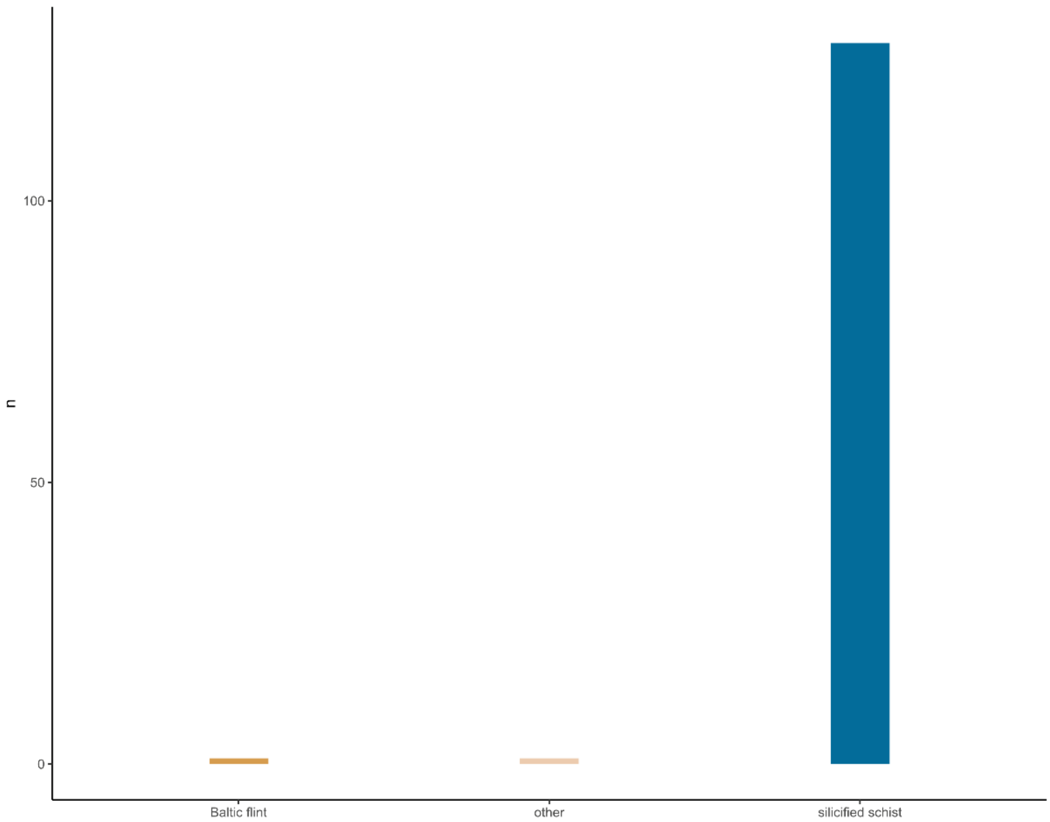

Fig. 41 Distribution of the raw materials used for the production of *Keilmesser* (n = 130) from Buhlen.

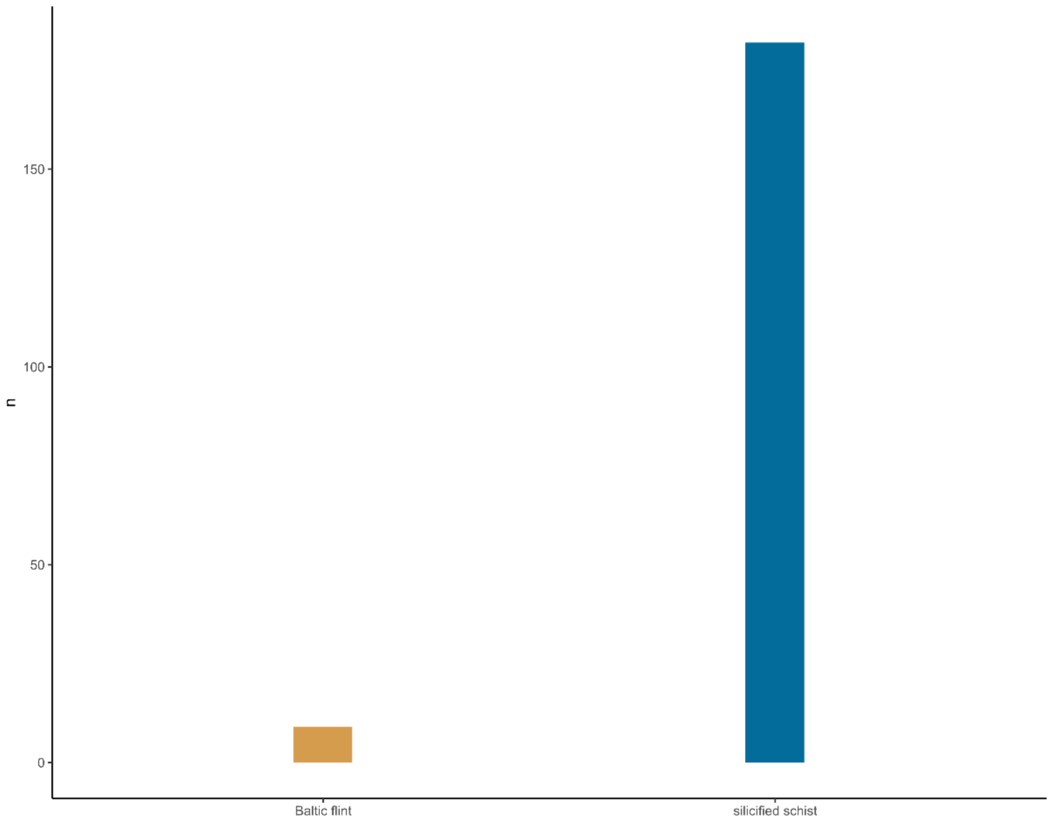

Fig. 42 Distribution of the raw materials used for the production of *Keilmesser* (n = 191) from Balver Höhle.

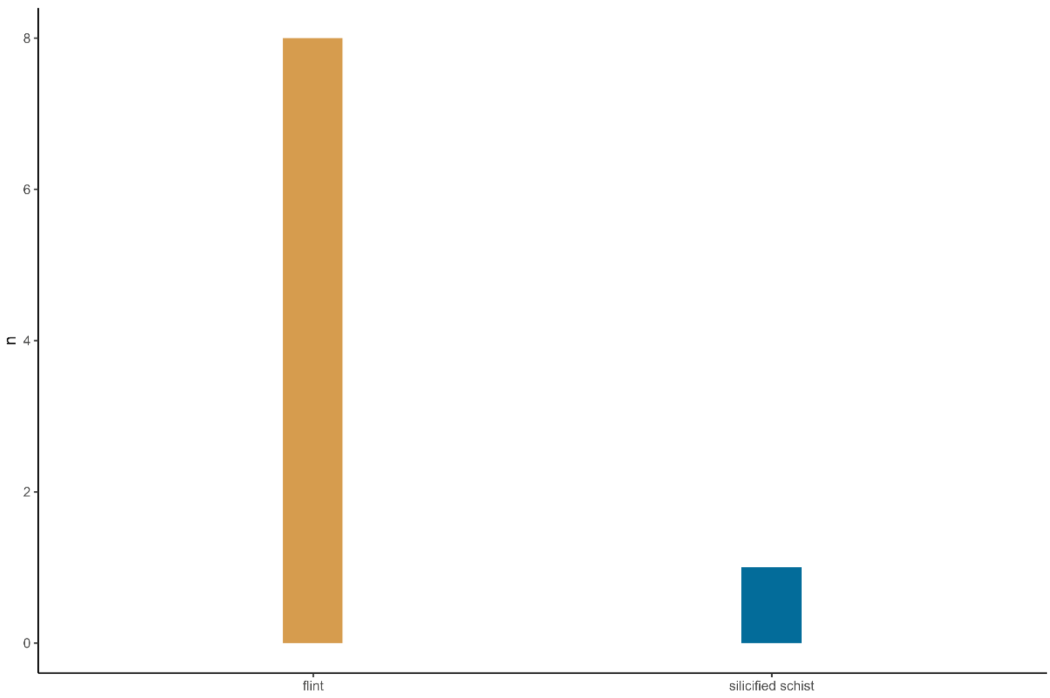

Fig. 43 Distribution of the raw materials used for the production of *Keilmesser* (n = 9) from Ramioul.

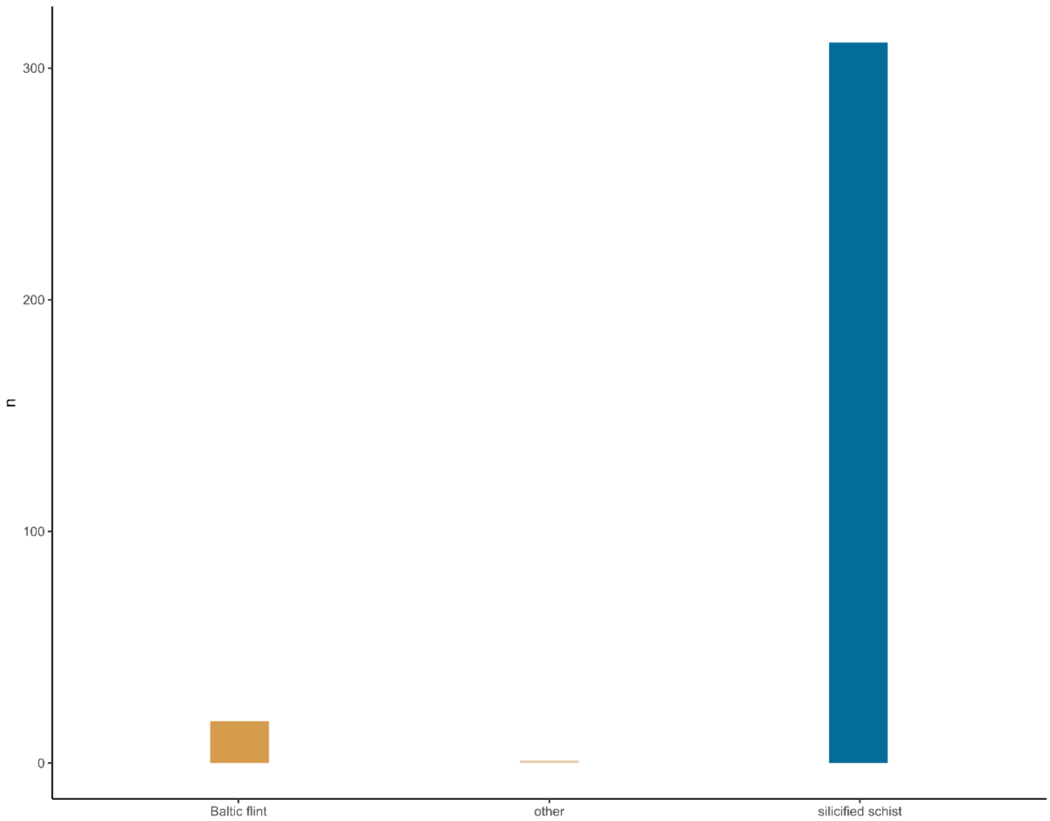

Fig. 44 Distribution of the raw materials used for the production of *Keilmesser* from Buhlen (n= 130), Balver Höhle (n = 191) and Ramioul (n = 9).

A similar situation as described for the *Keilmesser* is documented for the *Prądnik scrapers*. The sampled *Prądnik scraper* assemblage (n = 24) from Buhlen consists without exception of tools made of black silicified schist.

In Balve, the situation is identical. All n = 27 *Prądnik scrapers* are made of silicified schist.

None of the n = 3 *Prądnik scrapers* from Ramioul is a silicified schist tool. They all are made of flint.

To summarise, 94.4% (n = 51) of the *Prądnik scraper* assemblage from the three sites consists of tools made of silicified schist (**fig. 45**).

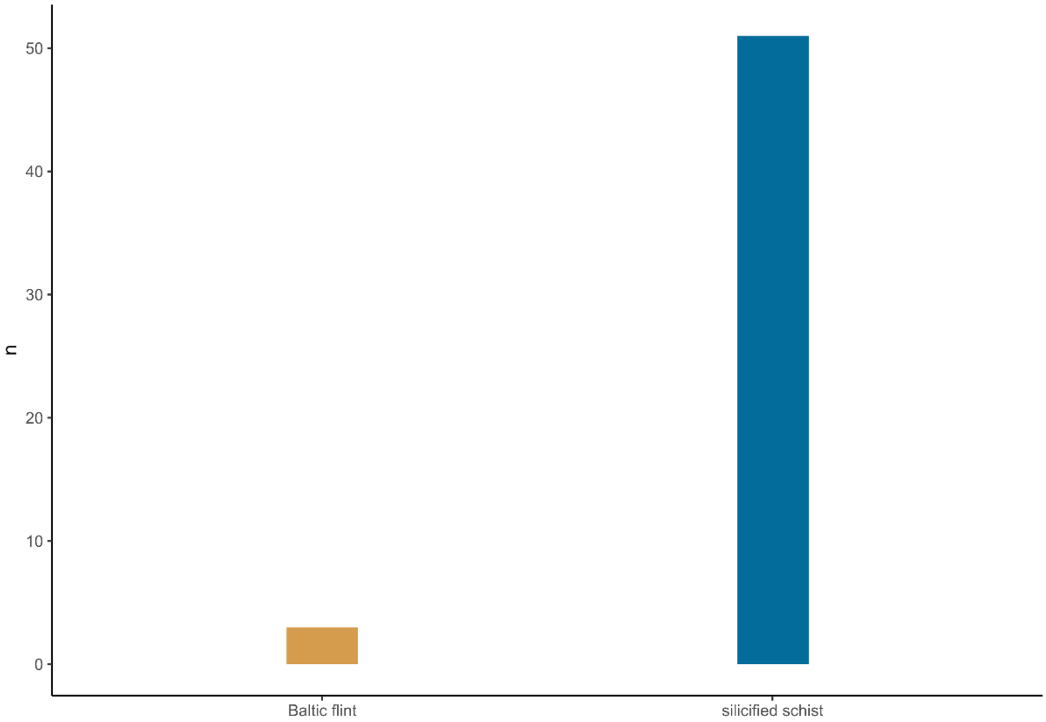

Fig. 45 Distribution of the raw materials used for the production of *Prądnik scraper* from Buhlen (n = 24), Balver Höhle (n = 27) and Ramioul (n = 3).

The properties of the two raw materials involved in the study – silicified schist (lydite) and flint - were measured. Surface roughness as well as hardness were considered for the material properties. To start, the hardness was measured with the Leeb rebound hardness tester (Proceq Equotip 550, Leeb C probe). The dataset can be found on GitHub [https://github.com/lschunk/Leeb_hardness]. As explained in the previous chapter, only one silicified schist artefact of the three assemblages fulfilled the necessary requirements to perform the hardness test. The measurements taken on this semi-finished tool from Balve (MU-278) resulted in a mean value of 779 HLC (**fig. 46**).

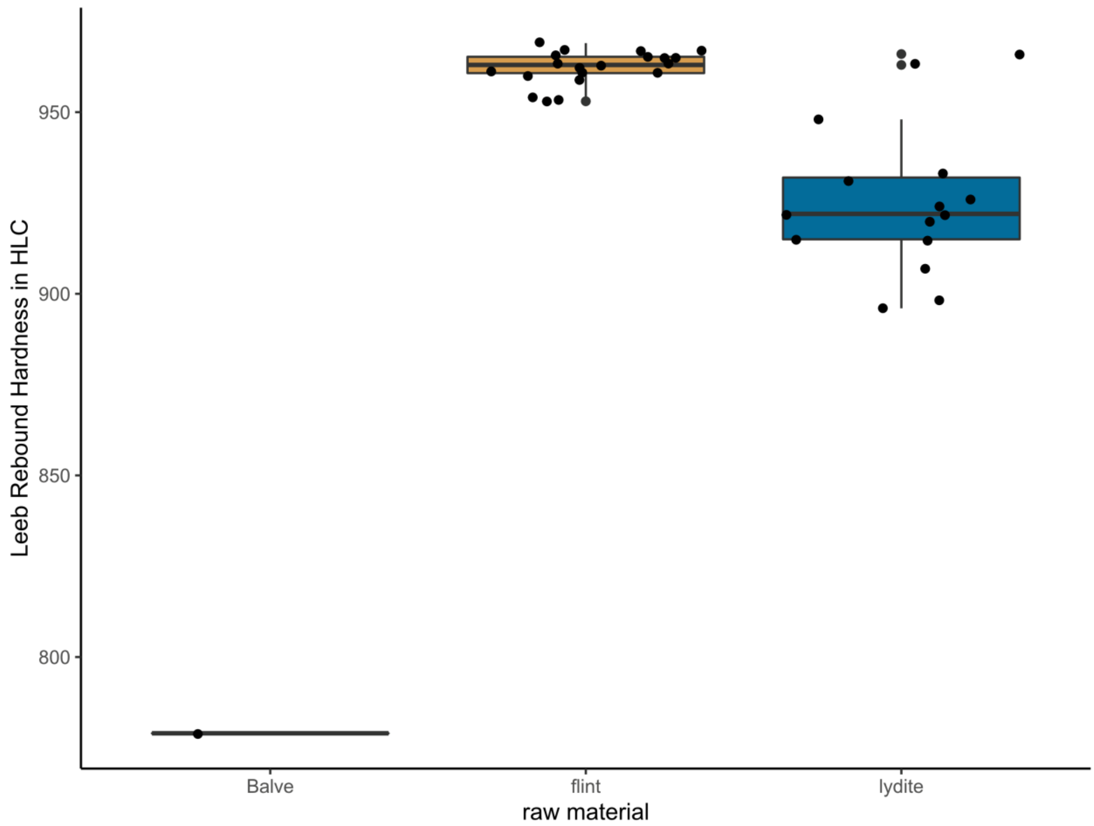

Fig. 46 Leeb Rebound Hardness in HLC measured for the two raw materials flint and lydite (samples initial experiment) and for the semi-finished tool from Balve (ID MU-278).

The same hardness test was applied for the standard samples later used in the experiments (Initial experiment and tool function experiment; see chapter 5.5). Calculating properties such as the raw material hardness allows for a better understanding and also a prediction of aspects such as tool efficiency and durability (Key and Lycett, 2017; Key, Fisch and Eren, 2018; Key, Proffit and de la Torre, 2020, Key, Pargeter and Schmidt, 2020). The standard samples, prepared for the experiment, are made of silicified schist and Baltic flint. The silicified schist was collected near the two sites Buhlen and Balver Höhle. These samples do have, since cut with the band saw, flat surfaces. Thus, the standard samples were perfectly suitable for the hardness measurement with the Leeb rebound tester. Neither the semi-finished *Keilmesser* from Balve nor the experimental standard samples fulfilled the size requirements. This could be compensated with some additional coupling paste, which connects the sample with the supporting base. Ten measurements per sample were taken in order to average the internal variance per sample. In total, n = 31 flint and n = 56 lydite standard samples were measured (for the experimental data lydite is here used as synonym to silicified schist). Not all of them were used in the experiments later. The measurements were mainly taken in order to get an idea, how similar or different the hardness of these two raw materials is. The Leeb rebound hardness test provides the answer for that (**fig. 47**). Based on the in total n = 87 tested samples, it is possible to say that flint has a higher

HLC value than the tested silicified schist does. The arithmetic mean for the flint is 960.8 HLC while the one from silicified schist is 917.9 HLC. The hardness measurements do not only result in a value for the hardness, but they also illustrate another important aspect. The flint hardness ranges from 944.1 HLC to 969.0 HLC. However, the range for the lydite is from minimum 785.9 HLC to maximum 966.0 HLC. The variance for silicified schist is considerably higher compared to the flint. Likely, the reason for that can be seen in the schistosity planes or the banding of the lydite. Lydite is a finely layered, brittle sedimentary rock that fractures conchoidally. The raw material is also characterised by small cracks. By applying the Leeb rebound hardness test, an impact body, a small ball, is driven with a defined energy against the surface of the sample. The velocity of the impact body before and after the impact gets measured. Based on these measurements, the ratio between the impact velocity and rebound velocity defines the Leeb hardness (HL, here HLC). Whenever the impact boy hits a less compact area of the surface (e.g. a crack underneath the surface), rebound energy gets lost and the Leeb hardness value will be smaller. This might be frequently the case for the silicified schist. Depending on the quality of the silicified schist, the Leeb hardness measurement will result in a lower or higher value per sample. When considering the range of the measured Leeb hardness of the lydite, the minimum values are comparable to the Leeb hardness of the semi-finished *Keilmesser* from Balve. The artefact has a Leeb hardness of 779 HLC and is thus similar to the lowest Leeb hardness value of 785.9 HLC from one of the standard samples.

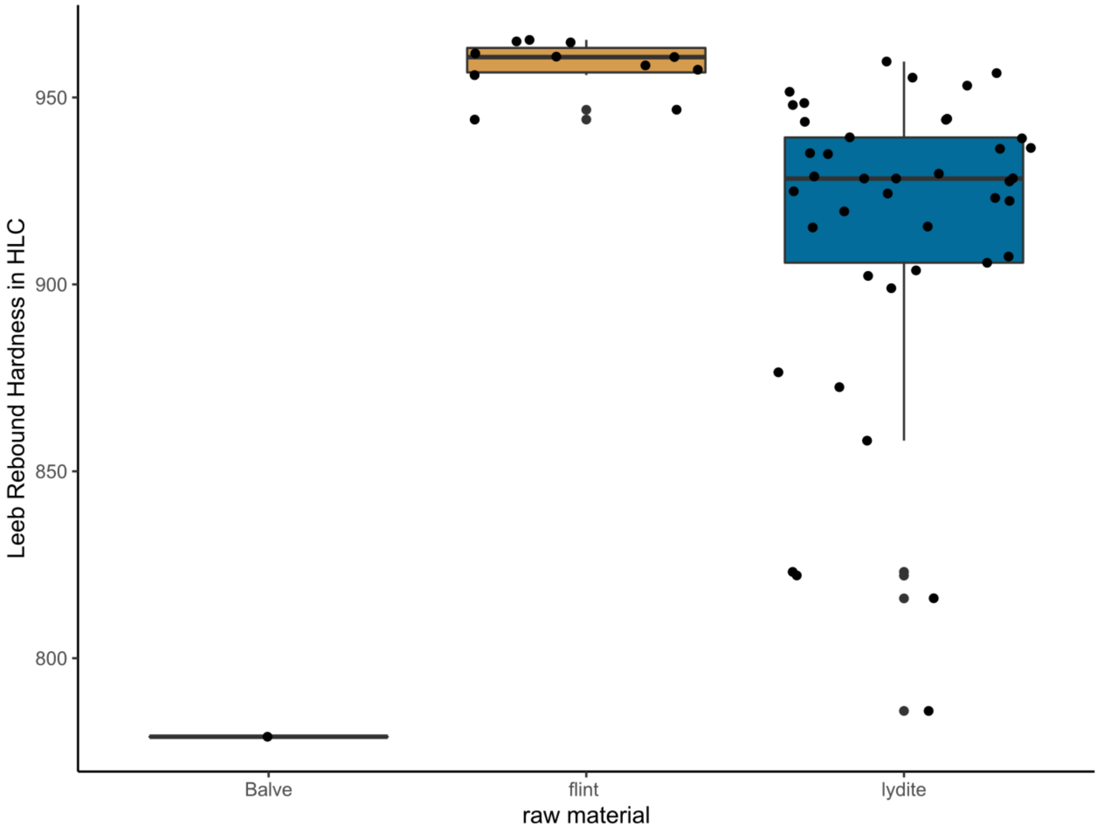

Fig. 47 Leeb Rebound Hardness in HLC measured for the two raw materials flint and lydite (samples tool function experiment) and for the semi-finished tool from Balve (ID MU-278).

As a second raw material property, the surface roughness was included in the raw material characterisation. Surface roughness can be measured with a confocal laser scanning microscope (for details see chapter 4.5.3). Unfortunately, the surface roughness of the archaeological samples were not considered during the data acquisition and thus not measured. Instead, measurements were taken on standard samples before they were used in the experiment ('artificial VS natural' experiment) (**fig. 48**). Surface roughness is a component of the surface texture and describes the unevenness of a surface height. Based on directional deviations from the surfaces, the surface roughness can be quantified. A large deviation stands therefore for rough surfaces while a small deviation is equal to smooth surfaces. In order to address the surface roughness of the measured standard sample here, *Sq*, the root mean square height, as one of the seven existing areal field parameters was chosen (for more information see Digital Surf, Besançon, France). Areal field parameters, especially *Sq*, are known to give more significant values. The results were calculated following the ISO 25178. The surface roughness was measured for n = 4 lydite as well as n = 4 flint standard samples. The arithmetic mean for the lydite samples is 22.392 µm while the one for the flint samples is 12.206 µm. Based on these values, flint surfaces are quantified as less rough than the lydite surface. It has to be pointed out that the measurements were taken on the standard samples, which are cut with a band saw (see chapter 4.5). The traces from the band saw are macroscopically clearly visible on the sample surface. These traces surely affect the surface roughness. Unfortunately, there is no reference collection or any comparable measurements taken on machine cut samples yet. Single comparable values measured on flint can be found in literature (Evans et al., 2014; Calandra et al., 2019c). These specific flint samples are knapped flakes and measured under similar (Evans et al., 2014) or even identical (Calandra et al., 2019c) settings than the standard samples within this project. The analysis for these flint samples was also done according to the ISO 25178. The measurements taken by Evans et al. lead to *Sq* values between 0.64 µm and 0.98 µm. The *Sq* values for other flint sample (Calandra et al., 2019c, supplementary table S3) ranges between 0.824 µm and 1.912 µm. Thus, these values are significantly lower than the values calculated on cut standard samples.

Additionally, the variance in the results from the standard samples has to be pointed out. While the measurements taken on the lydite samples ranging from 16.468 µm to 26.081 µm, the range is considerably bigger for the flint measurements. The minimum value for flint is 4.136 µm and the maximum is 28.733 µm. Without further measurements or a reliable reference collection, the variability within the calculated surface roughness values cannot be explained.

In general, although parameters such as the surface roughness are highly relevant, especially in the context of use-wear analysis and experimental design, they are not much explored yet in archaeology. The results presented here might indicate that lydite, even when both raw materials are cut identically with a band saw, has a higher surface roughness than flint. However, the existing information about the surface's roughness of the raw materials lydite and flint are not sufficient for further conclusions.

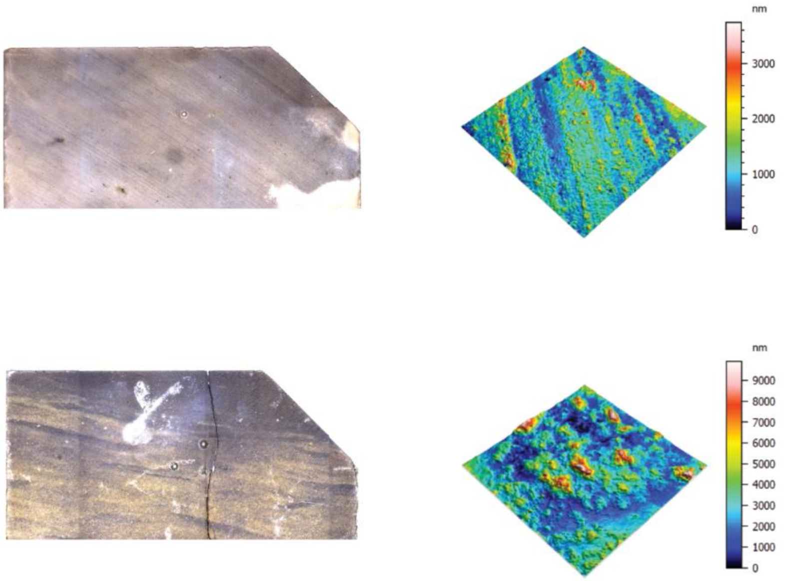

Fig. 48 Surface of unused standard samples for experimental approaches (left) and confocal micro-surface texture (right). The colour of the surfaces corresponds to the height on the z-axis. The upper row shows a flint sample, the lower row a lydite sample.

5.2 Techno-typological analysis

As mentioned above, the presentation of the results from the techno-typological analysis consider first the results from the *Keilmesser*, followed by the results from the *Prądnik scrapers*. In a later step, the focus is on the results gained from analysing the *Prądnik spalls*. All results can be also found in the appendix (see appendix I.).

5.2.1 Blanks and cortex

In this part of the analysis, the distinction was made whether an artefact displays a core tool or not. This aspect is relevant to *Keilmesser* and *Prądnik scrapers*. Another interesting aspect in this context is the amount of cortex on the tool's surface, since it can provide some indications to which degree the blank was modified.
In Buhlen, 67.0% (n = 87) of the *Keilmesser* could be defined as core tools (**fig. 49**). With 6.2% (n = 8) only, flakes have been transformed into *Keilmesser* considerably less frequently. In 26.9% (n = 35) of the artefacts the blank could not be determined as either core or flake. N = 55 of all *Keilmesser* are not covered with cortex at all. The remaining n = 75 artefacts have cortex. Most of them (n = 61) are core tools. Most of the time, the cortex can be found at the back of the tool (n = 38) or on the base (n = 22). Only in individual cases, the cortex is located in the proximal (n = 4) or medial (n = 9) tool area. The percentage of cortex measured on the complete tool surface is most often limited to less 25% (n = 43). In one third (n =25) of the tools with cortex, the percentage of cortex reaches up to 50%.

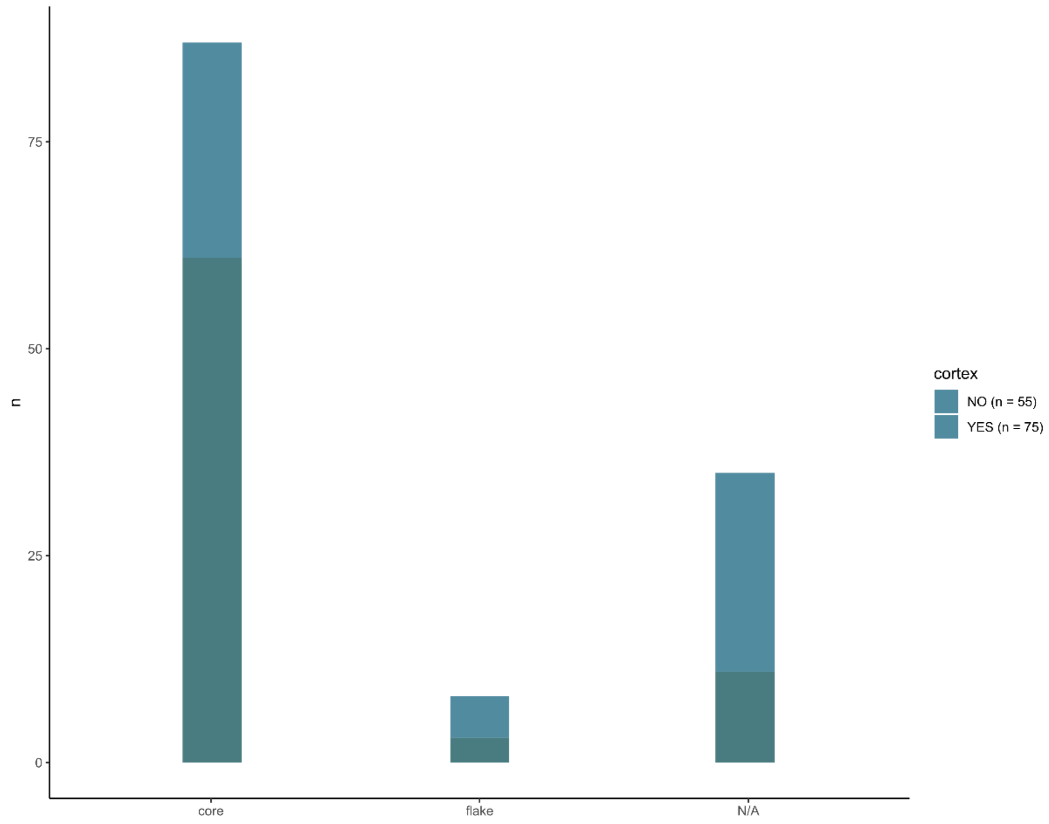

Fig. 49 Blank selection for the production of *Keilmesser* (n = 130) from Buhlen. Additionally, the figure includes the information whether an artefacts displays cortex or not.

In Balve, the majority of the tools, 71.2%, were also manufactured as core tools with n = 136 artefacts (**fig. 50**). A comparable small number of *Keilmesser*, as in Buhlen, was produced on flakes (4.7%, n = 9). The blank type was undeterminable in 24.1% (n = 46) cases. The question, whether the *Keilmesser* from the assemblage in Balve are covered with cortex or not, cannot be answered to full extent. One part of the assemblage was a short time loan from the LWL-Museum for Archaeology in Herne. When the material was studied a few years ago, this aspect was not part of the attribute analysis. Therefore, n = 35 *Keilmesser* need to be excluded. From the remaining n = 156 artefacts, n = 33 display no cortex. On the contrary, for n = 123 *Keilmesser*, cortex could be documented. Similar as in Buhlen, the cortex is by a majority (n = 95) located along the back of the tools. N = 6 pieces also show cortex on the tool base or in generally in the proximal area of the tool (n = 1). Cortex could be also documented in the medial (n = 14) or distal (n = 4) tool parts. N = 3 artefacts have cortex covering nearly the entire tool surface (except the active edge) with up to 75% cortex. One of these three artefacts is a semi-finished tool. For the other tools with cortex, the same as in Buhlen counts. The percentage of cortex most commonly (n = 67) reaches up to 25% of the surface. On n = 23 pieces, the amount of cortex is higher, but also limited to maximum 50%.

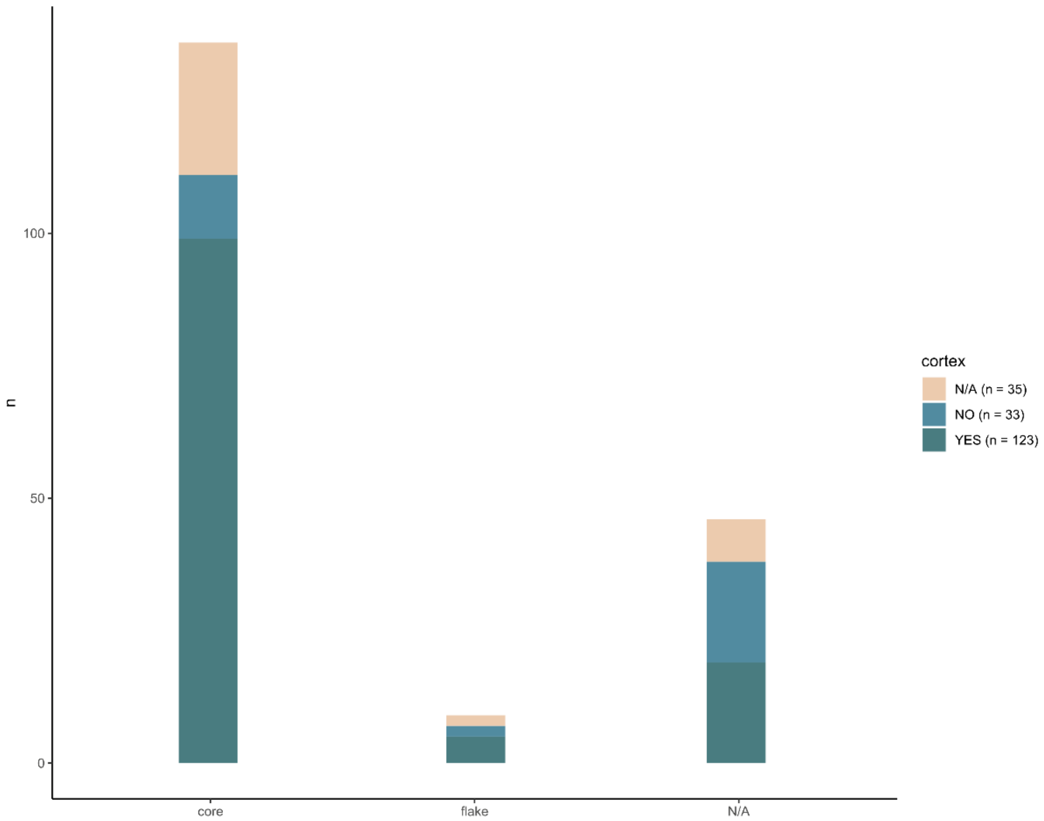

Fig. 50 Blank selection for the production of *Keilmesser* (n = 191) from Balver Höhle. Additionally, the figure includes the information whether an artefacts displays cortex or not. For some artefacts, this analysis was not done. Thus, these artefacts are labelled as N/A.

Despite the small assemblage, the *Keilmesser* from Ramioul manufactured on cores also predominate the assemblage (**fig. 51**). 44.4% (n = 4) are core tools, one artefact was made from a flake and again, 44.4% (n = 4) could not be determined. All *Keilmesser*, except the one made from a flake, show cortex. The cortex is mostly located on the back (= 7) and n = 1 artefacts has cortex on the proximal area of the dorsal tool surface. The percentage of cortex on the surface is comparable with the results from Buhlen and Balver Höhle. On only n = 2 *Keilmesser* up to 50% of cortex could be documented. The other n = 6 artefacts display lower cortex percentages with maximum 25%.

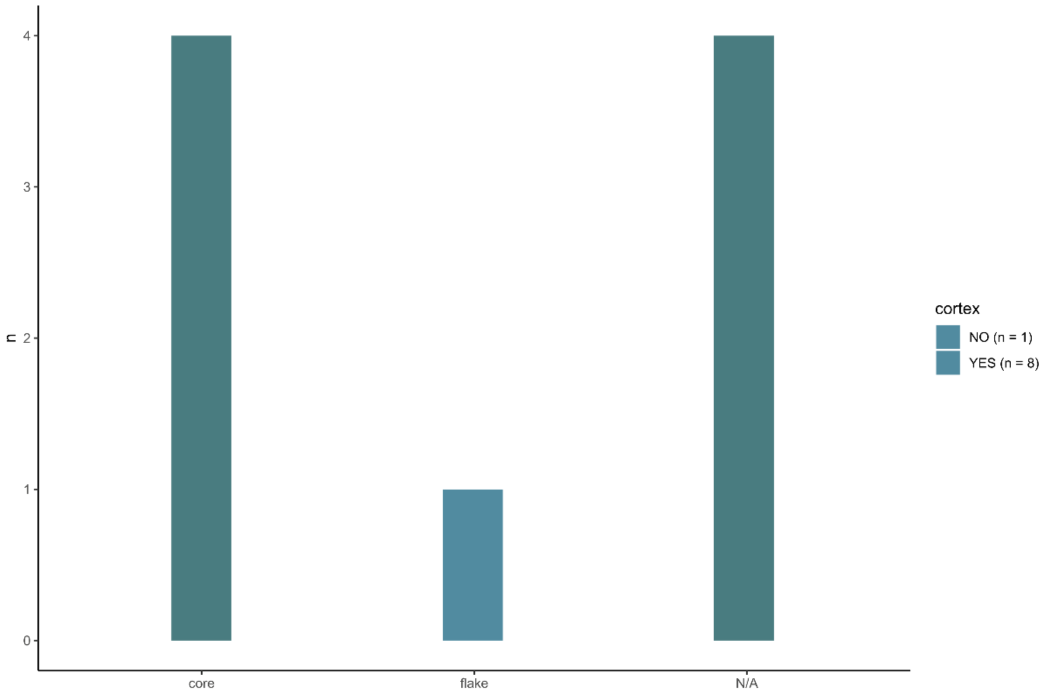

Fig. 51 Blank selection for the production of *Keilmesser* (n = 9) from Ramioul. Additionally, the figure includes the information whether an artefacts displays cortex or not.

These results combined for the three sites together illustrate a clear picture (**fig. 52**). The *Keilmesser* from these assemblages are by a majority of 68.8% (n = 227) core tools. For only a small amount of 5.5% (n = 18) a flake was used as a blank. For roughly a quarter (n = 85) of the tools the blank type could not be determined for sure.
Additionally, on the majority (69.8%, n = 206) of the *Keilmesser,* cortex could be documented, covering up to 25% of the surface (56.3%, n = 116). Most often, the cortex was located on the back (68.0%, n = 140) of the tools.

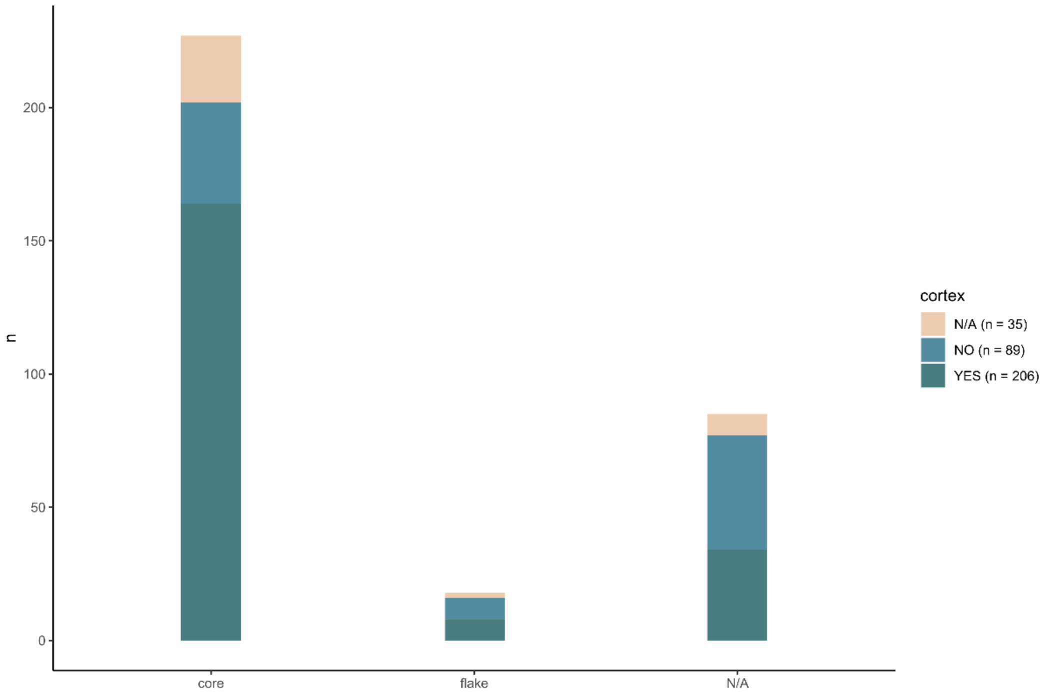

Fig. 52 Blank selection for the production of *Keilmesser* from Buhlen (n = 130), Balver Höhle (n = 191) and Ramioul (n = 9). Additionally, the figure includes the information whether an artefacts displays cortex or not. For some artefacts, this analysis was not done. Thus, these artefacts are labelled as N/A.

None of the *Prądnik scrapers* from the studied assemblages can be defined for sure as a core tool. In contrary, all *Prądnik scrapers* from Buhlen are clearly tools produced on a flake. The analysis for the quantity and location of cortex on the tool surfaces was done for the *Prądnik scrapers* as well. The results are contrasting to the ones from the *Keilmesser* though. However, considering the blanks chosen to produce the tools, the results are consistent. In Buhlen 79, 2 % (n = 19) of the *Prądnik scraper* do not show any cortex. The only n = 5 artefacts with cortex display up to 25% cortex along the back (n = 4) or on the base (n = 1).

Also in Balve, n = 21 (77.8%) artefacts could be documented as such. In the remaining n = 6 cases, the blank type was undeterminable. Nearly half (n = 13) of the *Prądnik scrapers* from the assemblage in Balve have no cortex. N = 8 artefacts display cortex along the back, n = 2 tools either has cortex in the medial or distal part of the tool. Except for one of these n = 10 *Prądnik scraper* the percentage of cortex per surface was less than 25%. For n = 4 *Prądnik scraper* this analysis was not conducted.

The results for the *Prądnik scrapers* from Ramioul are equivalent to the ones from Buhlen; all *Prądnik scrapers* are produced from flakes. In Ramioul, no cortex could be documented on the *Prądnik scrapers.*

The results taken together illustrate that 88.9% (n = 48) of the *Prądnik scrapers* are produced from flakes (**fig. 53**). For the other 10.1% (n =6) the blank type is unknown. With only 27.8% (n = 15) the quantity of tools with cortex is lower than compared to the *Keilmesser*.

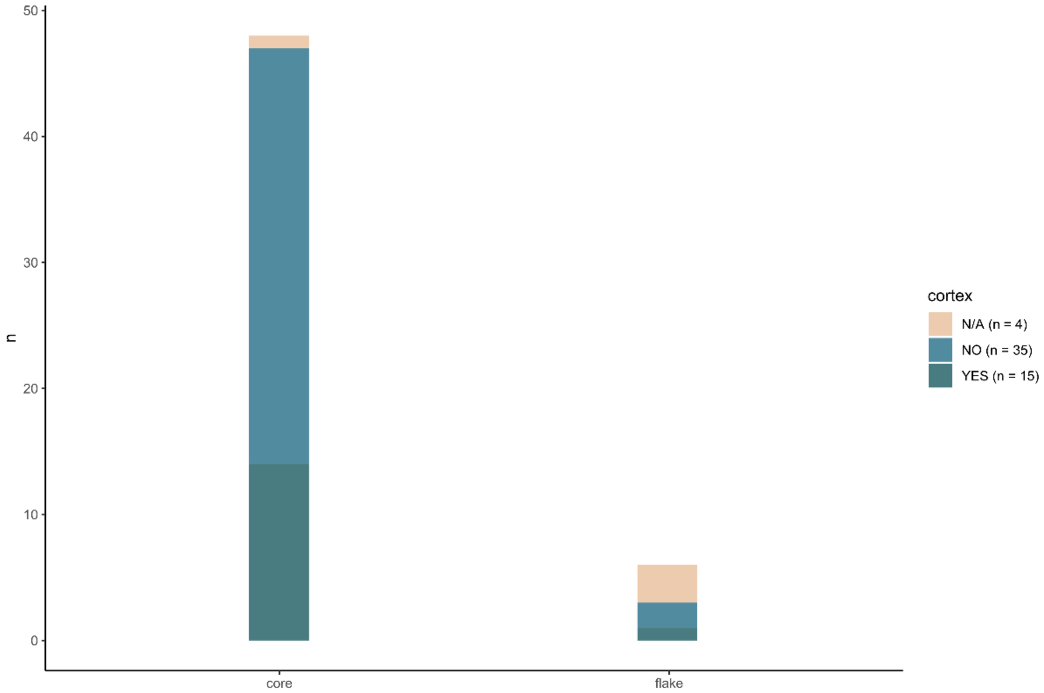

Fig. 53 Blank selection for the production of *Prądnik scraper* from Buhlen (n = 24), Balver Höhle (n = 27) and Ramioul (n = 3). Additionally, the figure includes the information whether an artefacts displays cortex or not. For some artefacts, this analysis was not done. Thus, these artefacts are labelled as N/A.

5.2.2 Morphometric quantitative analysis

The dimensions to address first are the length, width and thickness measurements. In general, the fragmented *Keilmesser* were omitted in this part of the analysis. The measurements of these tools can be found in the appendix (see appendix I.). Additionally, the results from the complete *Keilmesser* are separated from the ones from the *Keilmesser* tips.

The complete *Keilmesser* from the here studied assemblage from Buhlen (n = 111) can be classified in a size range from 30.0 mm to 113.5 mm length (**fig. 54, 57**). The arithmetic mean of the length is 53.0 mm. Concerning the width, the minimum and maximum are extending between 14.0 mm and 71.9 mm, with an arithmetic mean value of 32.9 mm (**fig. 58**). The thickness is ranging between 7.0 mm and 31.0 mm (**fig. 59**). The arithmetic mean amounts to 16.1 mm.

These measurements considered for the *Keilmesser* tips only, lead to the following picture. As to be expected, the n = 15 *Keilmesser* tips are significantly smaller in terms of the artefact length. The length ranges between 13.0 mm and 46.0 mm. The arithmetic mean is 28.1 mm. The minimum width measurement is 19.0 mm while the maximum is 42.0 mm. The arithmetic mean is similar to the one from the complete *Keilmesser* with 30.0 mm. The thickness is ranging from 8.0 mm to 20.0 mm with an arithmetic mean value of 12.6 mm.

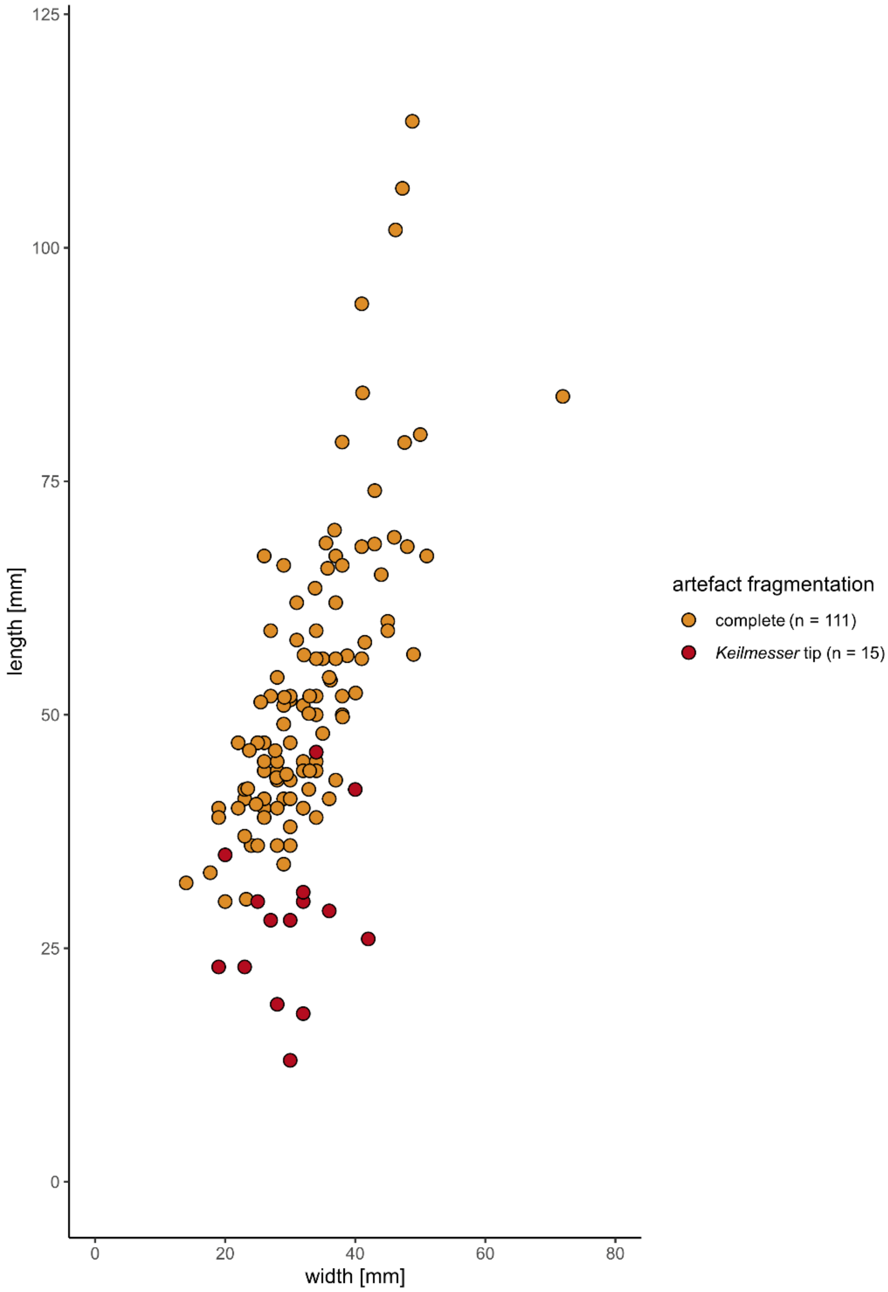

Fig. 54 Length-width ratio of the complete *Keilmesser* (n = 111) and *Keilmesser* tips (n = 15) from Buhlen.

In Balve, the results of the length, width and thickness measurements are based on n = 158 complete *Keilmesser*. The arithmetic mean of the length measurements is 55.5 mm with a minimum length of 29.7 mm and a maximum of 135.6 mm (**fig. 55, 57**). With these values, the margin is bigger than in Buhlen, but the mean values are comparable. The width is ranging between 18.7 mm and 81.4 mm with an arithmetic mean of 34.1 mm (**fig. 58**). The measured thickness values are similar to the ones from Buhlen (**fig. 59**). The margin is between 7.4 mm and 29.3 mm. The arithmetic mean value is 16.3 mm.

When looking at the *Keilmesser* tips only (n = 21), the measurements result in the following values. The length is ranging from 18.0 mm to 91.0 mm. The arithmetic mean amounts to 45.2 mm. The arithmetic mean value concerning the width is slightly higher than the one for the complete *Keilmesser* with 35.6 mm. The measured minimum value is thereby 22.9 mm and the maximum value 53.9 mm. The thickness margin is between 9.5 mm and 23.6 mm. The arithmetic mean is 15.5 mm.

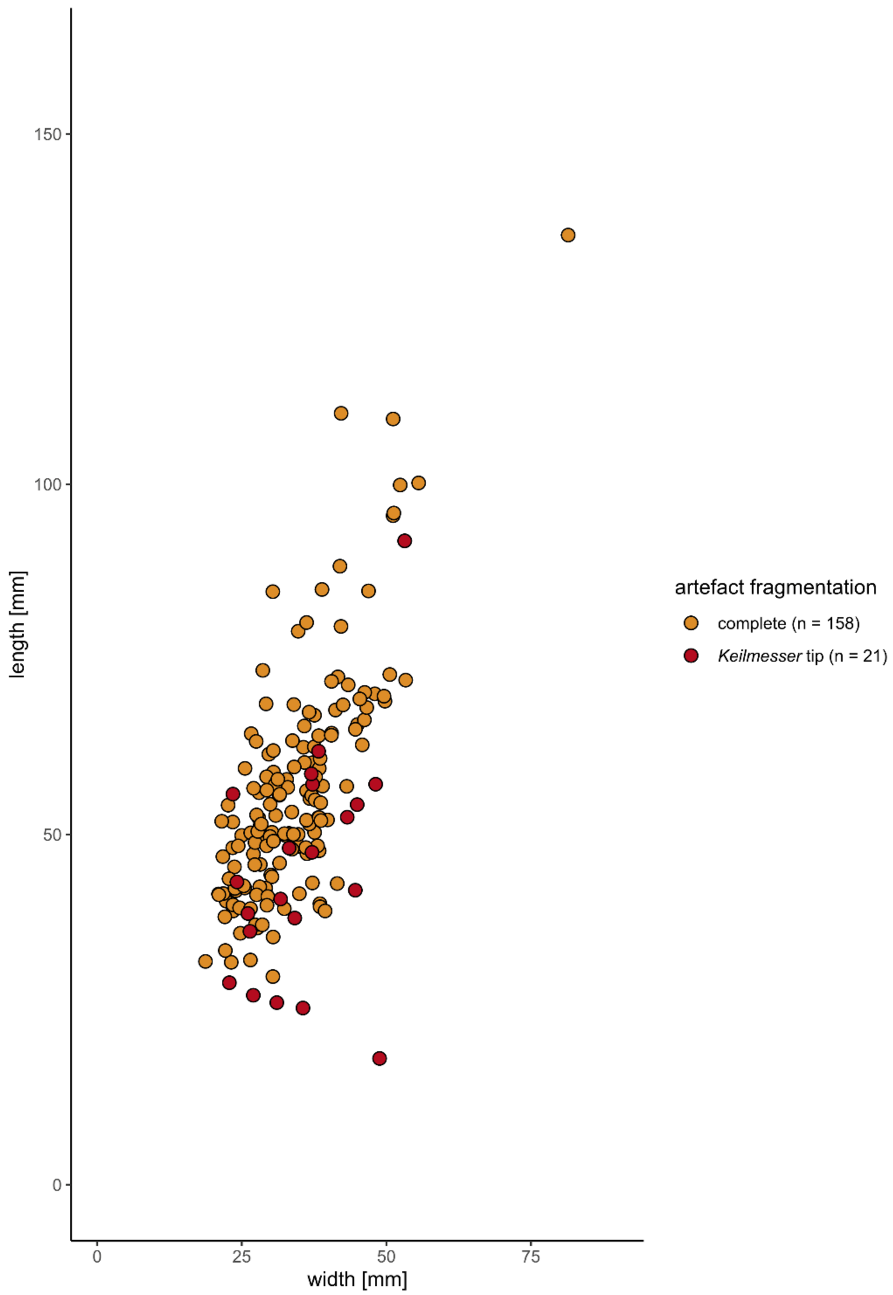

Fig. 55 Length-width ratio of the complete *Keilmesser* (n = 158) and *Keilmesser* tips (n = 21) from Balver Höhle.

In the same way as for Buhlen and Balve, the measurements were recorded for the *Keilmesser* from Ramioul. The results deviate not much from the results already mentioned, but since the assemblage from Ramioul is significantly smaller (n = 9), the results are of little consequence (**fig. 56, 57**). The minimum length is 42.0 mm, while the maximum is 117.0 mm. The arithmetic mean can be calculated as 71.2 mm.

Concerning the width, the minimum and maximum values extend between 27.0 mm and 57.0 mm, with an arithmetic mean value of 37.4 mm (**fig. 58**). The thickness of the *Keilmesser* ranges between 14.0 mm and 23.0 mm (**fig. 59**). The arithmetic mean is 18.7 mm.

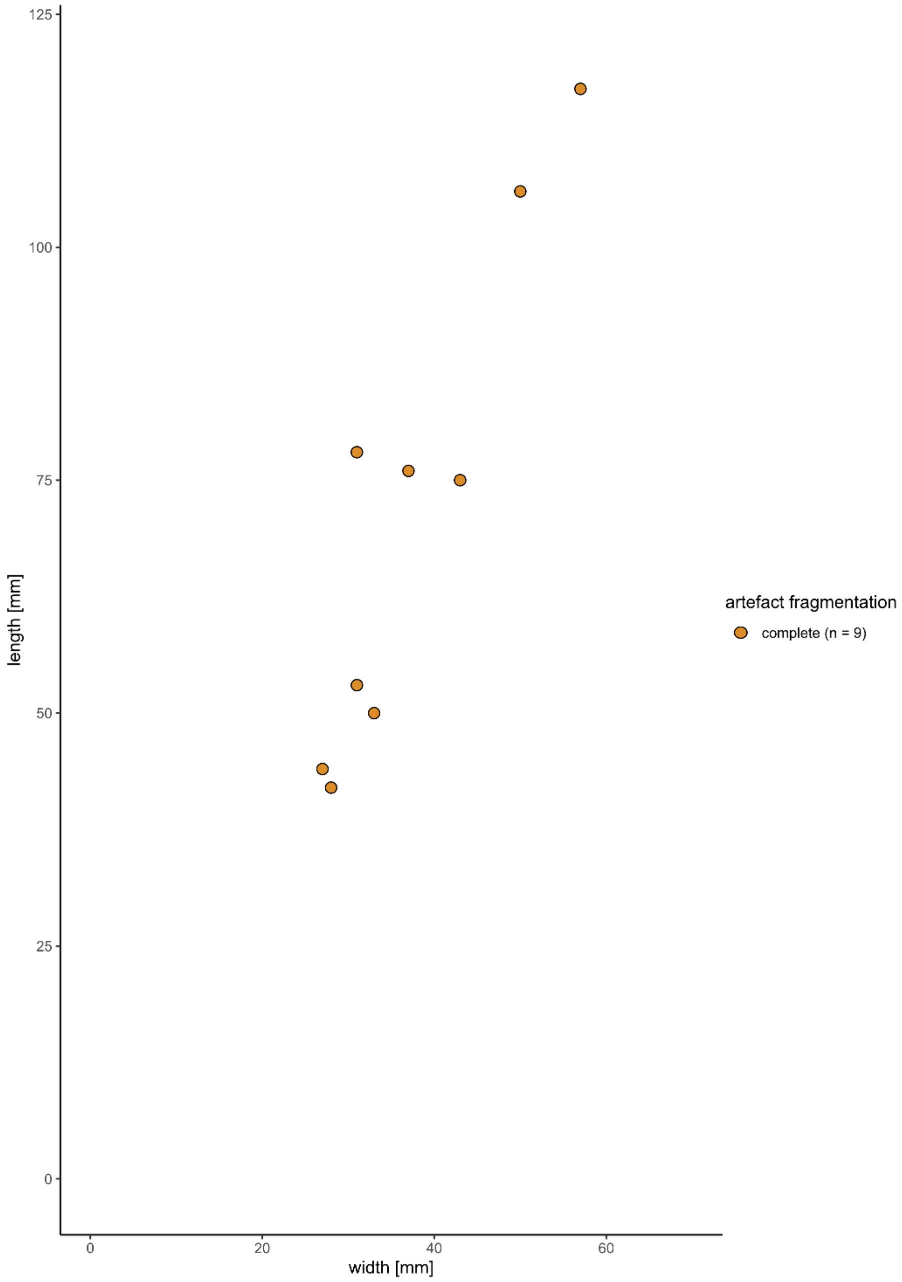

Fig. 56 Length-width ratio of the complete *Keilmesser* (n = 9) from Ramioul.

The results from the three sites taken together reveal the following picture. *Keilmesser* (n = 278) extend in their length from 29.7 mm to 135.6 mm (**fig. 57, 60**). The arithmetic mean is 55.5 mm. The width measurements ranging from 14.0 mm to 81.4 mm with an arithmetic mean value of 33.7 mm (**fig. 58**). The range for the thickness is between 7.0 mm and 31.0 mm (**fig. 59**). The arithmetic mean is 16.3 mm.

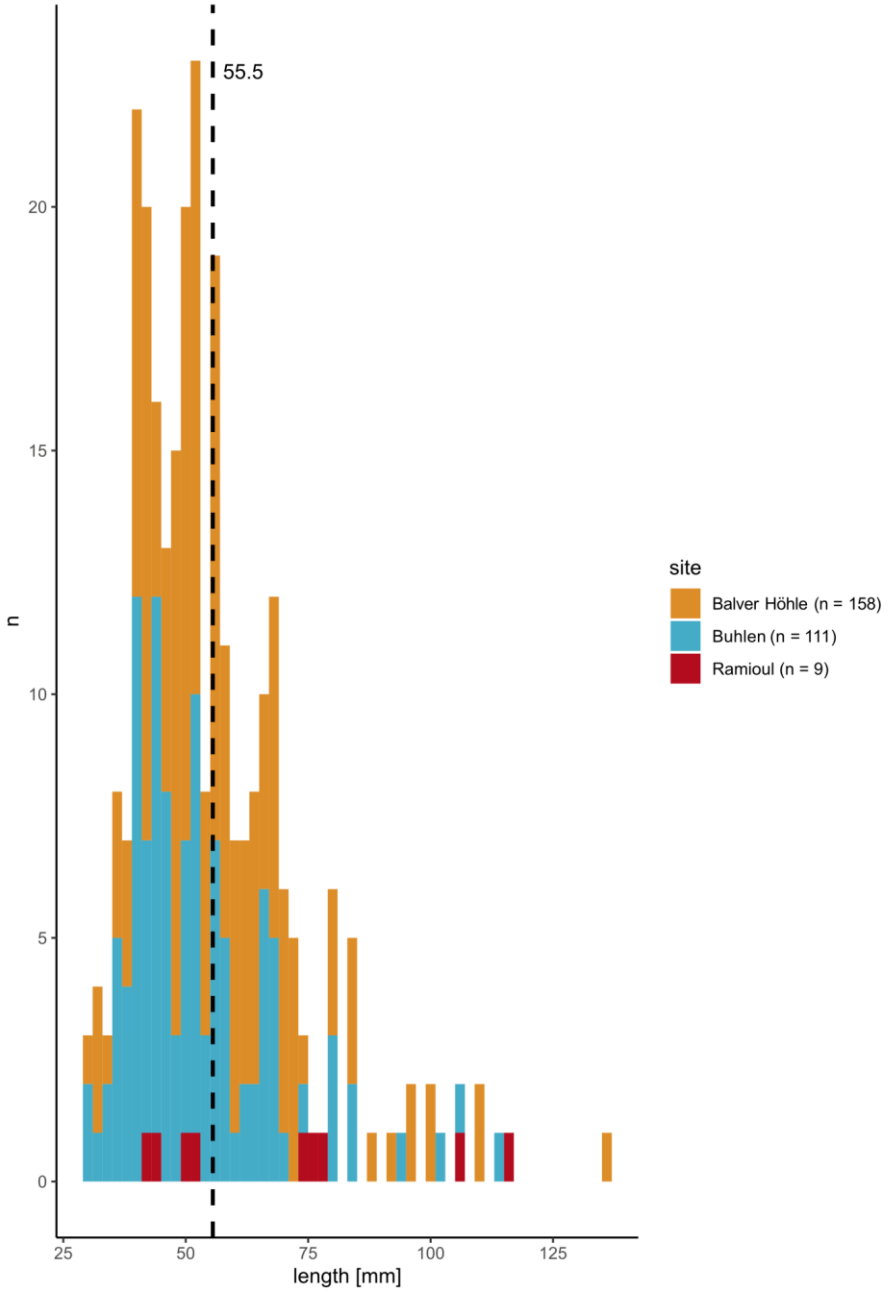

Fig. 57 Maximal length of the complete *Keilmesser* from Buhlen (n = 111), Balver Höhle (n = 158) and Ramioul (n = 9). The dashed line indicates the arithmetic mean value.

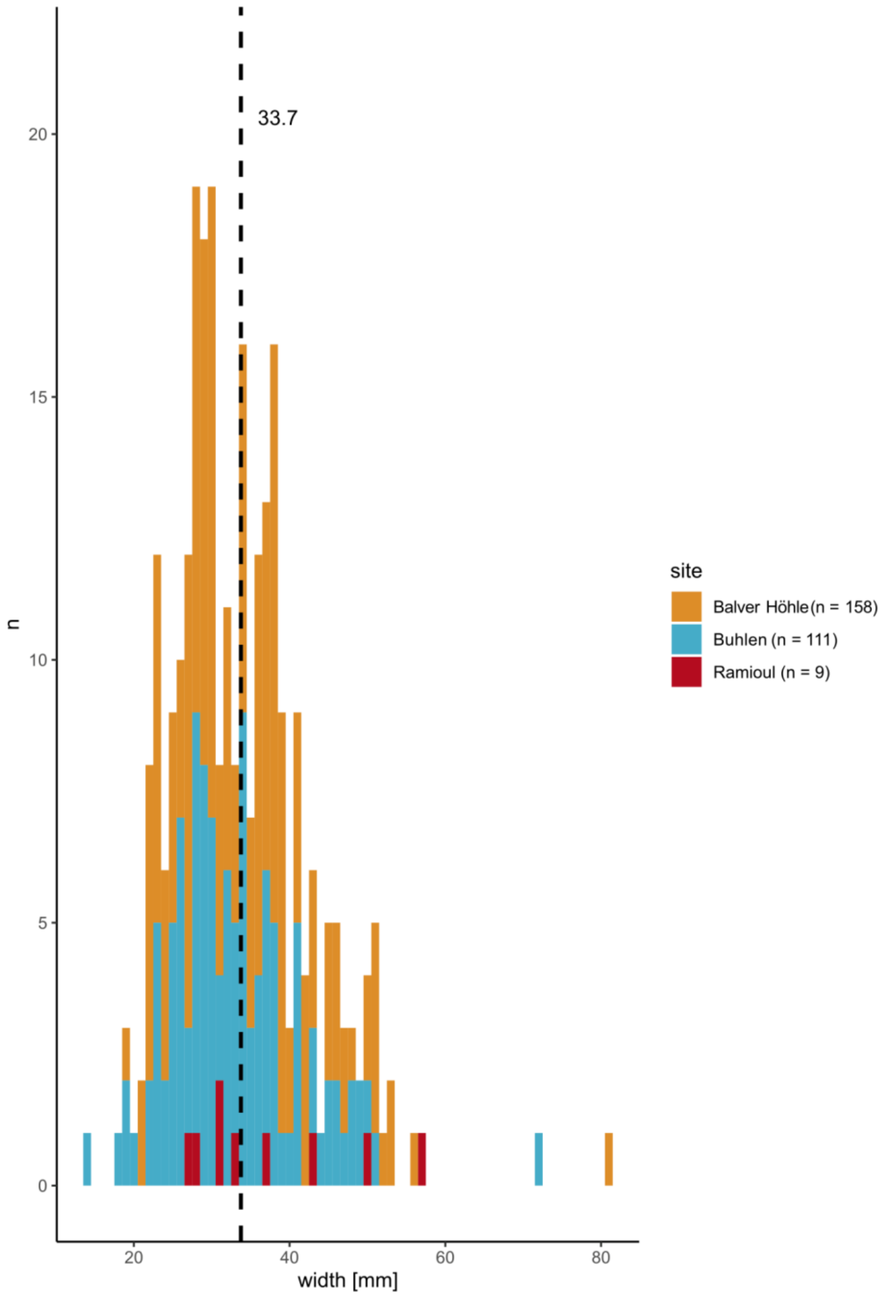

Fig. 58 Maximal width of the *Keilmesser* from Buhlen (n = 158), Balver Höhle (n = 111) and Ramioul (n = 9). The dashed line indicates the arithmetic mean value.

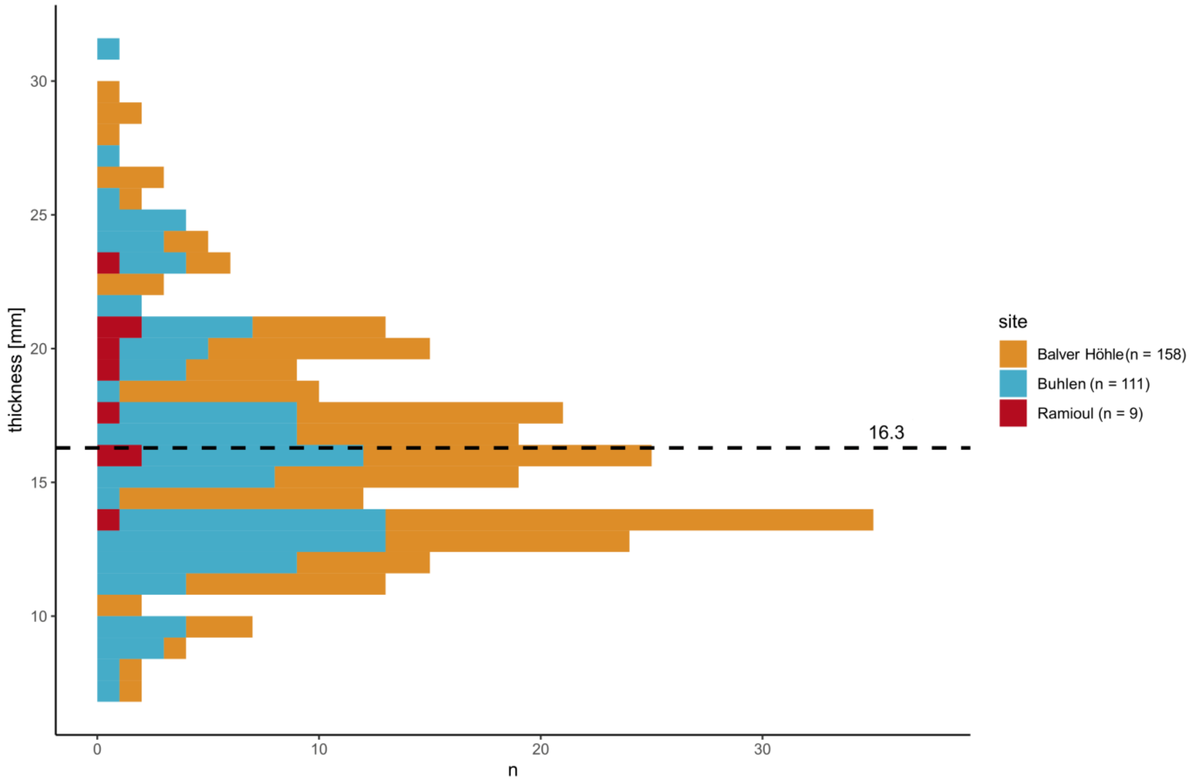

Fig. 59 Maximal thickness of the *Keilmesser* from Buhlen (n = 158), Balver Höhle (n = 111) and Ramioul (n = 9). The dashed line indicates the arithmetic mean value.

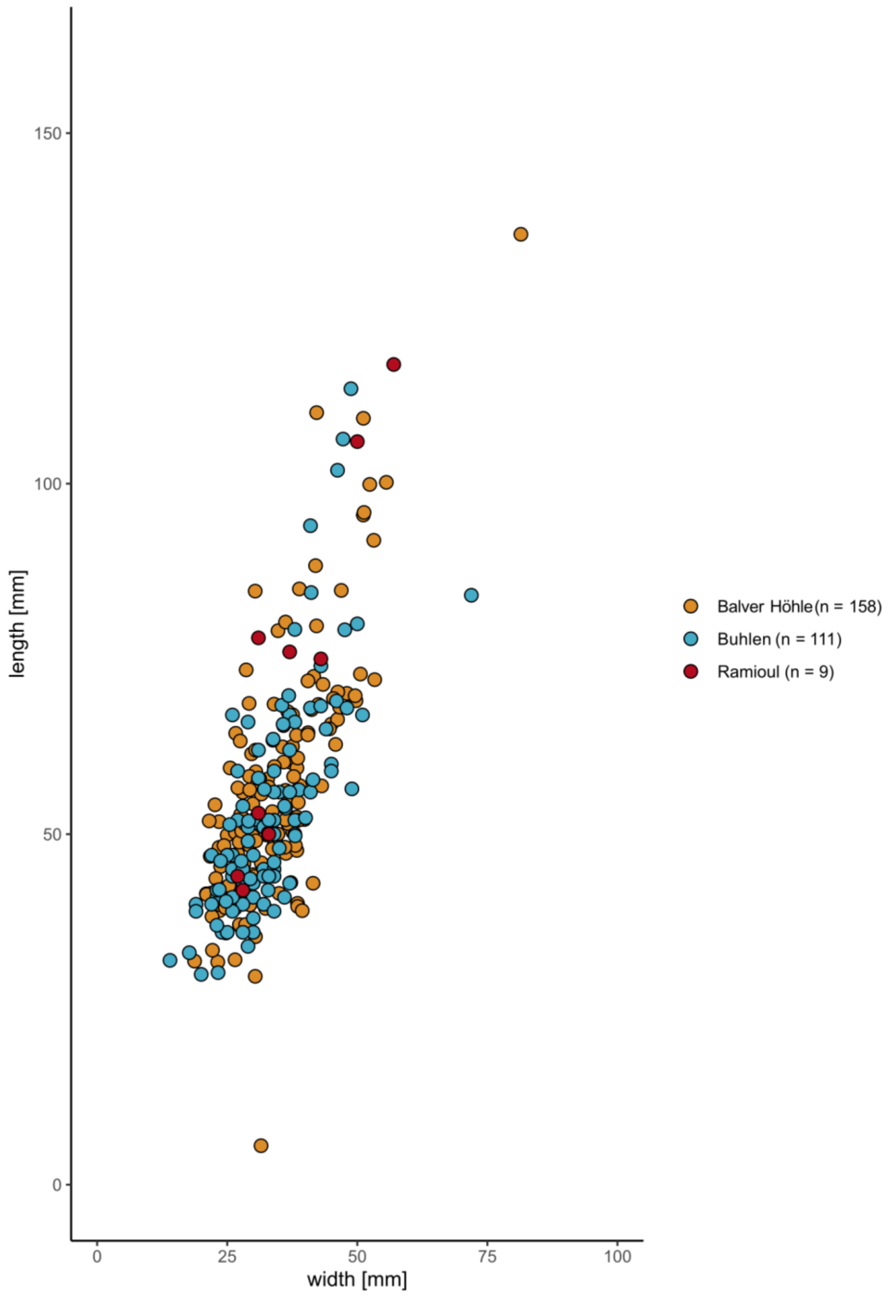

Fig. 60 Length-width ratio of the complete *Keilmesser* from Buhlen (n = 111), Balver Höhle (n = 158) and Ramioul (n = 9).

The dimensions – length, width and thickness - were measured for all *Prądnik scrapers.* In Buhlen, the results of the length measurements are in a range between 27.0 mm and 78.0 mm (**fig. 61, 64**). The arithmetic mean of the length is 43.5 mm. The mean value for the width is 28.5 mm with a minimum measurement of 18.0 mm and a maximum of 48.0 mm (**fig. 65**). The thickness of *Prądnik scrapers* is ranging between 4.0 mm and 15.8 mm with an arithmetic mean of 9.2 mm (**fig. 66**).

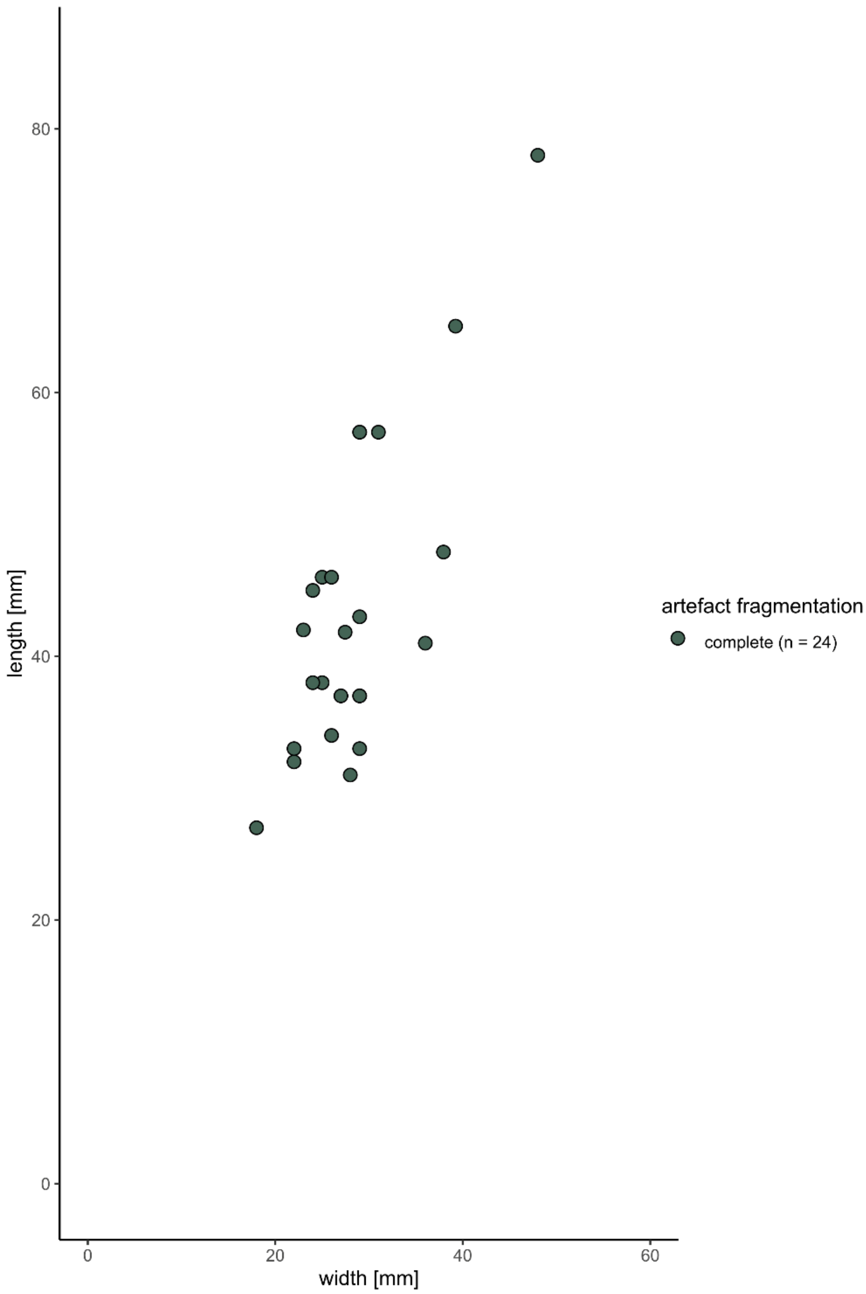

Fig. 61 Length-width ratio of the *Prądnik scrapers* (n = 24) from Buhlen.

The *Prądnik scrapers* from Balve can be classified in a size range from 33.4 mm to 75.7 mm length (**fig. 62, 64**). The arithmetic mean of the length is 50.5 mm. The width extends from 20.6 mm to 53.3 mm, with an arithmetic mean value of 32.8 mm (**fig. 65**). The thickness is ranging between 1.2 mm and 20.4 mm (**fig. 66**). The arithmetic mean is 13.9 mm.

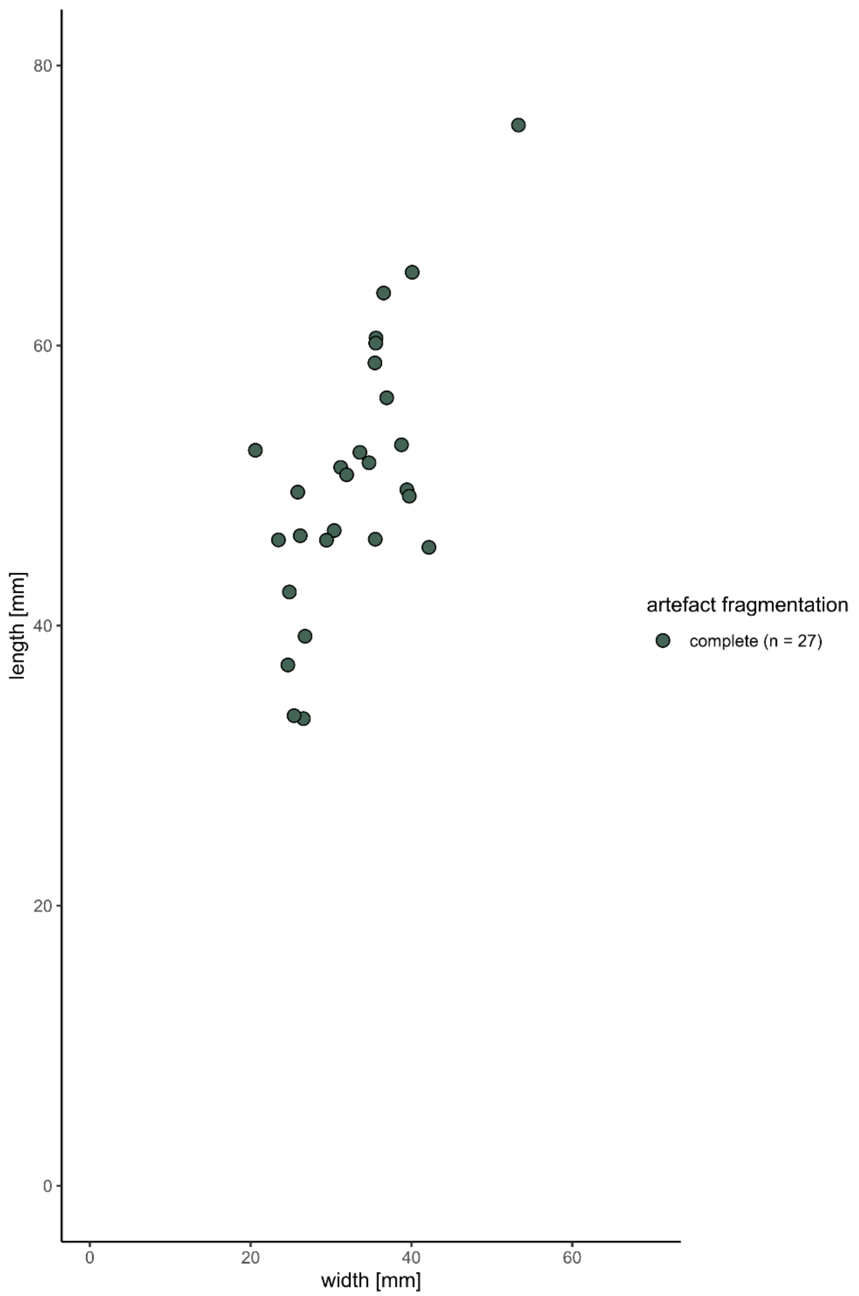

Fig. 62 Length-width ratio of the *Prądnik scrapers* (n = 27) from Balver Höhle.

The margins for the *Prądnik scraper* length from Ramioul are 45.0 mm and 52.0 mm (**fig. 63, 64**). The arithmetic mean value adds up to 48.3 mm. The minimum and maximum width values extend between 35.0 mm and 37.0 mm, with an arithmetic mean value of 35.7 mm (**fig. 65**). The arithmetic mean of the thickness is 12.0 mm (**fig. 66**). The measurements range from 11. 0 mm to 14.0 mm.

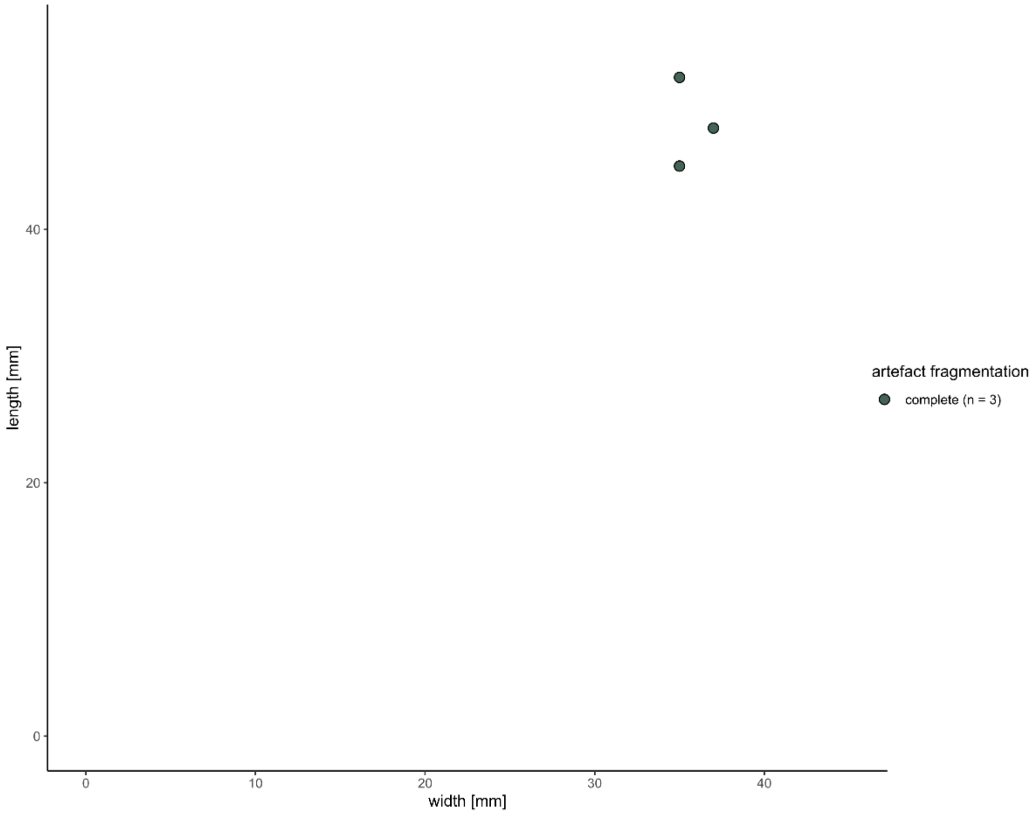

Fig. 63 Length-width ratio of the *Prądnik scrapers* (n = 3) from Ramioul.

Taken together, the measurements for the *Prądnik scrapers* length from the three sites result in a range from 27.0 mm to 78.0 mm with a mean value of 47.3 mm (**fig. 64, 67**). All together, the *Prądnik scrapers* have a minimum width of 18.0 mm and a maximum of 53.3 mm (**fig. 65**). The arithmetic mean is 31.0 mm. The thickness of *Prądnik scrapers* ranges between 1.2 mm and 20.4 mm, with an arithmetic mean of 11.7 mm (**fig. 66**). The measurements from the *Prądnik scrapers* are in general smaller than the ones taken from the *Keilmesser.*

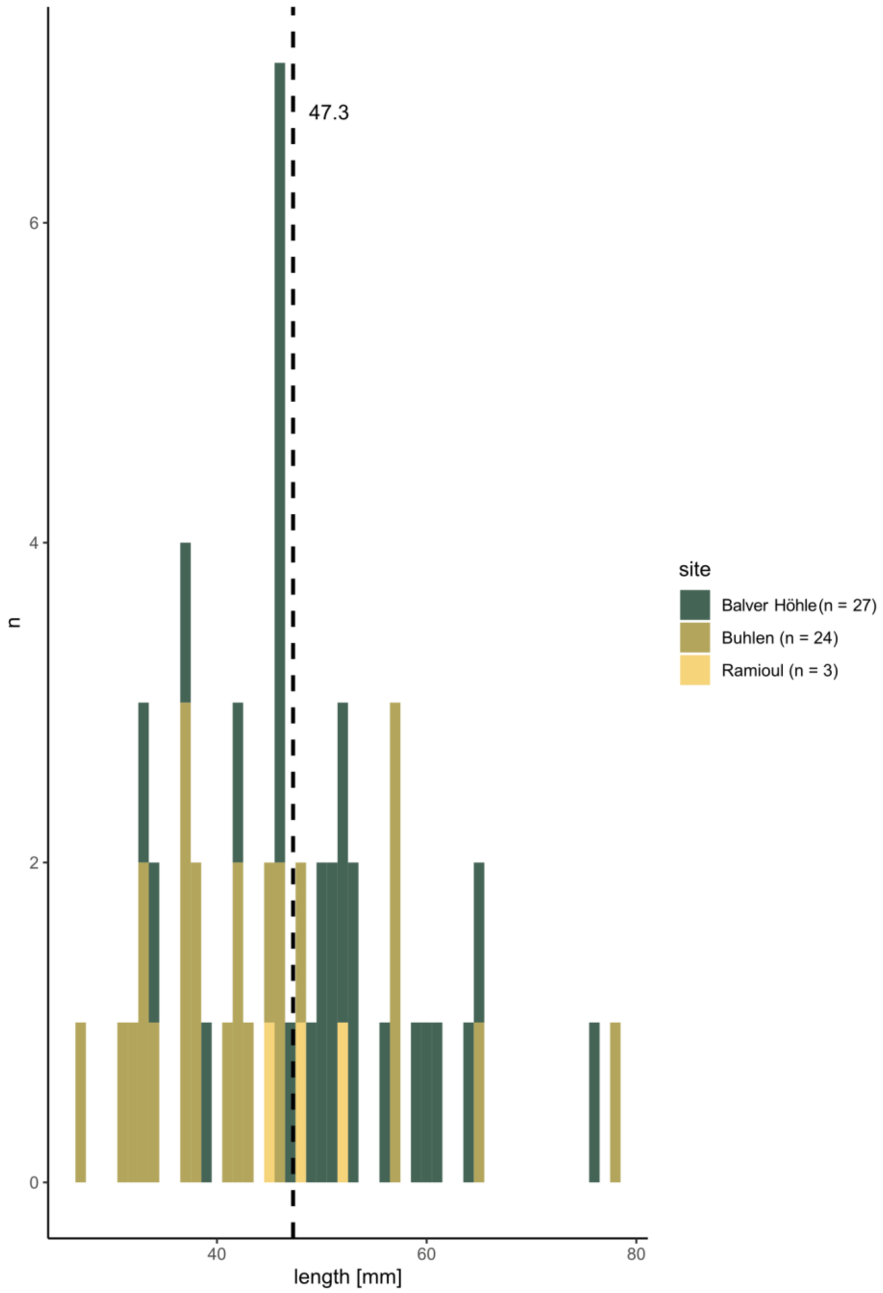

Fig. 64 Maximal length of the *Prądnik scrapers* from Buhlen (n = 24), Balver Höhle (n = 27) and Ramioul (n = 3). The dashed line indicates the arithmetic mean value.

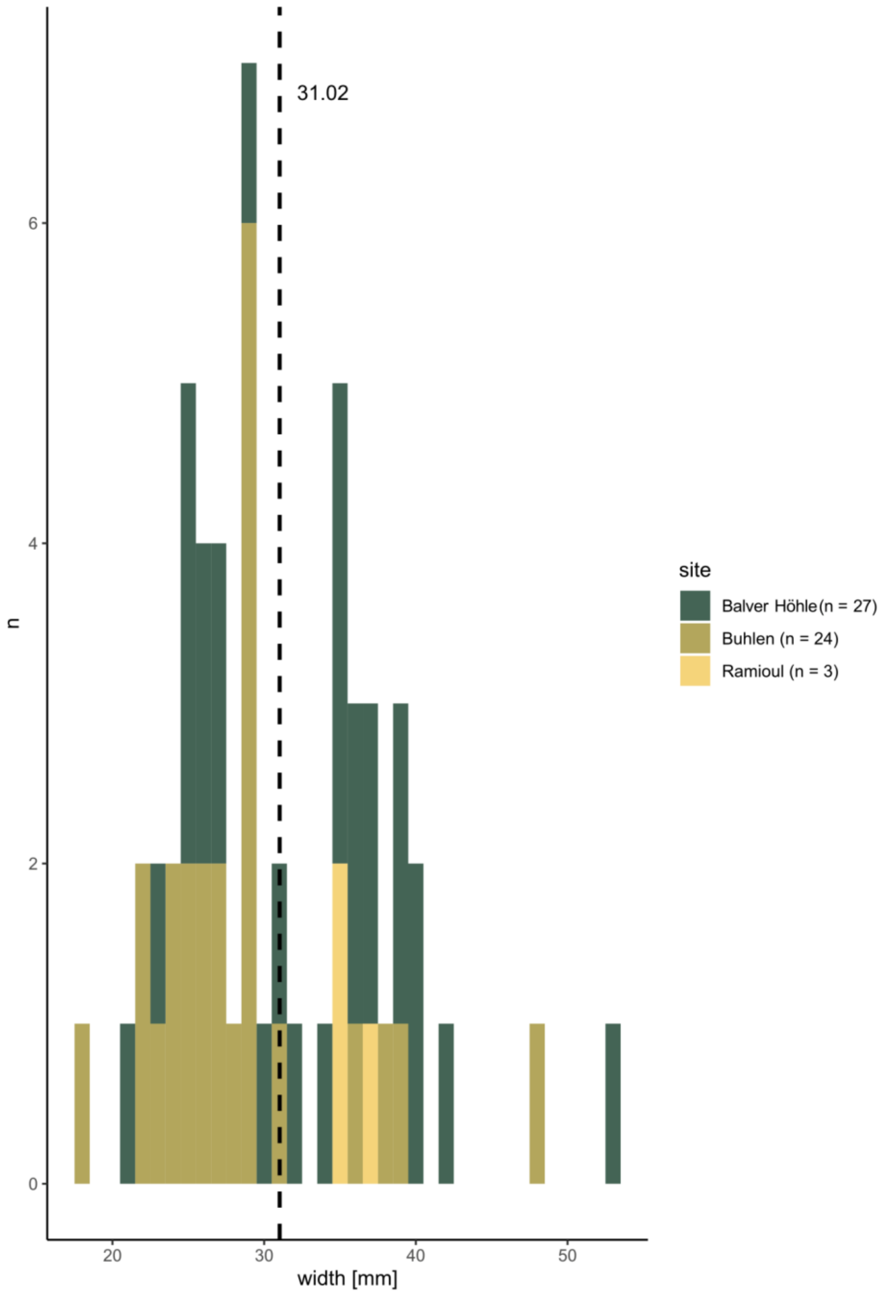

Fig. 65 Maximal width of the *Prądnik scrapers* from Buhlen (n = 24), Balver Höhle (n = 27) and Ramioul (n = 3). The dashed line indicates the arithmetic mean value.

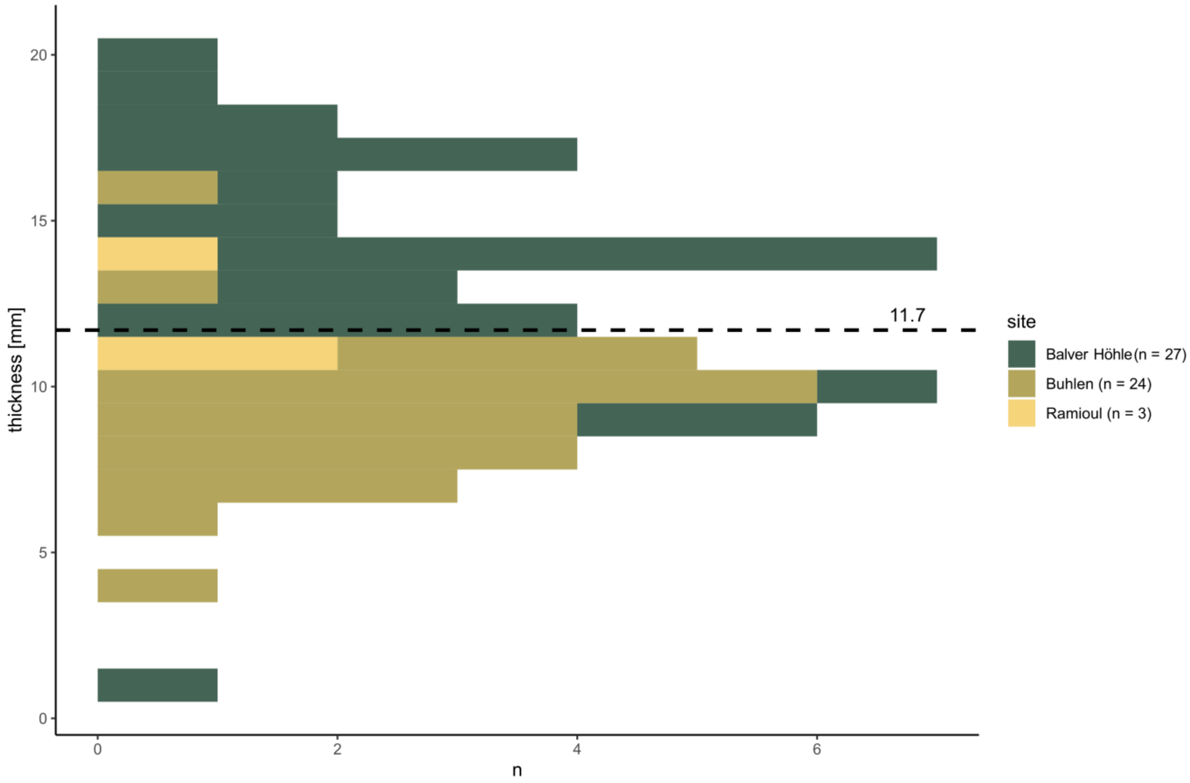

Fig. 66 Maximal thickness of the *Prądnik scrapers* from Buhlen (n = 24), Balver Höhle (n = 27) and Ramioul (n = 3). The dashed line indicates the arithmetic mean value.

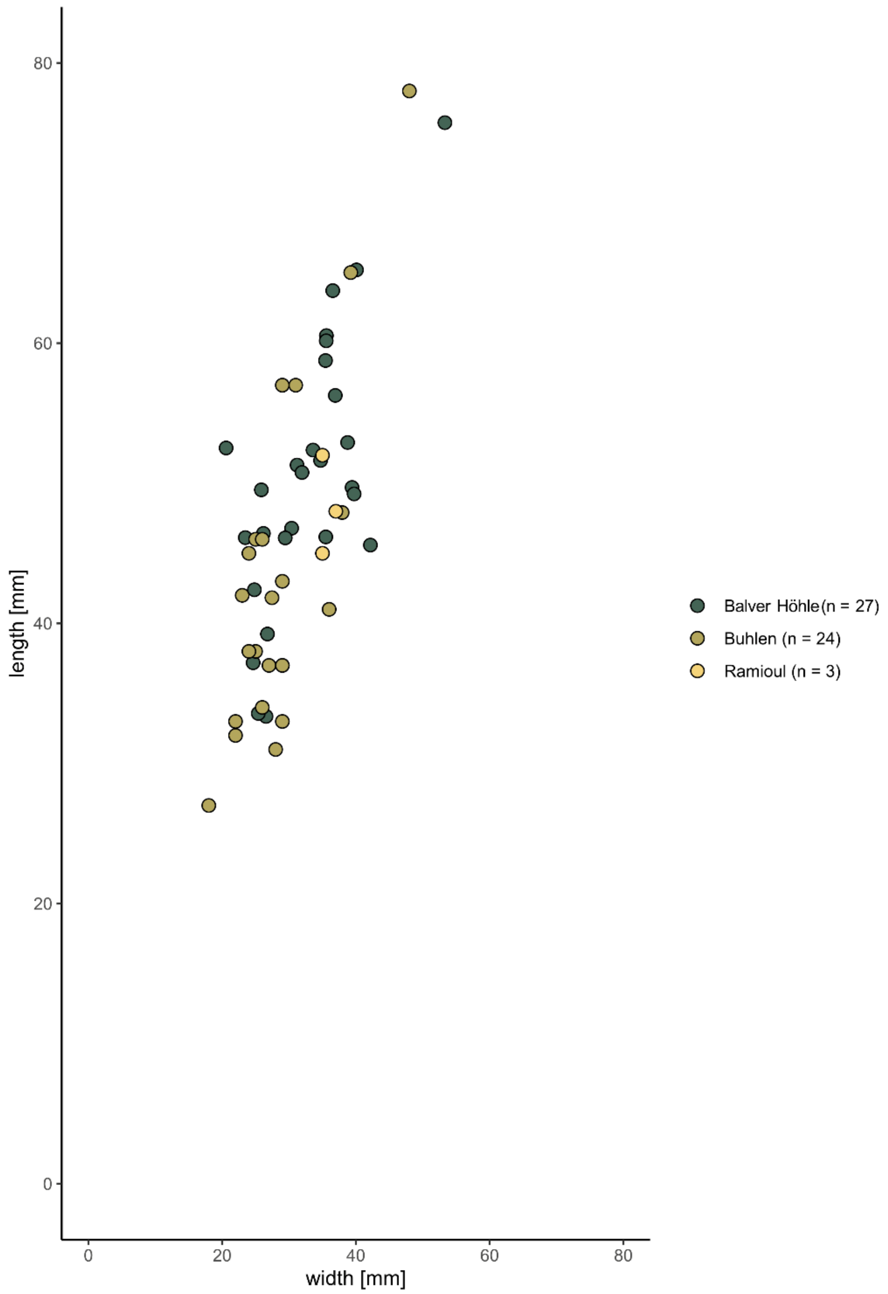

Fig. 67 Length-width ratio of the *Prądnik scrapers* from Buhlen (n = 24), Balver Höhle (n = 27) and Ramioul (n = 3).

5.2.3 Tool back

This part of the qualitative analysis is about the characteristics of the back of the *Keilmesser*. Because locally used siliceous schist is mostly found in blocks, plates or barely rounded pebbles, the raw material piece itself mostly offers convenient striking angles for directed retouch. This aspect is the base to argue that the piece of raw material was carefully selected (Jöris, 2001; Jöris and Uomini, 2019). Following this argument, the raw material shape was integrated into the overall tool design. As a result, only few *Keilmesser* show clear traces of distinct knapping along the back.

This general observation is applicable to the studied assemblage from Buhlen. N = 46 pieces of the n = 111 complete *Keilmesser* are characterised by a natural back that is either unworked or covered with cortex (**fig. 68**). Some pieces with a natural cortex back display additional minimal retouch (n = 29). N = 18 artefacts can be described as partly retouched, n = 18 as retouched.
Additionally, the thickness of the tool back was also recorded at the most pronounced part of the back (**fig. 72**). The thickness of the back ranges for the complete Keilmesser from 4.0 mm to 26.8 mm with an arithmetic mean of 11.9 mm.

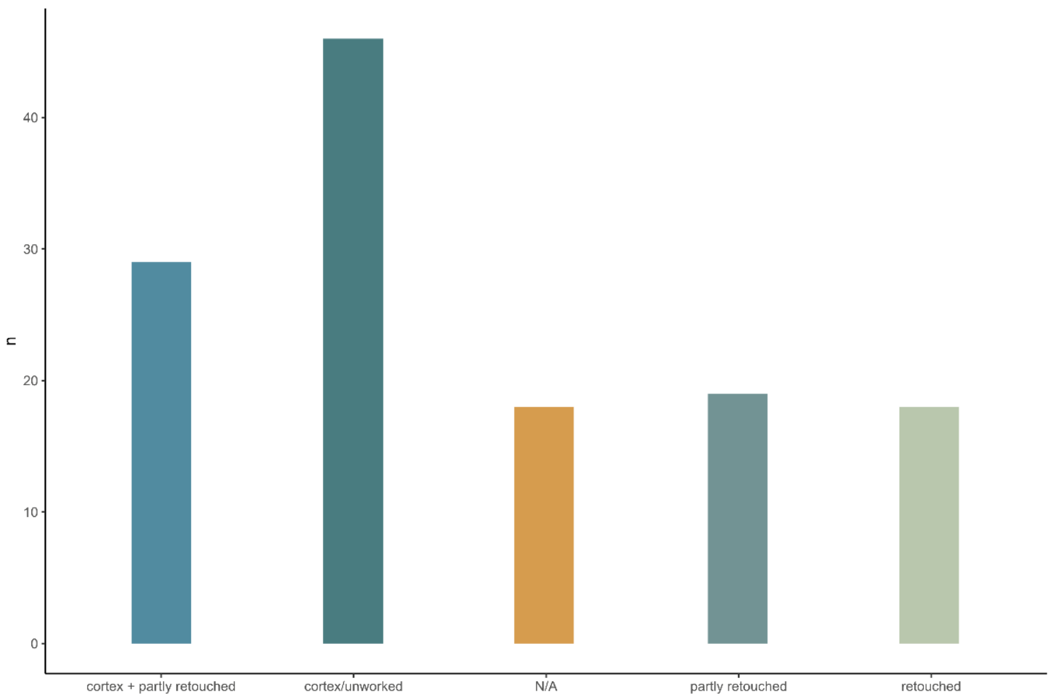

Fig. 68 Characteristics of the back of the complete *Keilmesser* (n = 111) from Buhlen.

A similar situation can be found for the *Keilmesser* from Balver Höhle (**fig. 69**). The majority of the tools with n = 77 artefacts do not display any work traces along the back of the tool. Frequently, the tools show small areas of retouch combined with the natural, unworked cortex (n = 35). The partly retouched back is characteristic for n = 23 artefacts, while n = 23 pieces show distinct retouch.
The thickness measurements of the back at its maximum extend was taken for all complete *Keilmesser* from Balve (**fig. 72**). The values ranging between 2.9 mm and 27.9 mm. The arithmetic mean amounts to 12.2 mm.

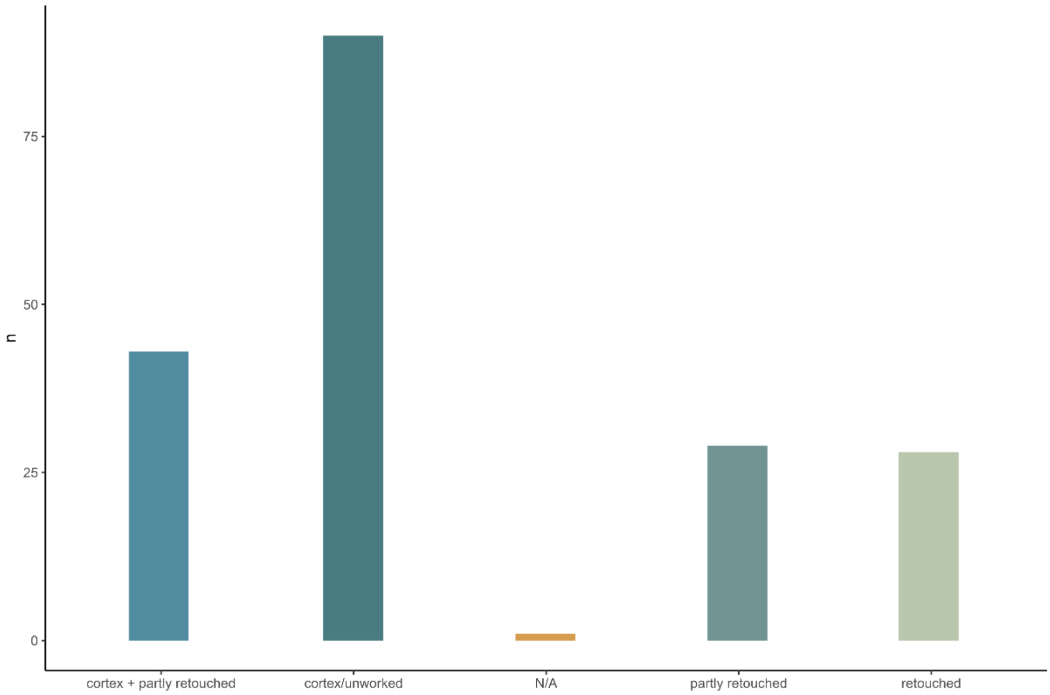

Fig. 69 Characteristics of the back of the complete *Keilmesser* (n = 158) from Balver Höhle.

In Ramioul, n = 2 of the entire nine *Keilmesser* do not show work traces and thus display a natural back (**fig. 70**). Minimal traces of retouch along the back, showing also cortex, can be found on n = 5 artefacts. N = 2 artefacts document clear retouch. Interestingly, the integration of the raw material piece in the tool manufacturing concept also seems to count for the artefacts which are made of flint and not only for the silicified schist tools. The assemblages from Ramioul is extremely small, but it shows that six out of eight flint *Keilmesser* are characterised by an either natural or slightly retouched back.
Additionally, the thickness of the tool back was also recorded, leading to a minimum value of 6.0 mm and a maximum of 21.0 mm for the artefacts from Ramioul (**fig. 72**). The mean value is 14.1 mm.

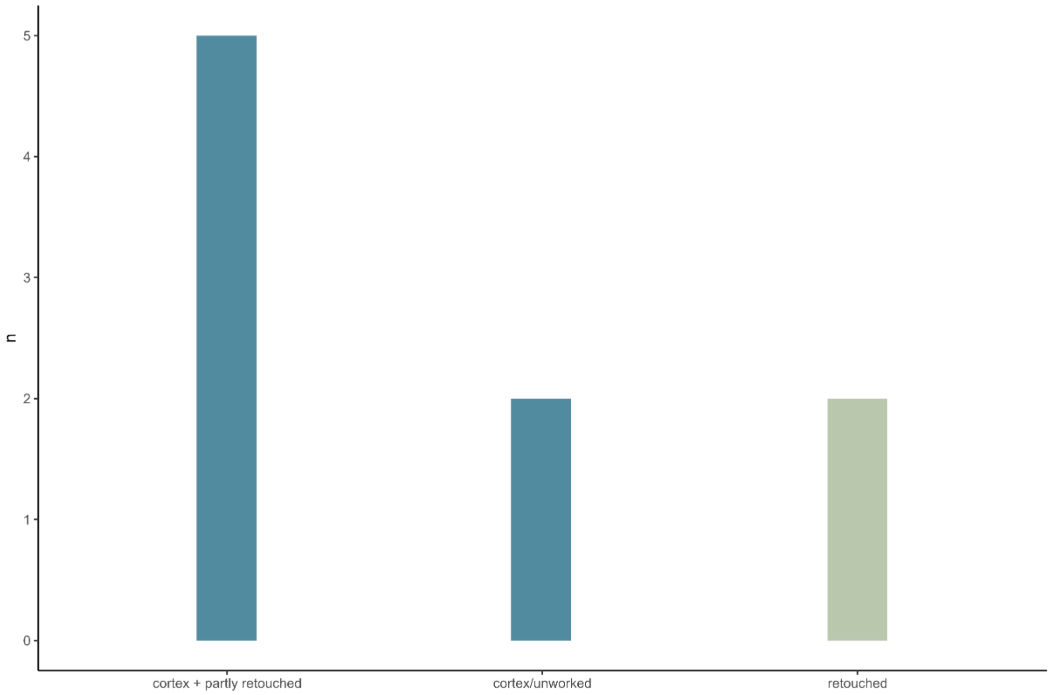

Fig. 70 Characteristics of the back of the complete *Keilmesser* (n = 9) from Ramioul.

The three assemblages together document a clear picture (**fig. 71**). The back of these analysed *Keilmesser* is predominantly characterised by the absence of working traces (n = 125) or minimal modifications (n = 69). This makes 69.8% of the artefacts, which can be described as tools with a natural back. Only for a small amount of 15.5% of all *Keilmesser*, a distinct modification (retouch) can be documented.

Additionally, the thickness measurements of the back measured on all complete *Keilmesser* lead to similar ranges and arithmetic mean values for the three sites (**fig. 72**). The measurements taken together result in a range from 2.9 mm to 27.9 mm. The arithmetic mean value is reflected by the value 12.1 mm.

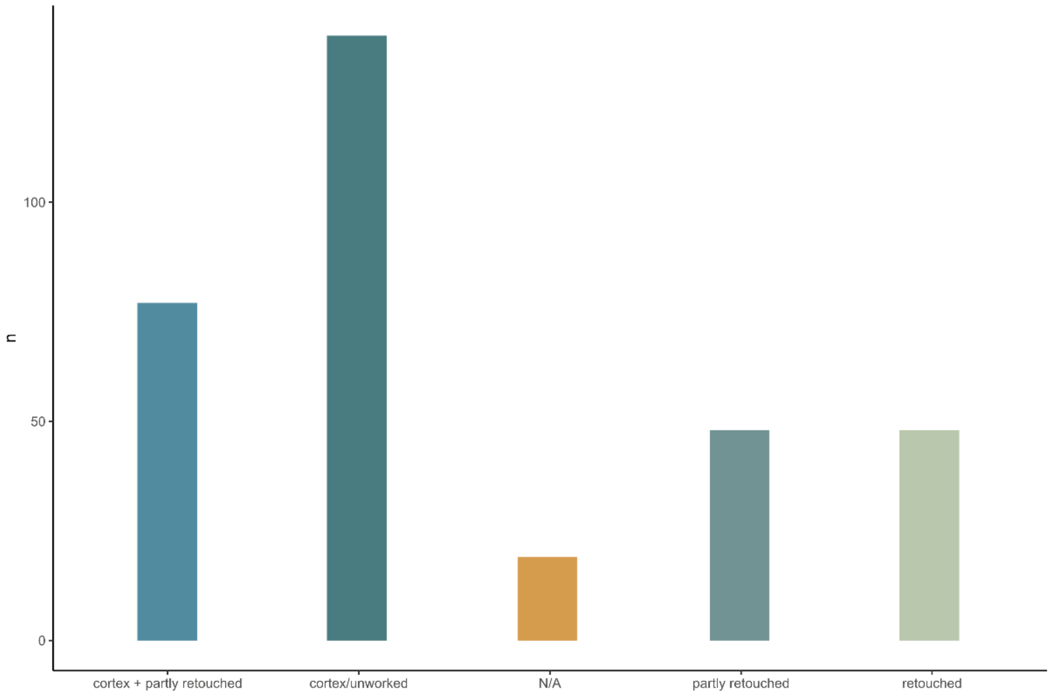

Fig. 71 Characteristics of the back of the complete *Keilmesser* from Buhlen (n = 111), Balver Höhle (n = 158) and Ramioul (n = 9).

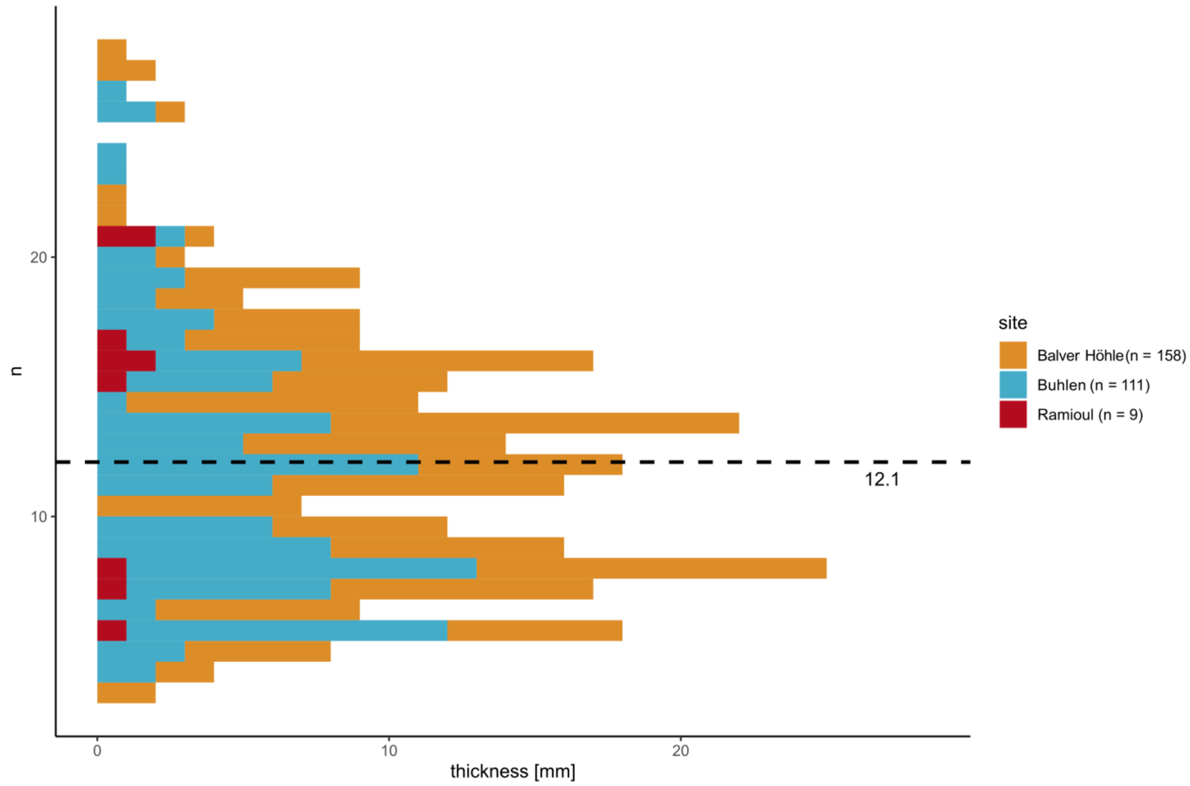

Fig. 72 Maximal thickness back of the *Keilmesser* from Buhlen (n = 111), Balver Höhle (n = 158) and Ramioul (n = 9). The dashed line indicates the arithmetic mean value.

The characteristics of the tool back are also of interest concerning the *Prądnik scrapers*. Additionally, the retouch of the active edge opposed to the back is mentioned, too.

In Buhlen, the backs of the *Prądnik scrapers* are most often partly retouched (n = 10), sometimes even entirely retouched (n = 9; **fig. 73**). The fewest tools still display cortex (n = 3) or cortex with little retouch (n = 2) along the back. At the most pronounced part, the backs of the *Prądnik scrapers* have a thickness of 1.0 mm to 11.0 mm (**fig. 77**). The arithmetic mean amounts to 5.5 mm.

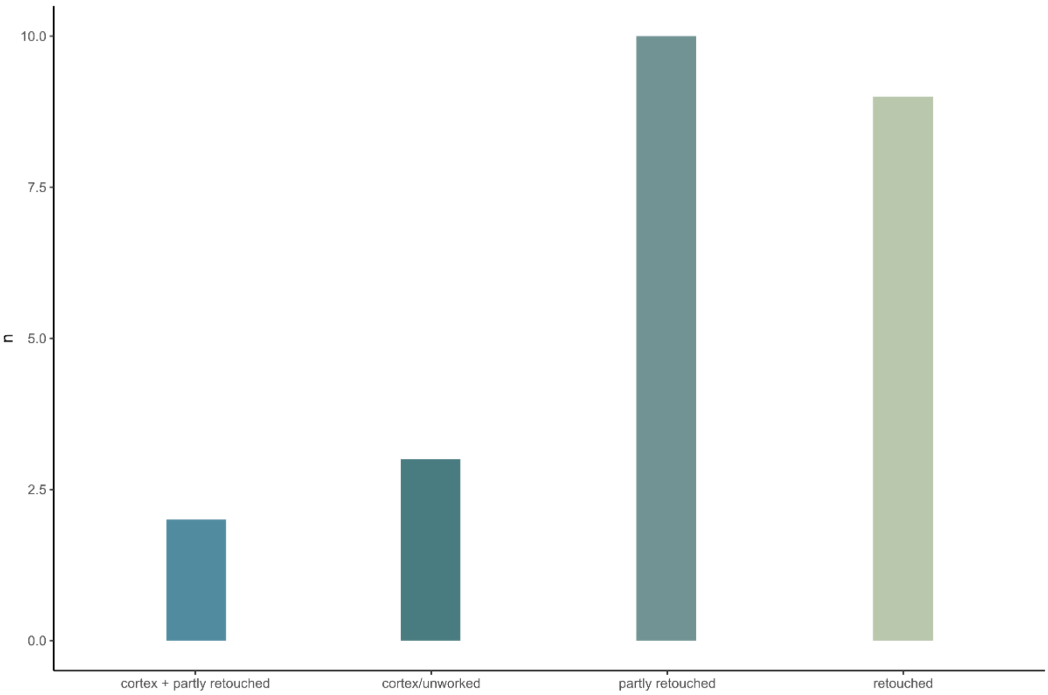

Fig. 73 Characteristics of the backs of the complete *Prądnik scrapers* (n = 24) from Buhlen.

Comparable is the situation in Balve (**fig. 74**). The *Prądnik scrapers* from Balve are also mainly partly retouched (n = 11) along the back. Definite retouch is visible on n = 5 *Prądnik scrapers.* On the remaining tools could either cortex (n = 8) or cortex combined with slight retouch (n = 3) be documented. The minimum back thickness for the *Prądnik scrapers* is 4.6 mm and the maximum is 18.1 mm with a mean value of 9.9 mm (**fig. 77**).

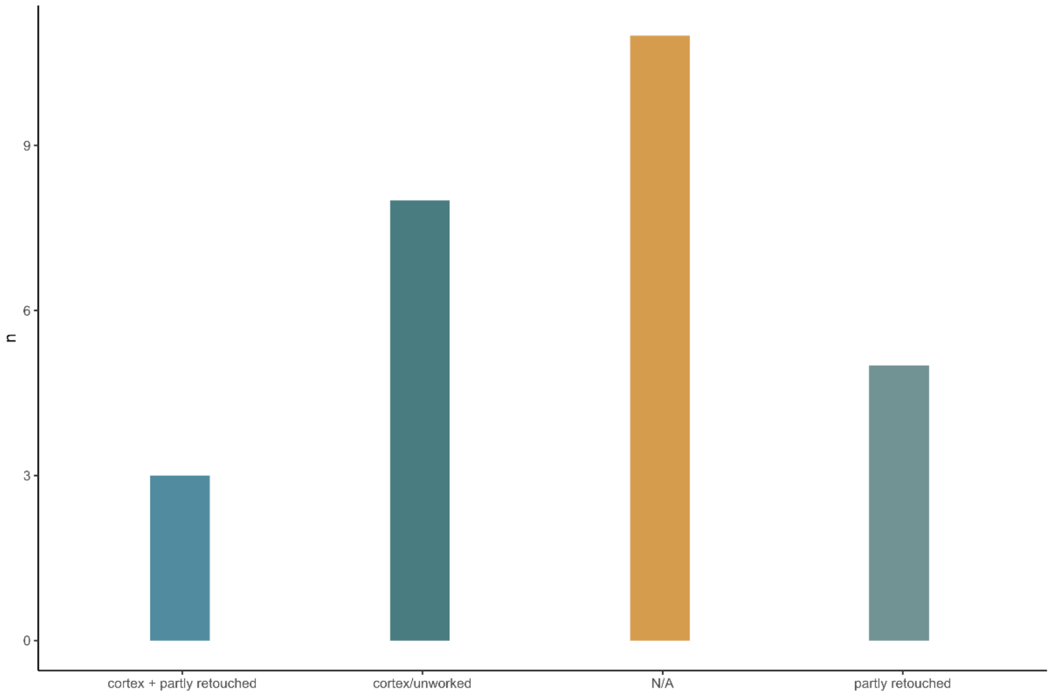

Fig. 74 Characteristics of the backs of the complete *Prądnik scrapers* (n = 27) from Balver Höhle.

The *Prądnik scrapers* from the assemblage in Ramioul are retouched (n = 3) in the back area (**fig. 75**). Additionally, the thickness of the tool back was recorded, leading to a minimum value of 5.0 mm and a maximum of 6.0 mm (**fig. 77**).

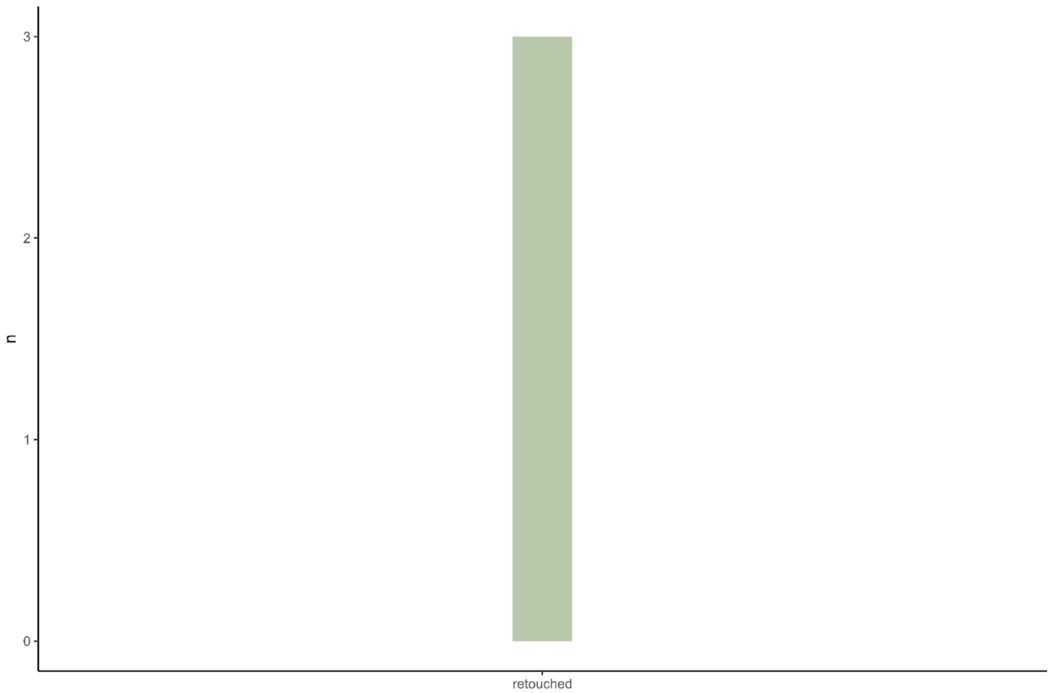

Fig. 75 Characteristics of the back of the complete *Prądnik scrapers* (n = 3) from Ramioul.

The results from this analysis are contrary to the ones from the *Keilmesser* (**fig. 76**). While the *Keilmesser* were most often not worked along the back, the *Prądnik scrapers* clearly display working traces and modifications. Modifications such as (partial) retouch taken together lead to a ratio of 70.4% (n = 38) to 29.6% (n = 16) of the tools. The 29.6% of the *Prądnik scrapers* are thus natural or only slightly modified along the back.
The backs of all *Prądnik scrapers* from Buhlen, Balve and Ramioul have a thickness at its most pronounced part of 4.0 mm up to 20.4 mm, leading to a mean value of 7.7 mm (**fig. 77**).

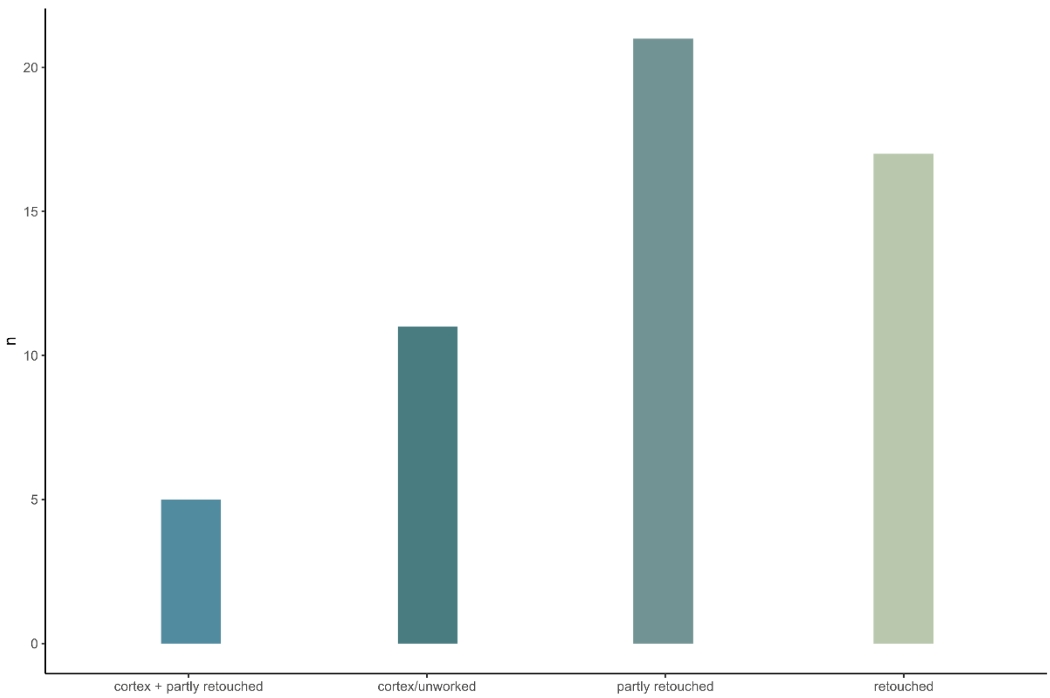

Fig. 76 Characteristics of the backs of the complete *Prądnik scrapers* from Buhlen (n = 24), Balver Höhle (n = 27) and Ramioul (n =3).

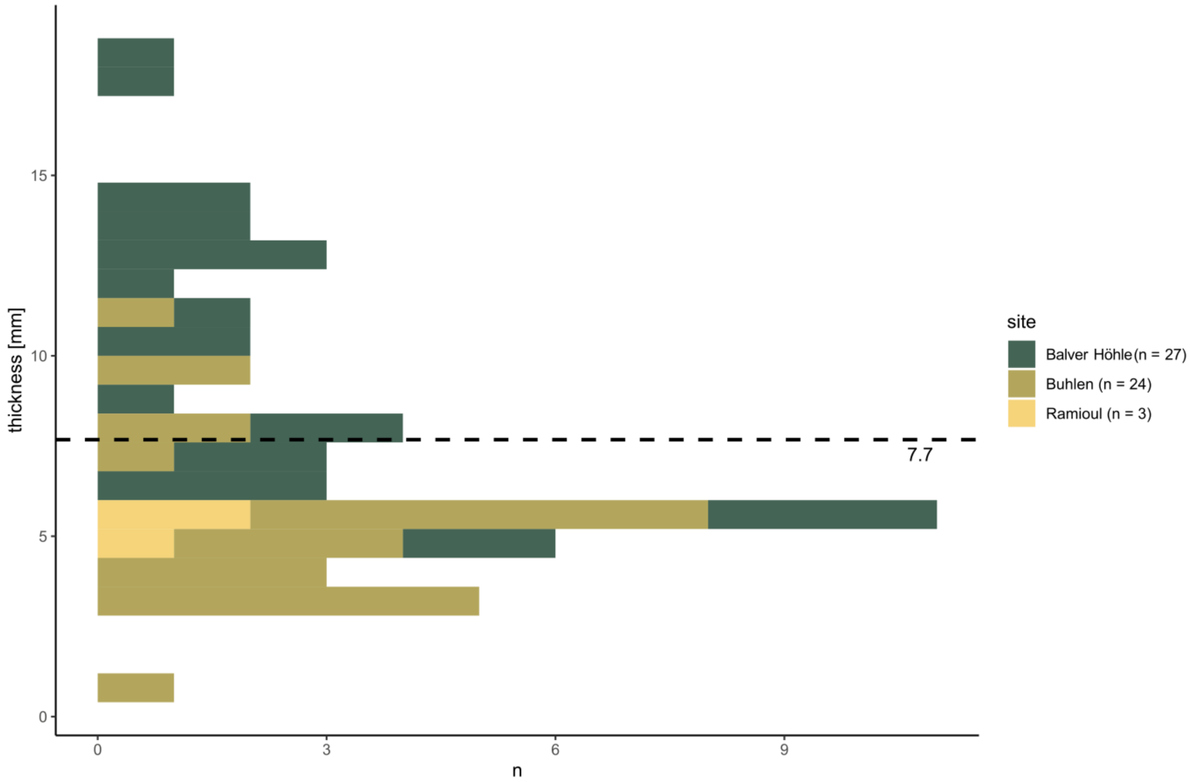

Fig. 77 Maximal back thickness of the *Prądnik scrapers* from Buhlen (n = 24), Balver Höhle (n = 27) and Ramioul (n = 3). The dashed line indicates the arithmetic mean value.

5.2.4 Active edge retouch

Another recorded attribute was the retouch along the active edge. The active edges of the *Keilmesser* from Buhlen are to a percentage of 81.5% (n = 106) bifacially retouched, some artefacts are semi-bifacially retouched (14.6%, n = 19; **fig. 78**).

The *Keilmesser* from Balve do also mainly display a bifacially edge retouch (74.4%, n = 142), followed by tools with a semi-bifacial retouch (20.4%, n = 39; **fig. 79**).

In Ramioul, the *Keilmesser* are either bifacially retouched (44.4%, n = 4) or semi-bifacially retouched (44.4%, n = 4; **fig. 80**).

Keilmesser from the three sites are by a majority bifacially retouched (76.4%, n = 252), some are semi-bifacially retouched (18.8%, n = 62) and only a few pieces are unifacially retouched (3.3%, n = 11; **fig. 81**).

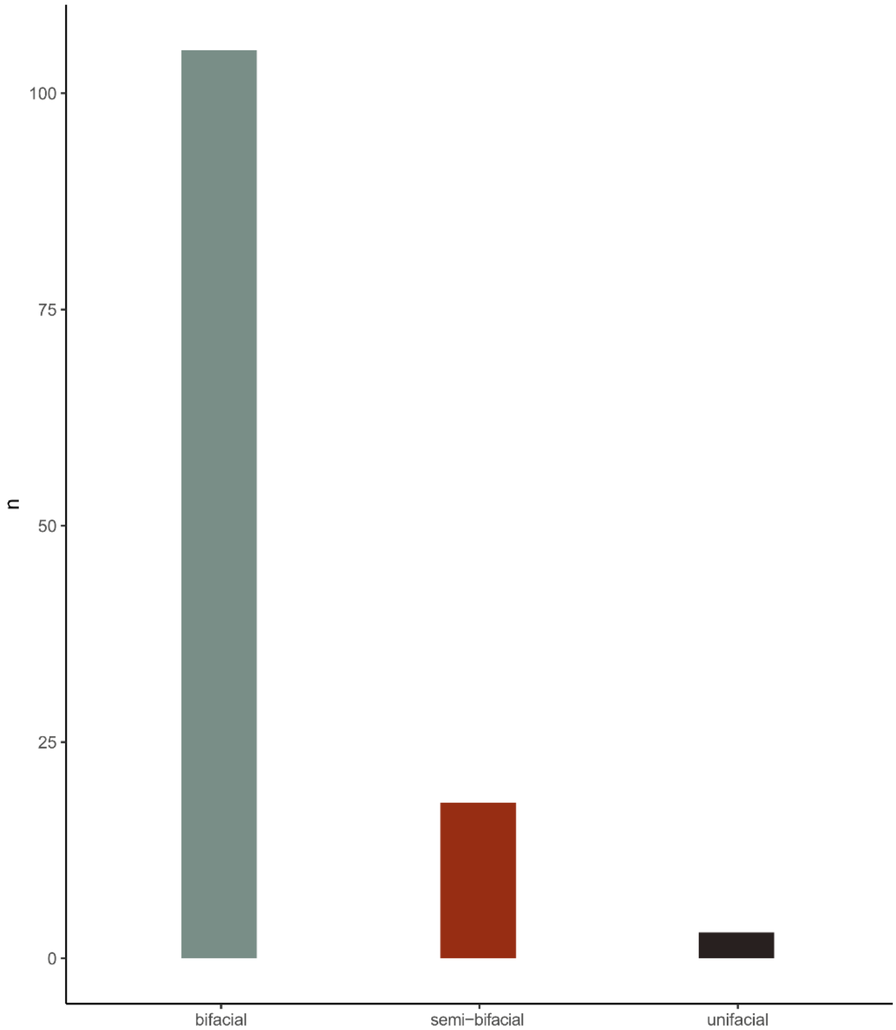

Fig. 78 Retouch type along the active edge of complete *Keilmesser* (n = 111) and *Keilmesser* tips (n = 15) from Buhlen.

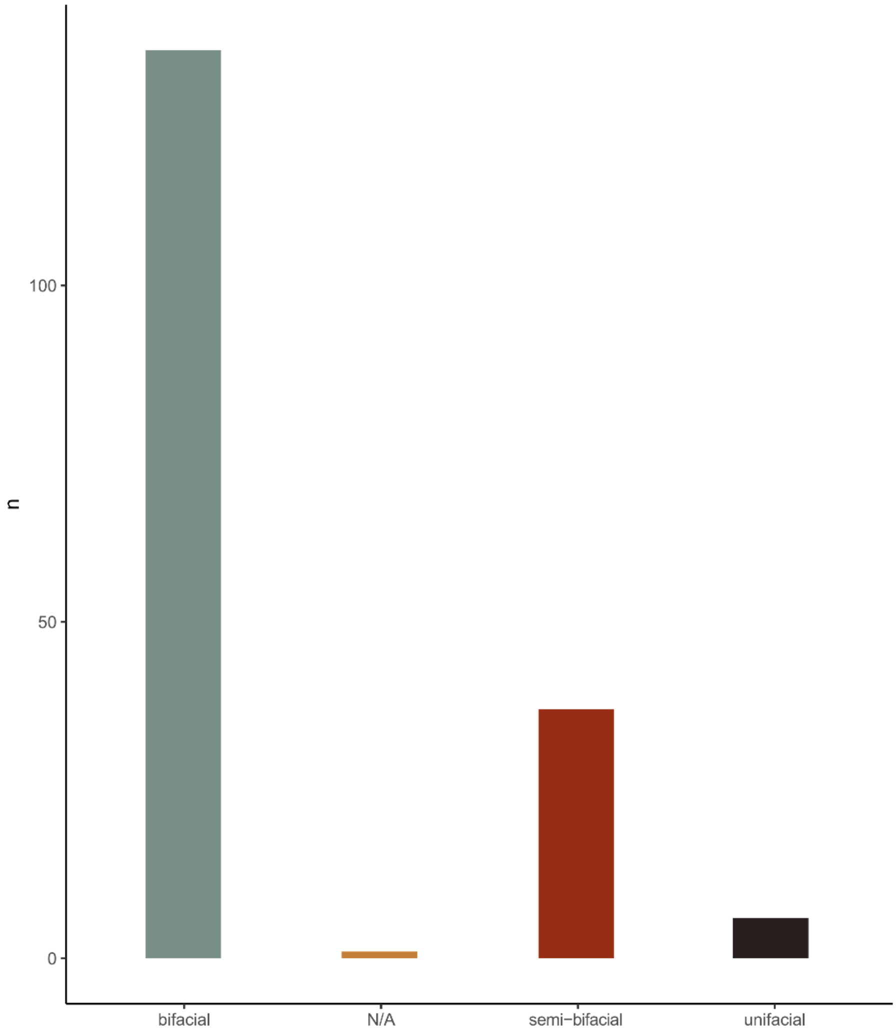

Fig. 79 Retouch type along the active edge of complete *Keilmesser* (n = 158) and *Keilmesser* tips (n = 21) from Balver Höhle. For a small part of the assemblage, this analysis was not done (N/A).

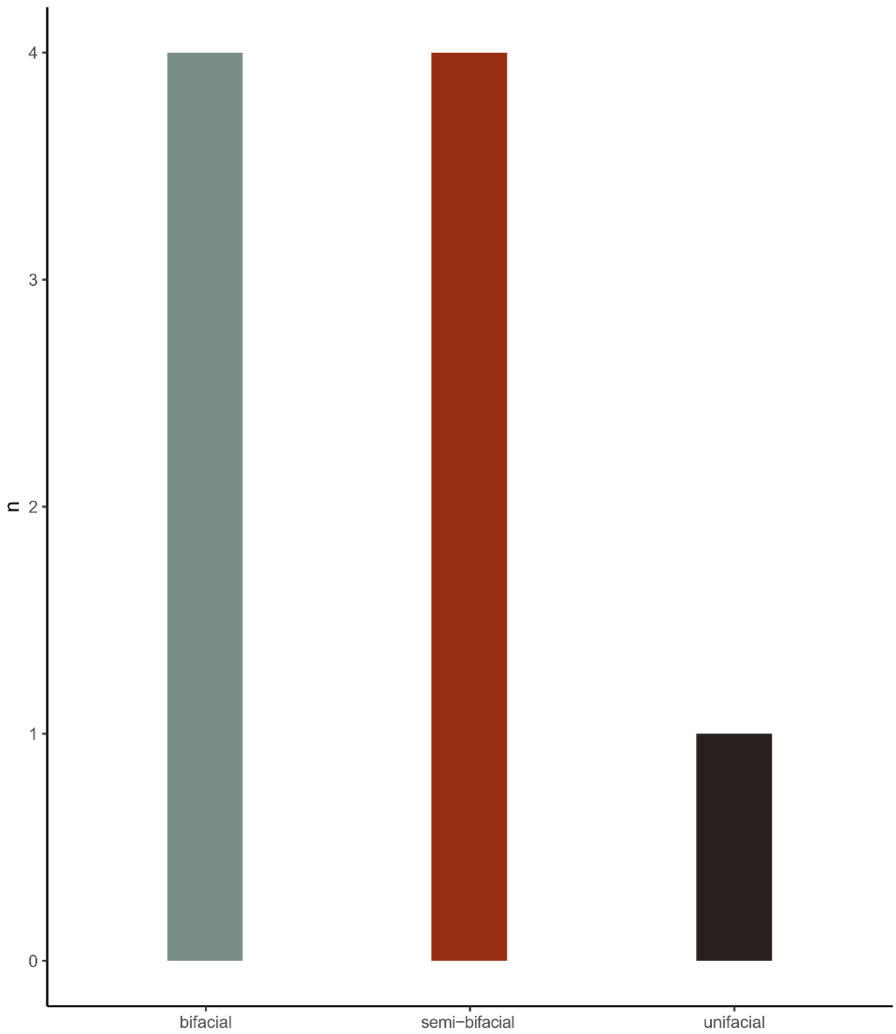

Fig. 80 Retouch type along the active edge of complete *Keilmesser* (n = 111) from Ramioul.

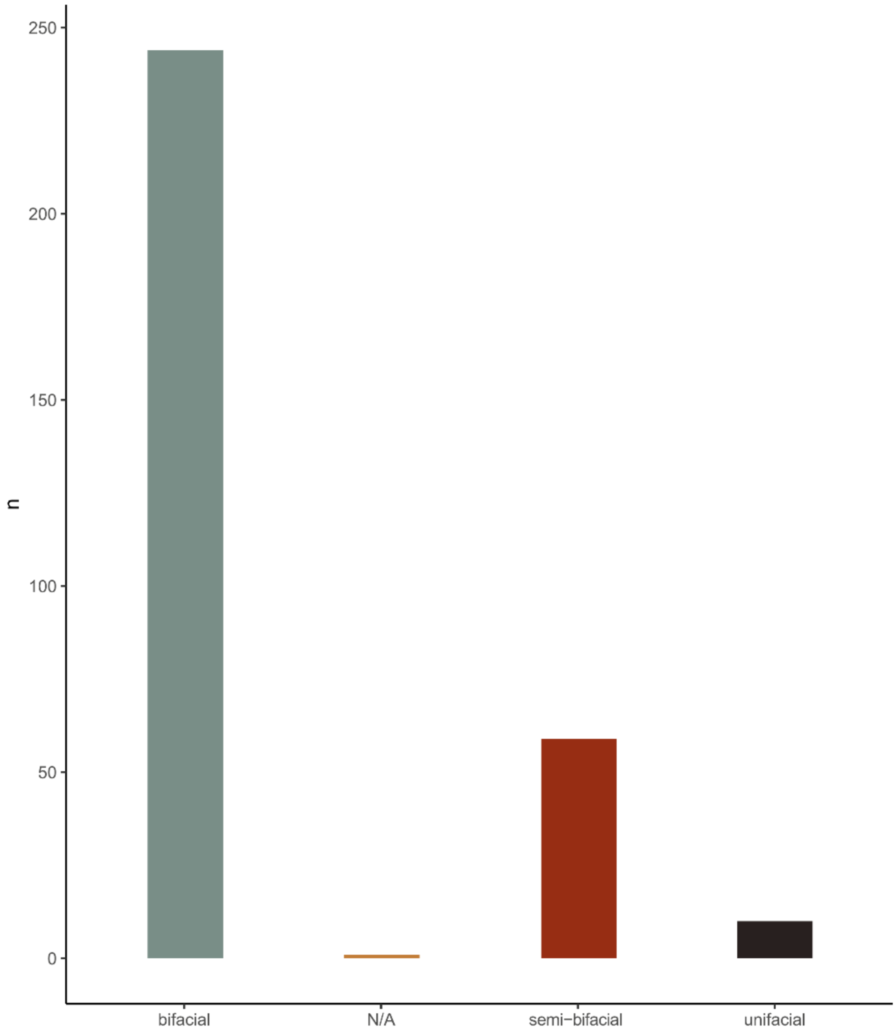

Fig. 81 Retouch type along the active edge of complete *Keilmesser* and *Keilmesser* tips from Buhlen (n = 111; n = 15), Balver Höhle (n = 158; n = 21) and Ramioul (n = 9). For a small part of the assemblage, this analysis was not done (N/A).

The active edge retouch was also documented for the *Prądnik scrapers* involved within this study. In Buhlen, the back of the Prądnik scrapers is most often (45.8%, n = 11) opposed to a unifacially retouched active edge (**fig. 82**). Some artefacts are semi-bifacially retouched (29.2%, n = 7) or bifacially retouched (25.0%, n = 6).

In Balve, the active edge opposed to the back is mostly semi-bifacially retouched (44.4%, n = 12), sometimes unifacially retouched (33.3%, n = 9; **fig. 83**). One artefact is bifacially retouched. This analysis was initially not done for a small part of the assemblage (n = 5) and thus the data is missing.

The active edge of the studied *Prądnik scrapers* from Ramioul is either unifacially retouched (66.7%, n = 2) or semi-bifacially retouched (33.3%, n = 1; **fig. 84**).

To summarise these observations, the results concerning the active edge retouch of the *Prądnik scrapers* from the three analysed assemblages stands in contrast to the data recorded for the *Keilmesser* (**fig. 85**). A majority of 40.7% (n = 22) of the *Prądnik* *scrapers* are only unifacailly retouched or 37.0% (n = 20) are semi-bifacially retouched. Some artefacts display a bifacial edge retouch (13.0%, n = 7).

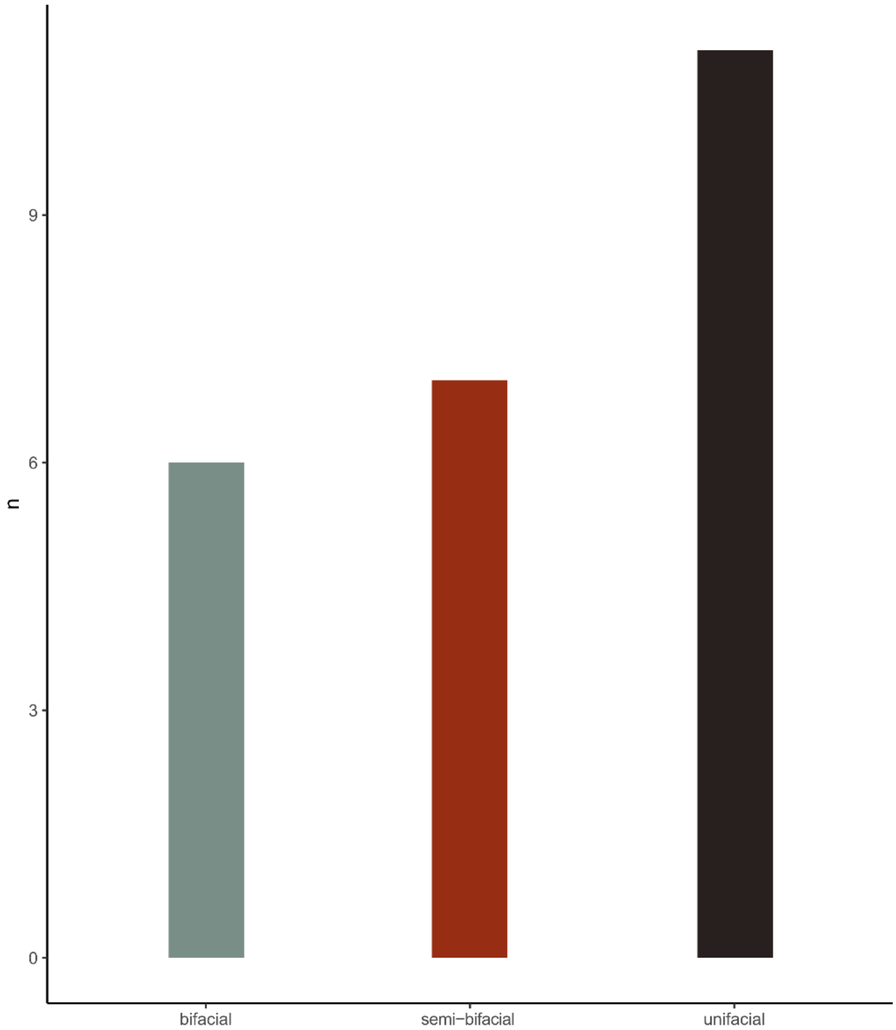

Fig. 82 Retouch type along the active edge of *Prądnik scrapers* (n = 24) from Buhlen.

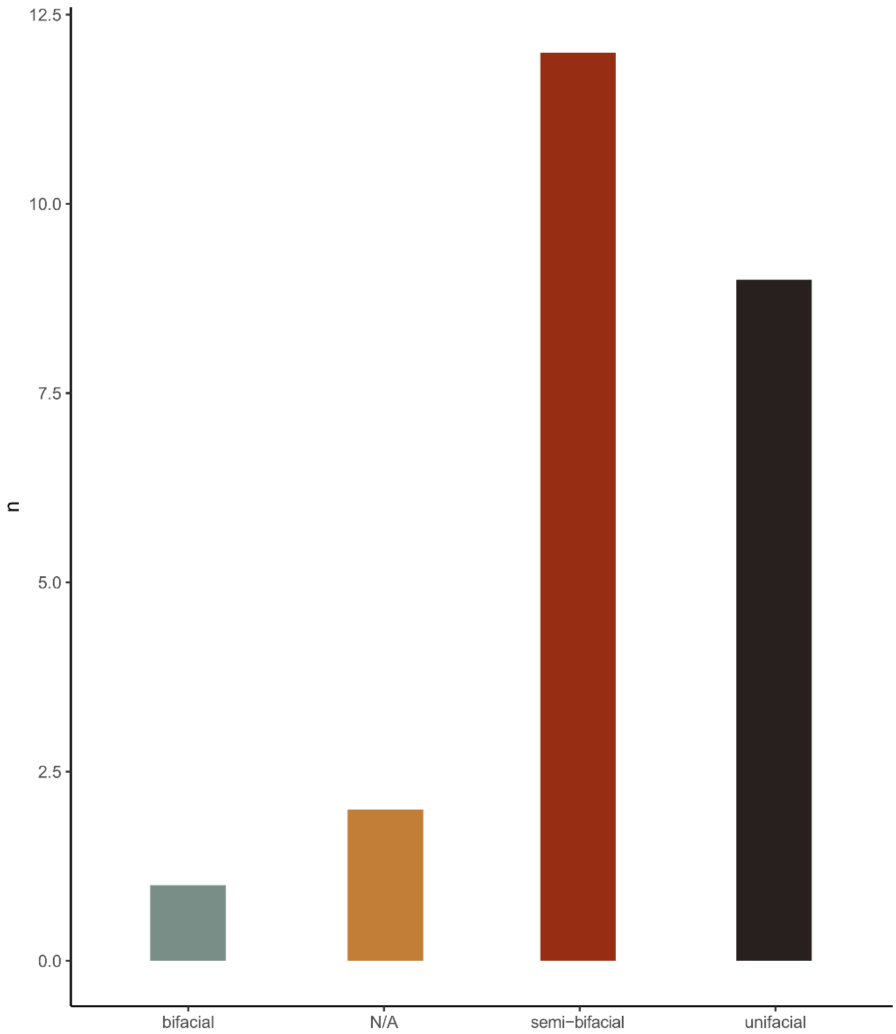

Fig. 83 Retouch type along the active edge of *Prądnik scrapers* (n = 27) from Balver Höhle. For a small part of the assemblage, this analysis was not done (N/A).

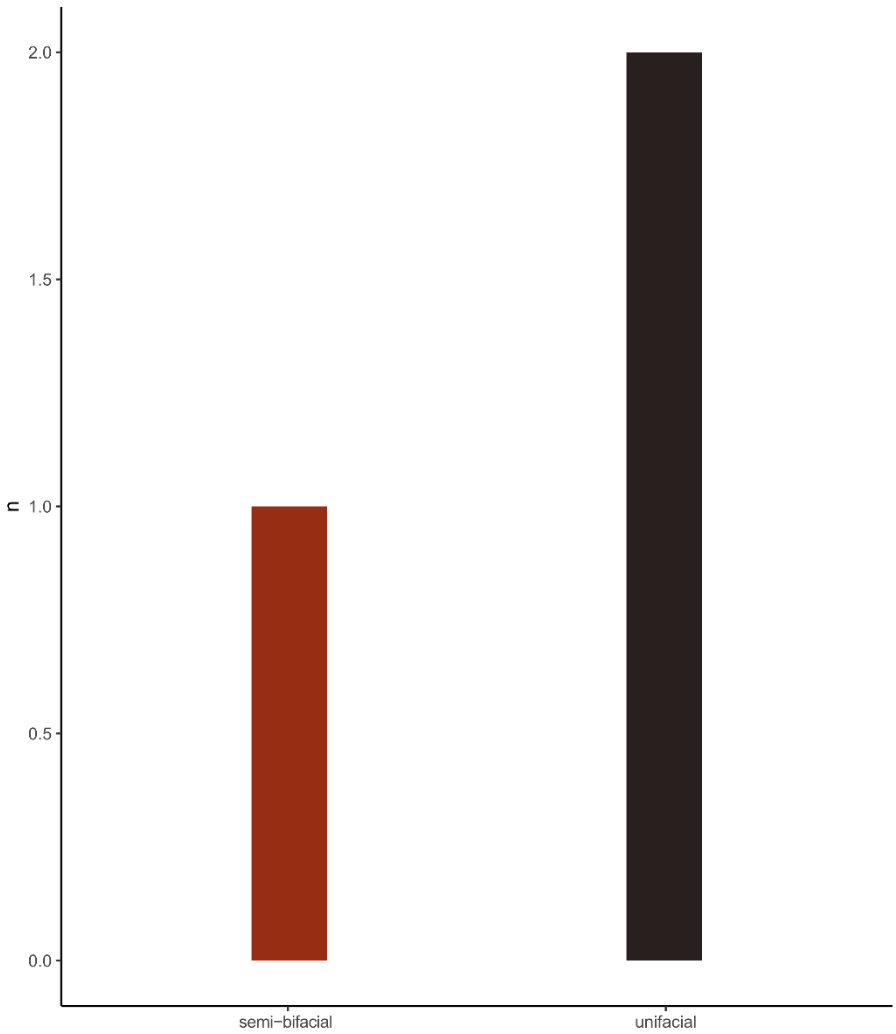

Fig. 84 Retouch type along the active edge of *Prądnik scrapers* (n = 3) from Ramioul.

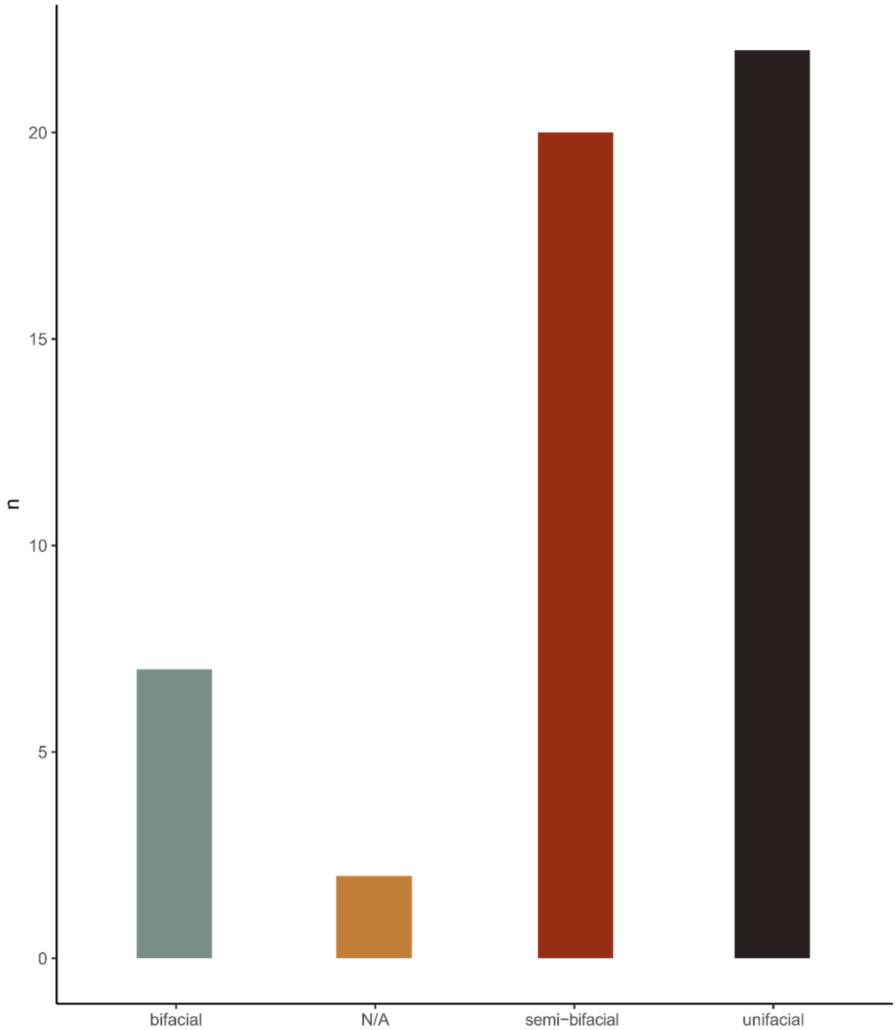

Fig. 85 Retouch type along the active edge of *Prądnik scrapers* from Buhlen (n = 24), Balver Höhle (n = 27) and Ramioul (n = 3). For a small part of the assemblage, this analysis was not done (N/A).

5.2.5 Lateralisation

Based on the asymmetry of *Keilmesser*, tool lateralisation can be defined.
A clear dominance of right-lateral tools can be documented in Buhlen (**fig. 86**, **tab. 12**). With n = 117 artefacts, the right-sided *Keilmesser* represent 90.0% of the studied assemblage. A small amount of n = 10 artefacts were classified as left-lateral tools. For n = 3 *Keilmesser* the lateralisation could not be defined with certainty. Here, it should be pointed out again, that the studied assemblage from Buhlen does not reflect the entire amount of artefacts found in Buhlen. In particular the quantity of selected *Prądnik spalls* is considerably smaller. Thus, the mentioned results differ from already published ones (Jöris, 2001; Jöris and Uomini, 2019).

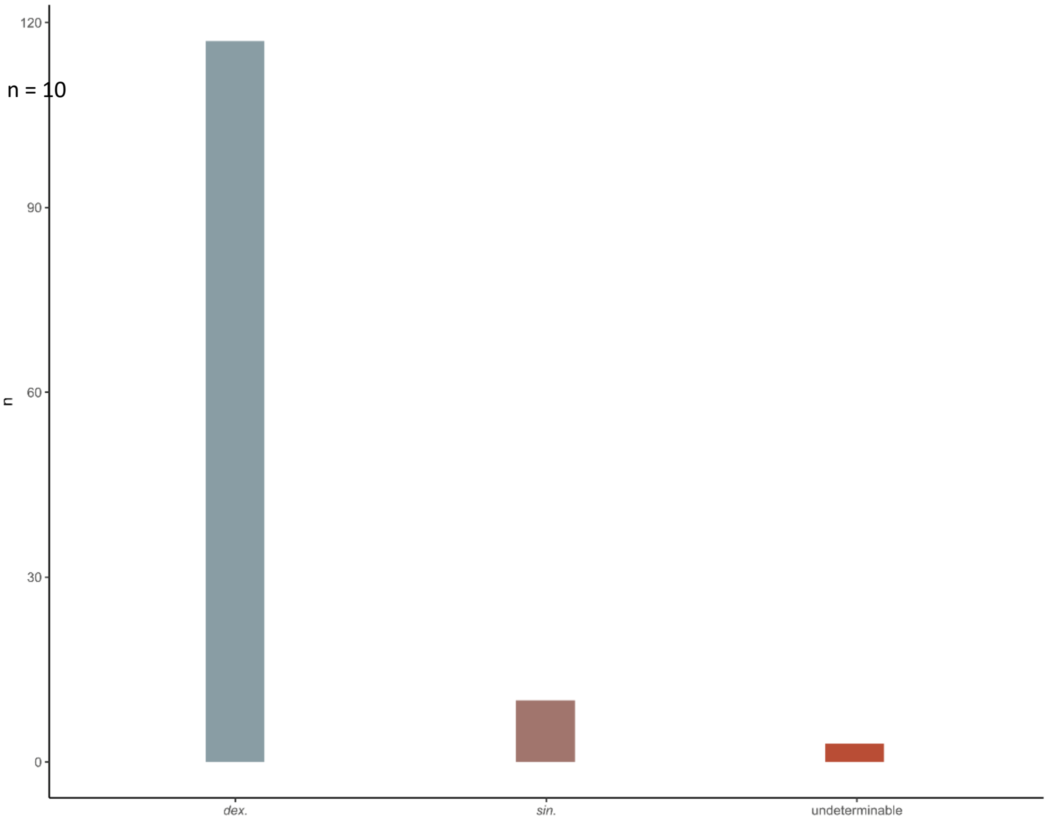

Fig. 86 Determination of the tool lateralisation for the *Keilmesser* (n =130) from Buhlen.

The same trend can be found in the *Keilmesser* assemblage from Balver Höhle (**fig. 87**, **tab. 12**). A clear majority (71.2%, n = 136) of the tools were identified as right-sided artefacts. As left-sided tools count 26.2% (n = 50) of the Keilmesser in Balve. The laterality of n = 5 pieces could not be defined.

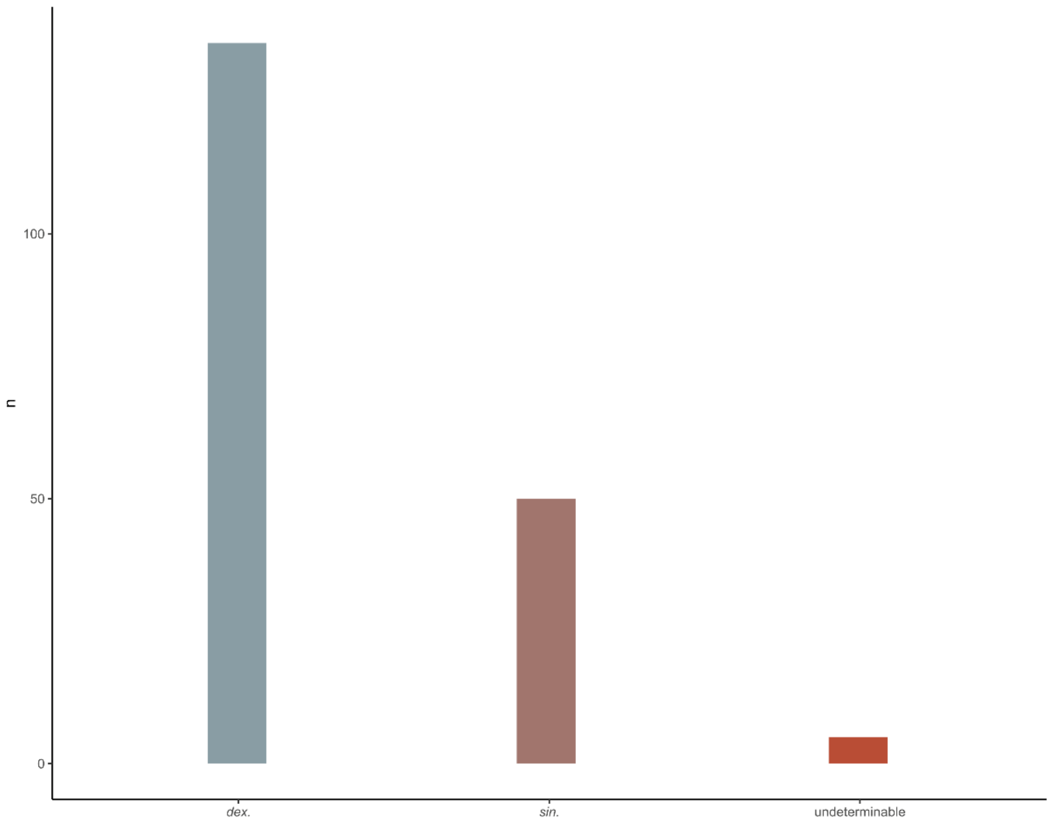

Fig. 87 Determination of the tool lateralisation for the *Keilmesser* (n =191) from Balver Höhle.

The right-sidedness of the *Keilmesser* also prevails in the assemblage from Ramioul (**fig. 88**, **tab. 12**). N = 8 tools could be documented as right-lateral tools, whereas only n = 1 counts as a left-sided tool.

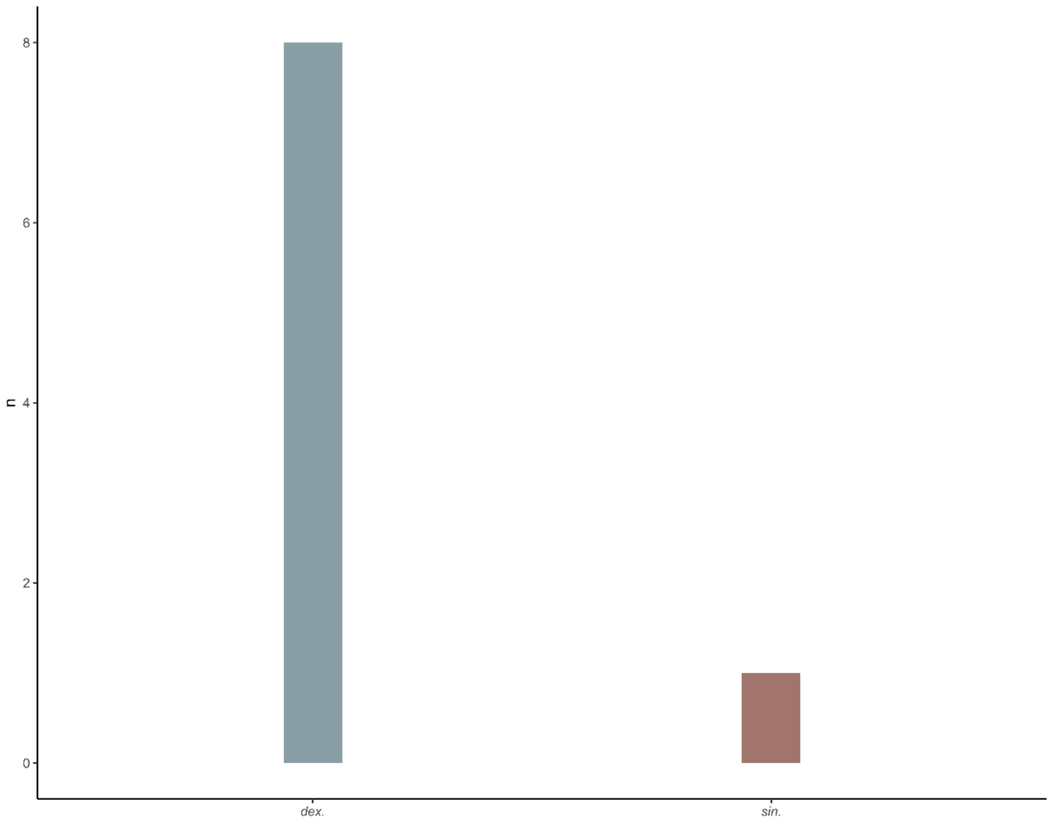

Fig. 88 Determination of the tool lateralisation for the *Keilmesser* (n =9) from Ramioul.

In the three analysed sites, a clear tendency can be named (**fig. 89**, **tab. 12**). The *Keilmesser* are predominantly right-sided, represented by 79.1% of the assemblages. Left-laterality is documented in 18.5% of all *Keilmesser* only.

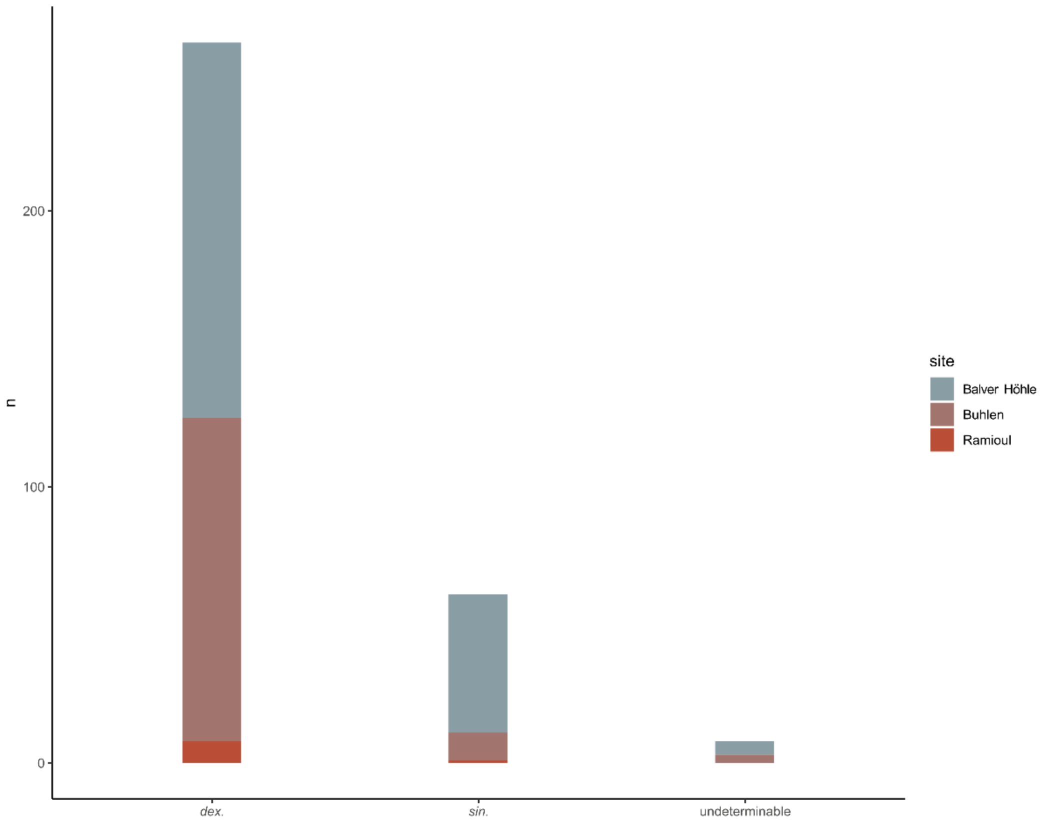

Fig. 89 Determination of the tool lateralisation for the *Keilmesser* from Buhlen (n = 130), Balver Höhle (n = 191) and Ramioul (n = 9).

site		*Keilmesser*			
		sin.	*dex.*	N/A	total
Buhlen	n	10	117	3	**130**
	%	7.7	90.0	2.3	100.0
Balve	n	50	136	5	**191**
	%	26.2	71.2	2.6	100.0
Ramioul	n	1	8	0	**9**
	%	11.1	88.9	0.0	100.0
total	**n**	**61**	**261**	**8**	**330**
	%	18.5	79.1	2.4	100.0

Table 12 Determination of the tool lateralisation for the *Keilmesser* from Buhlen, Balver Höhle and Ramioul.

As *Keilmesser*, *Prądnik scrapers* display a morphological asymmetry. Therefore, the laterality of the *Prądnik scrapers* can be defined in the same way (**tab. 13**). The *Prądnik scraper* from Buhlen illustrate a clear dominance (n = 19) of right lateral tools (**fig. 90**). Only n = 3 *Prądnik scrapers* are documented as left lateral tools. For n = 2 of the in total n = 24 artefacts the tool laterality could not be defined.

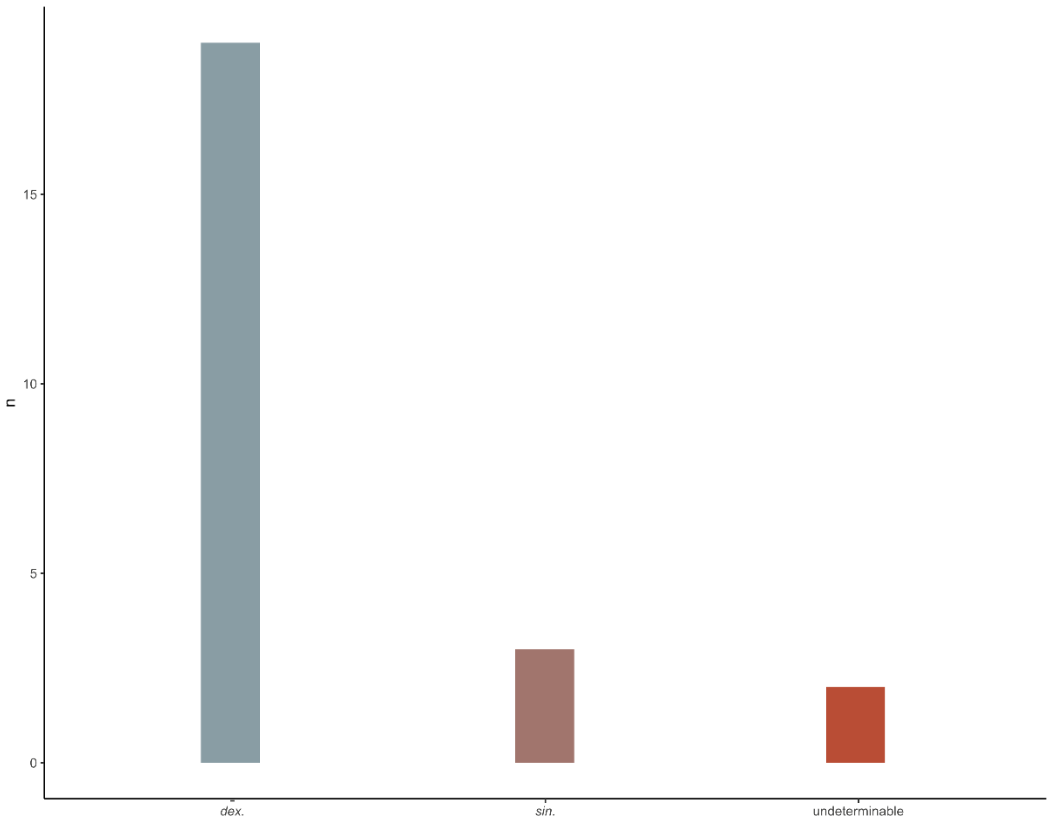

Fig. 90 Determination of the tool lateralisation for the *Prądnik scrapers* (n = 24) from Buhlen.

A similar picture is becoming evident for the *Prądnik scrapers* from Balve (**fig. 91**). By a majority of 85.2% (n = 23), the tools are right-sided. N = 4 *Prądnik scrapers* count as left-sided artefacts.

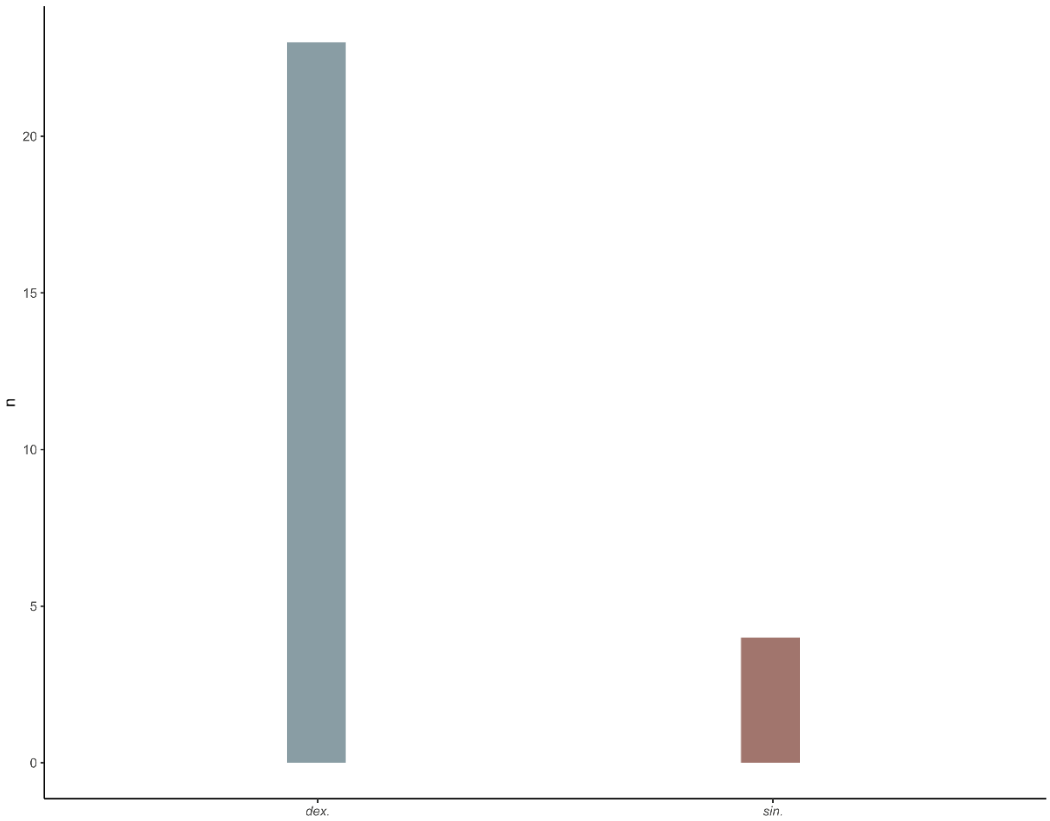

Fig. 91 Determination of the tool lateralisation for the *Prądnik scrapers* (n = 27) from Balver Höhle.

N = 2 of the n = 3 *Prądnik scraper* from Ramioul display a right laterality, the other *Prądnik scraper* is left lateral (**fig. 92**).

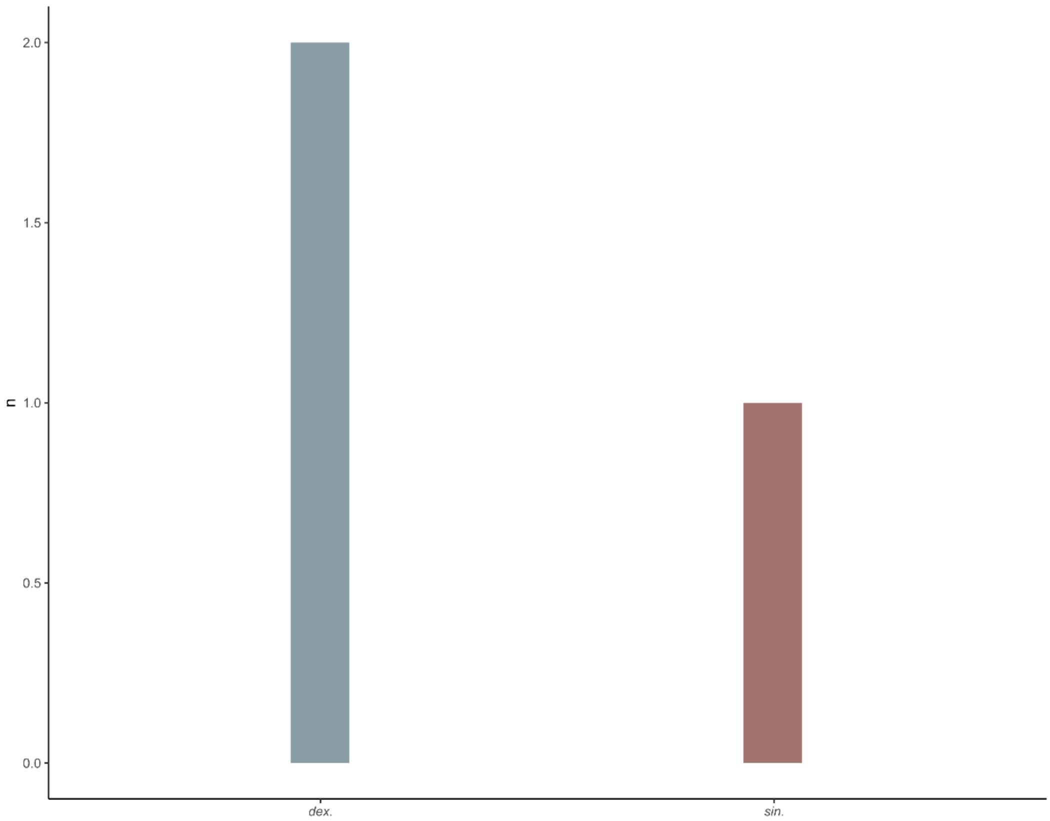

Fig. 92 Determination of the tool lateralisation for the *Prądnik scrapers* (n = 3) from Ramioul.

To summarise, a predominance of right lateral *Prądnik scrapers* can be documented for the three studied sites Buhlen, Balve and Ramioul (**fig. 93**). The ratio of right lateral to left lateral tools is 81.5% (n = 44) to 14.8% (n = 8).

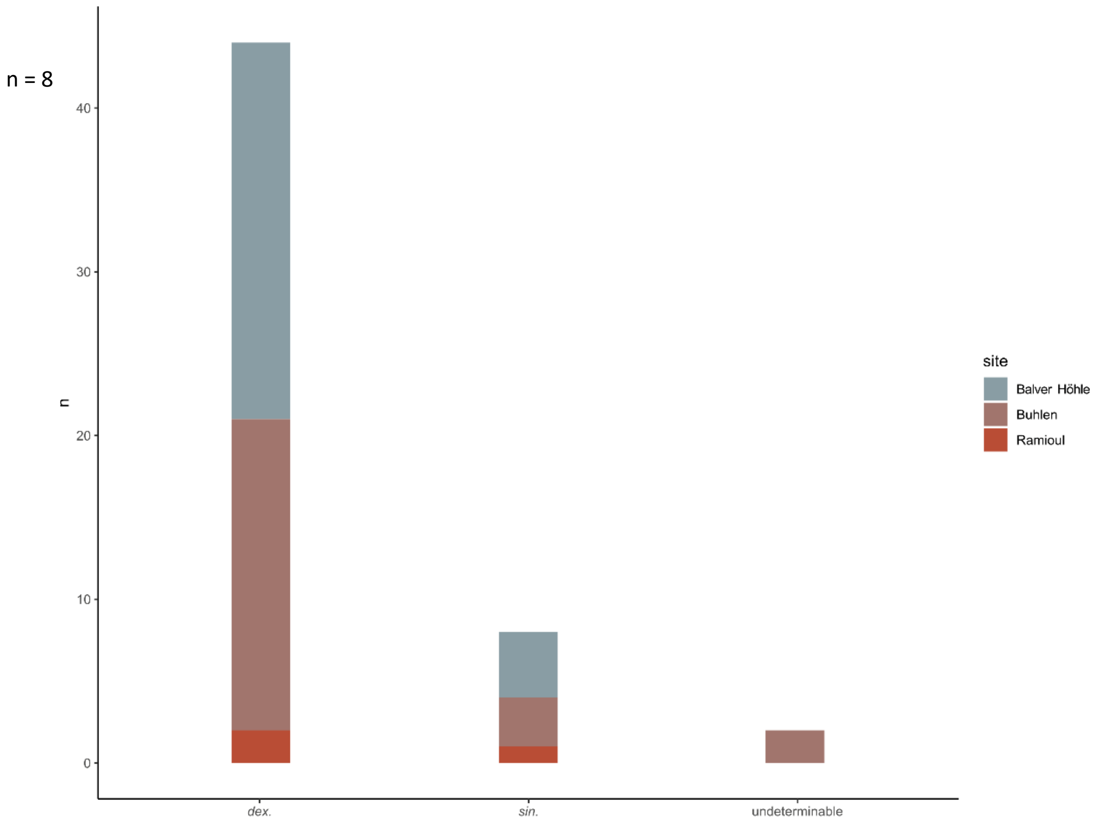

Fig. 93 Determination of the tool lateralisation for the *Prądnik scrapers* from Buhlen (n = 24), Balver Höhle (n = 27) and Ramioul (n = 3). The laterality of n = 2 artefacts could not be determined. These artefacts are excluded from the figure.

site		*Prądnik scraper*			
		sin.	*dex.*	N/A	total
Buhlen	n	3	19	2	**24**
	%	12.5	79.2	8.3	100.0
Balve	n	4	23	0	**27**
	%	14.8	85.2	0.0	100.0
Ramioul	n	1	2	0	**3**
	%	33.3	66.7	0.0	100.0
total	**n**	**8**	**44**	**2**	**54**
	%	14.8	81.5	3.7	100.0

Table 13 Determination of the tool lateralisation for the *Prądnik scrapers* from Buhlen, Balver Höhle and Ramioul.

5.2.6 Morphological shape analysis

The idea, to assign each *Keilmesser* to one of the previously described seven *Keilmesser* shapes were taken up in this subchapter. Only complete *Keilmesser* were involved in this part of the analysis. Due to some transitional morphology, it was not possible to ascribe every artefact strictly to one of the *Keilmesser* shapes. These tools are marked as undeterminable.

In Buhlen n = 111 *Keilmesser* could be assigned to a *Keilmesser* shape (**fig. 94**). While there is no *Königsaue Keilmesser* within the Buhlen assemblage, all other *Keilmesser* shapes are represented. Out of the remaining six different types, one stands out slightly. Exactly one third (n = 37) of the tools are '*Prądnik knives*'. Subsequently, the *Keilmesser* shapes *Buhlen* (n = 20), *Klausennische* (n = 19) and *Balve* (n = 18) a part of the assemblage in about the same sum. Much scarcer are those tools, which can be morphologically assigned to the *Keilmesser* shapes *Bockstein* (n = 5) and *Lichtenberg* (n = 6).

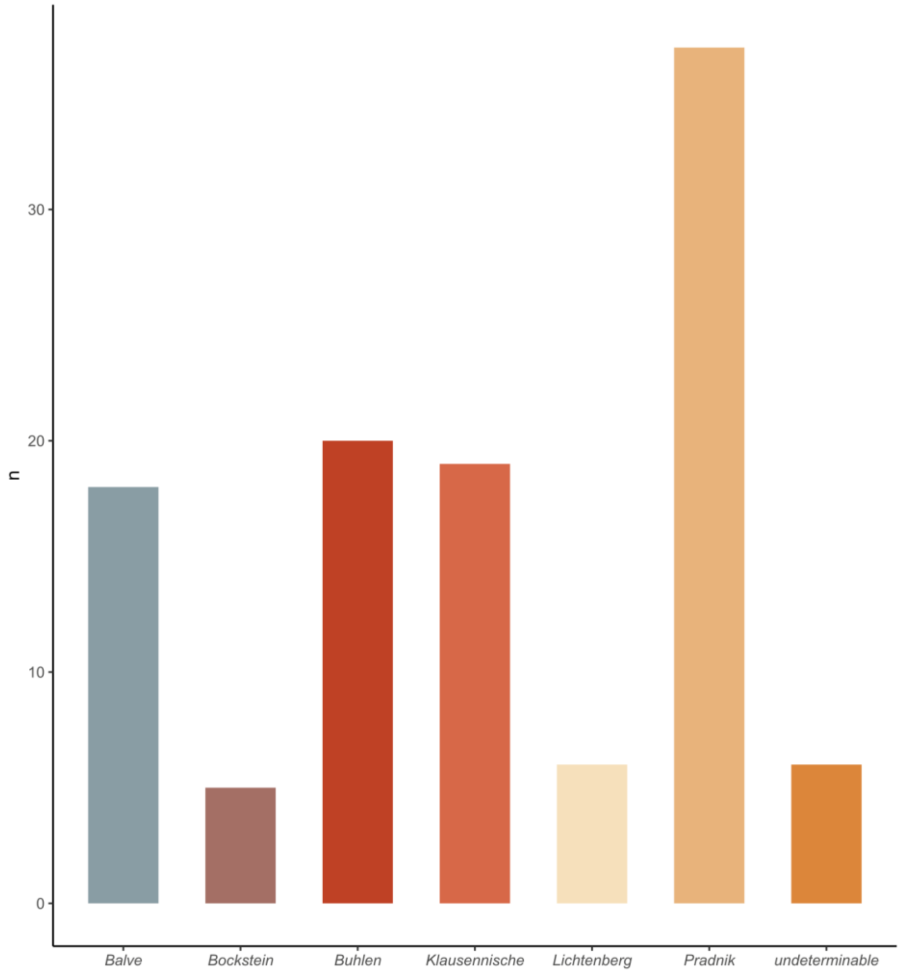

Fig. 94 Distribution of the complete *Keilmesser* (n = 111) from Buhlen to one of the described *Keilmesser* shapes.

A slightly different picture reveals the assignment of the *Keilmesser* shapes for the *Keilmesser* inventory from Balve (**fig. 95**). The type *Lichtenberg* is not represented at all. As in the Buhlen assemblage, the majority of Keilmesser can be ascribed as '*Prądnik knives*' (n = 47). This is followed by the *Keilmesser* shapes *Klausennische* (n = 37), *Balve* (n = 36) and *Bockstein* (n = 29). *Keilmesser* which can be morphologically defined as type *Buhlen* (n = 8) and *Königsaue* (n = 1) are rarely represented.

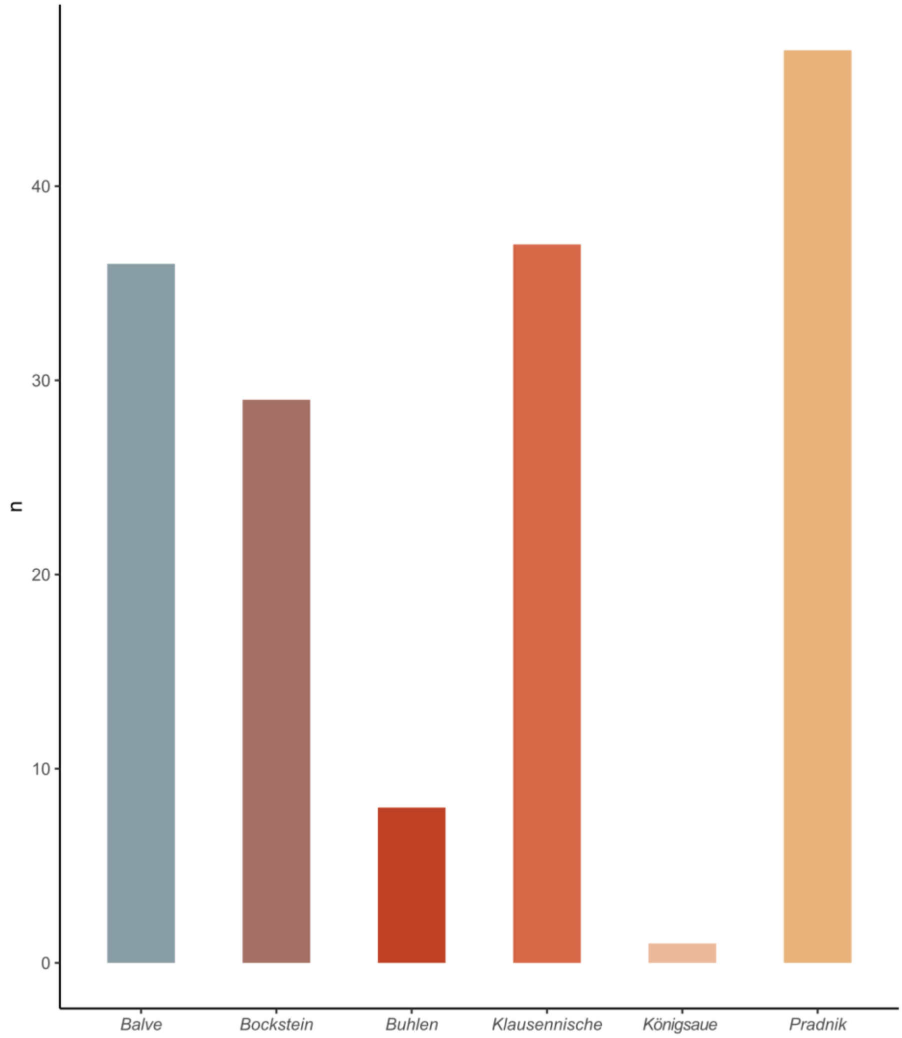

Fig. 95 Distribution of the complete *Keilmesser* (n = 158) from Balver Höhle to one of the described *Keilmesser* shapes.

In Ramioul, the *Keilmesser* assemblage can only be ascribed to three of the seven *Keilmesser* shapes (**fig. 96**). The *Keilmesser* shapes *Balve, Klausennische and Prądnik* are present in equal parts (each n = 3).

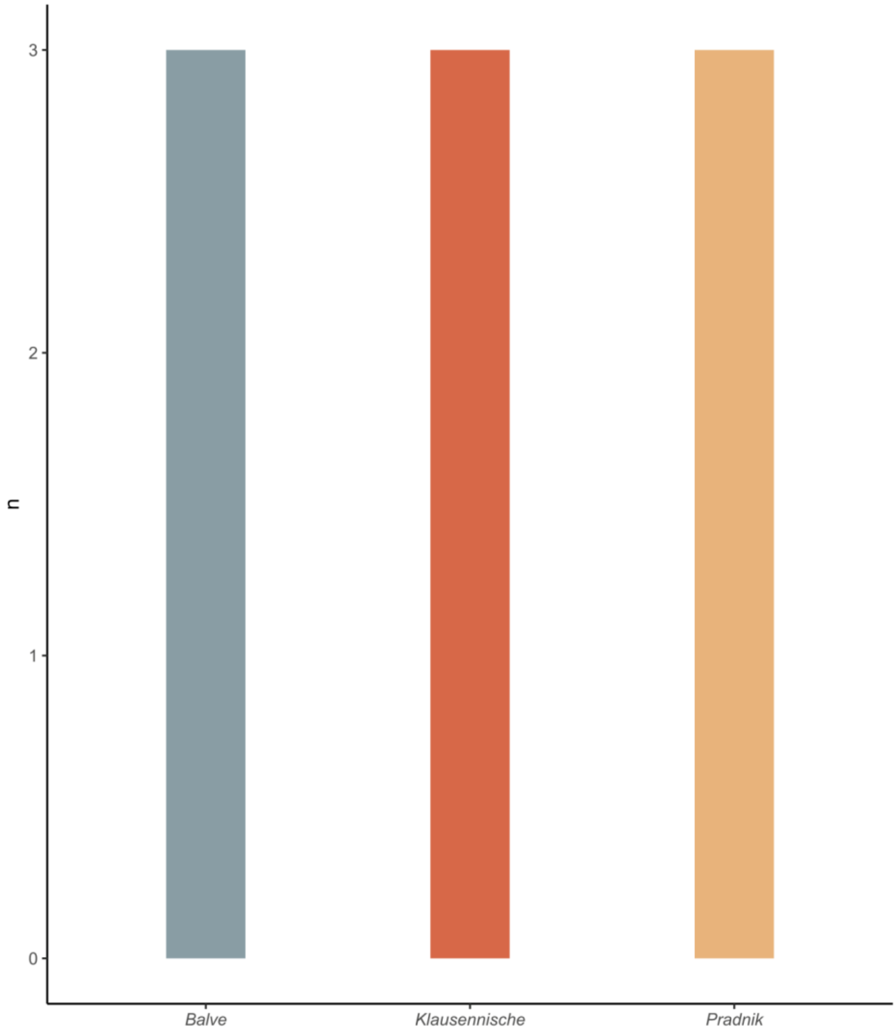

Fig. 96 Distribution of the complete *Keilmesser* (n = 9) from Ramioul to one of the described *Keilmesser* shapes.

Taken together, this means, the most often represented *Keilmesser* shape in the three studied assemblages is the '*Prądnik knife'* (n = 87; **fig. 97**). Together with the types *Balve* (n = 65) and *Klausennische* (n = 59) they compose three quarter of the artefacts.

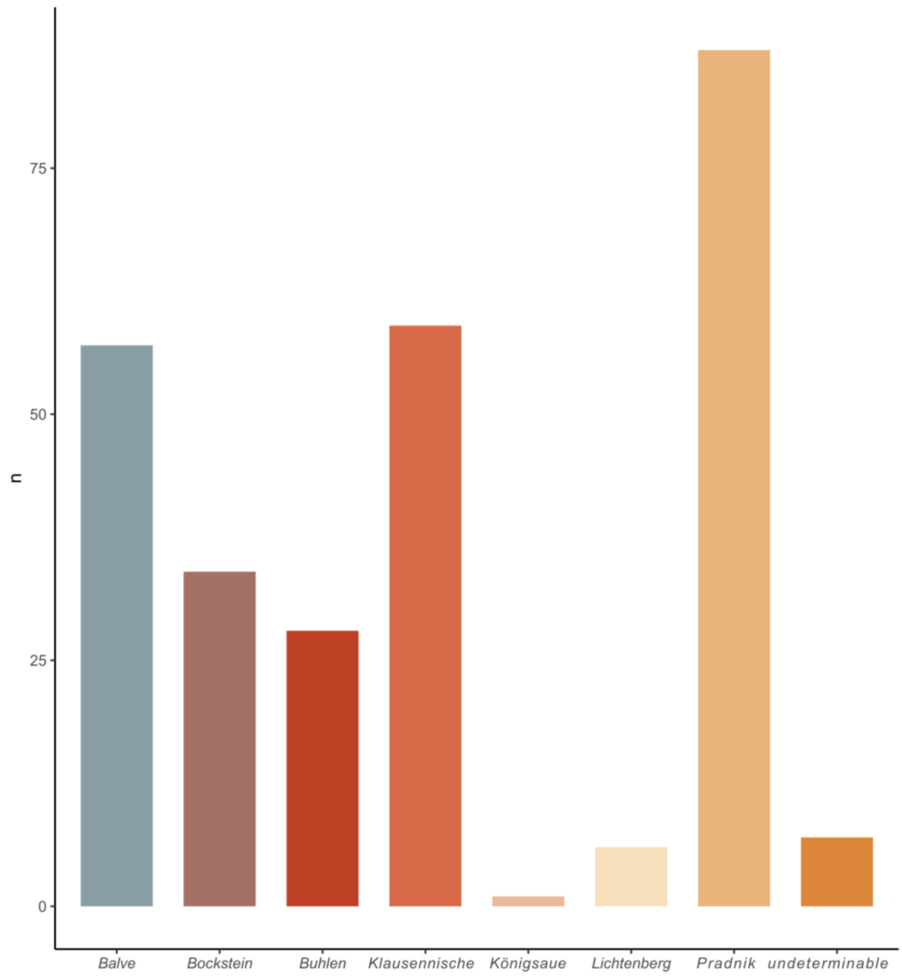

Fig. 97 Distribution of the complete *Keilmesser* from Buhlen (n = 111), Balver Höhle (n = 158) and Ramioul (n = 9) to one of the described *Keilmesser* shapes.

In an additional step, the perimeter sections were measured for the *Keilmesser* from the three assemblages. For this analysis, only complete artefacts were suitable.

In Buhlen, the artefacts have a base and back length of minimum 33.0 mm and maximum 120.0 mm. The second perimeter section, the distal posterior part ranges from 6.0 mm to 92.0 mm. Some artefacts (n = 2), however, are characterized by a lack of this area. The determined values are therefore 0.0 cm. The active edge, as the third perimeter area, shows a size range from 21.0 mm to a maximum of 113.0 mm.

The results from the measurements taken from the Balve assemblage illustrate similar proportions. The section that spans from the base to the back ranges from 30.0 mm to 142.0 mm. The connecting section, the distal posterior part, has a minimum of 10.0 mm and maximum of 93.0 mm. Again, some artefacts do not have this section. In these cases (n = 24) the back directly connects to the active edge. The active edge displays a range between 26.0 mm and 127.0 mm.

In Ramioul, the first section – base and back – ranges from 57.0 mm to 105.0 mm. The margins for the distal posterior part are between 19.0 mm and 82.0 mm. The minimum measurement for the active edge is 13.0 mm while the maximum is 113.0 mm.

The analysis of the determined perimeter sections measured on all *Keilmesser* from the three sites illustrates the following: The proportions of the first section – base and back and the second perimeter section - the distal posterior part - seem to be closely related. The smaller the second section, the larger the dimensions of the back and base. Regardless of this, the length of the working edge is almost constant and occupies on average between 33 and 37 percent of the total perimeter.

In order to determine the actual relationship between the morphologically defined *Keilmesser* shapes and the metrically measured perimeter sections, the data was combined in one graph (**fig. 98 - 101**). The dimensions were plotted in a ternary plot, comprising the mm measurements of the three perimeter sections together at once. The ascribed *Keilmesser* shapes were highlighted in different colours. In case, distinct *Keilmesser* shapes exist, they should cluster graphically grouped together. However, these clusters are not visible as such. Instead of clear clusters, there is a transition between the *Keilmesser* shapes represented by the individual data points. Only the *Keilmesser* classified as shape *Bockstein* separate from the rest of the data. In the case of the *Bockstein Keilmesser*, the distal posterior part is missing (+/- 0 mm). Consequently, the *Keilmesser* of this shape can be found on one axis and not somewhere in the middle of the graph.

The described distribution of the data is relevant for the analysed *Keilmesser* from all three sites. The data taken together displays all data points distributed 'randomly' together without clustering into distinct groups. Noticeable is the location of the plotted points. The data plots are not in the middle of the ternary plot, they all tend to be closer to the active edge axis. The other scenario would be expected if the proportions of the three perimeter sections are equal in length.

The fact that the measured values do not match with the morphologically defined *Keilmesser* shapes raises the question of the relevance or correctness of this classification. Rather, it should be questioned why the *Keilmesser* shapes seem to reflect some transitional stages and whether processes such as reworking, sharpening or transformation may cause the differences in the morphology of Keilmesser (Jöris, 2001, 2004; Jöris and Uomini, 2019).

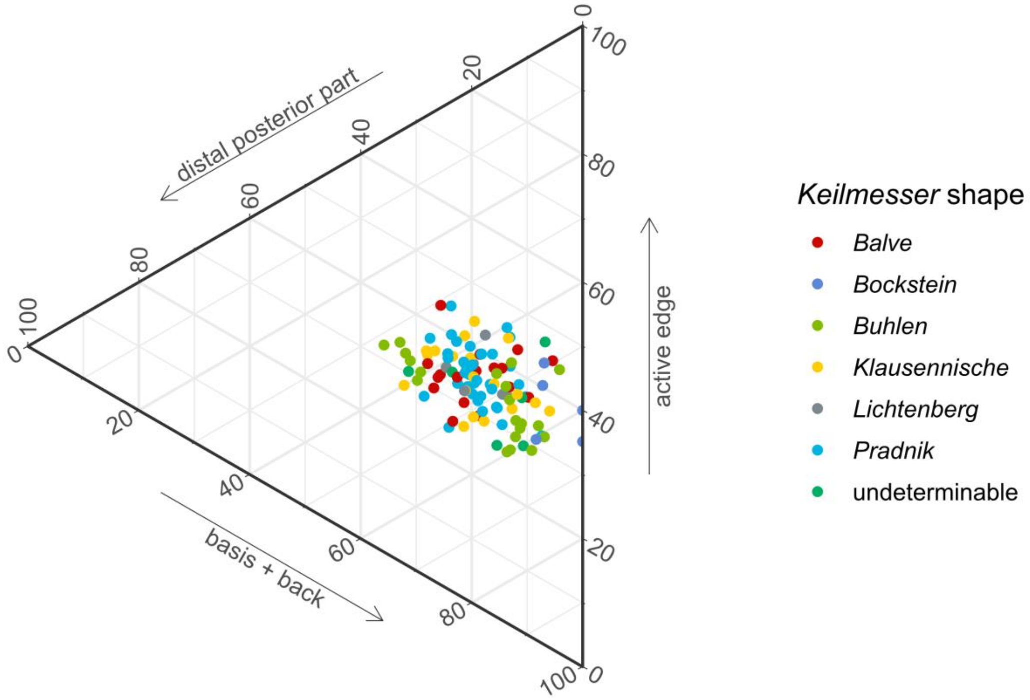

Fig. 98 Size-independent comparison of the shape variation in the perimeter of the complete *Keilmesser* from Buhlen, showing the ratio of the perimeter sections back and base, distal posterior part and active edge. The data points are coloured based on the assigned *Keilmesser* shape.

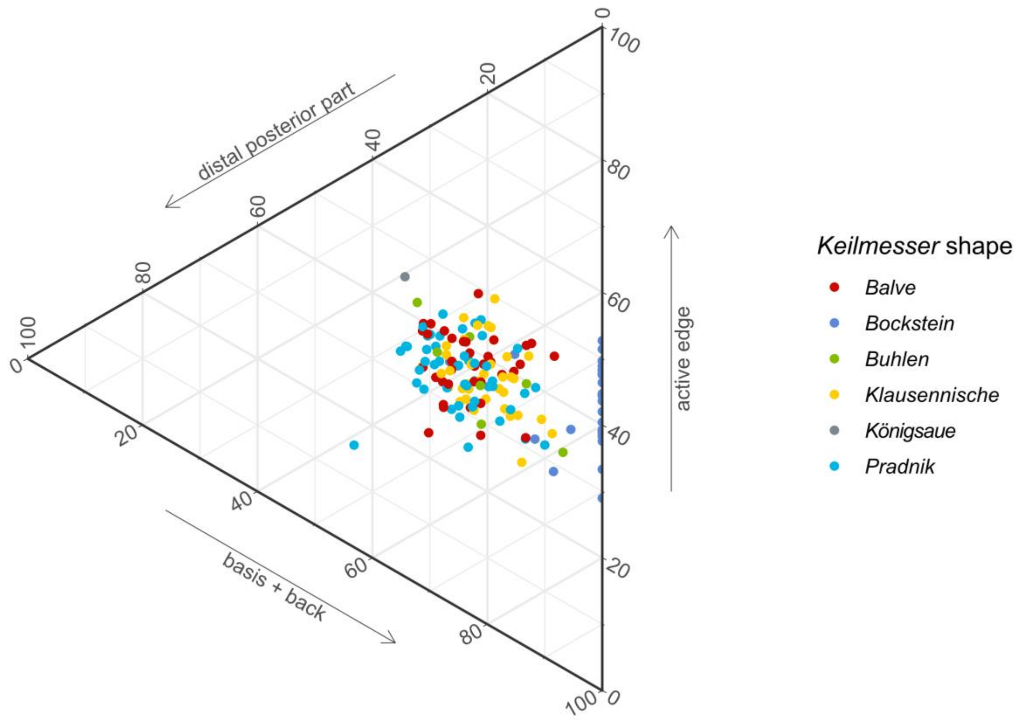

Fig. 99 Size-independent comparison of the shape variation in the perimeter of the complete *Keilmesser* from Balver Höhle, showing the ratio of the perimeter sections back and base, distal posterior part and active edge. The data points are coloured based on the assigned *Keilmesser* shape.

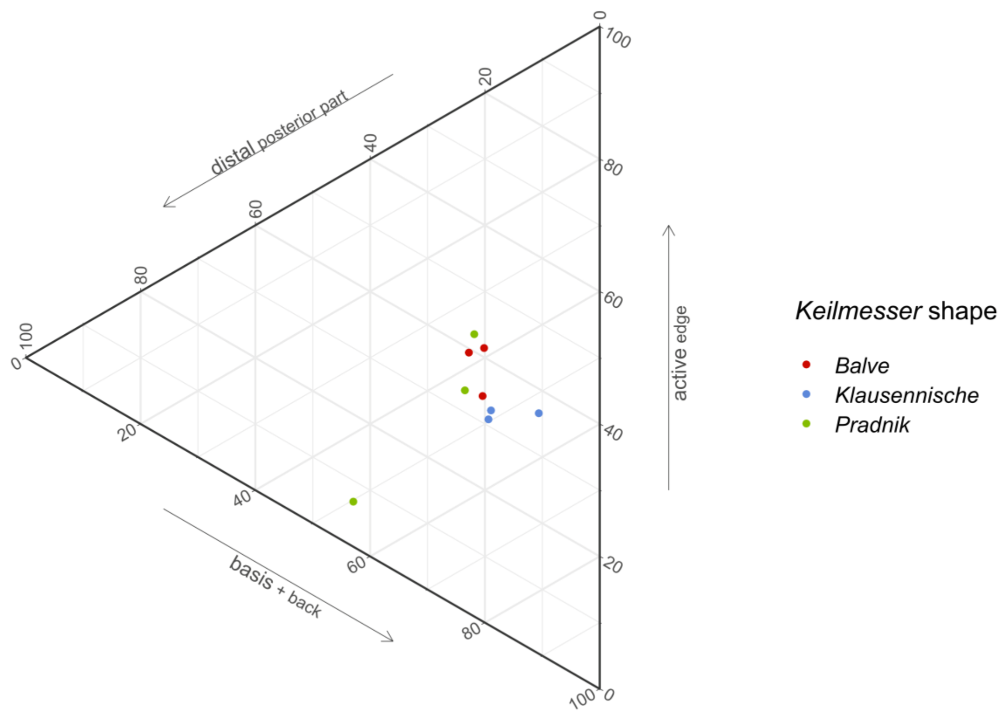

Fig. 100 Size-independent comparison of the shape variation in the perimeter of the complete *Keilmesser* from Ramioul, showing the ratio of the perimeter sections back and base, distal posterior part and active edge. The data points are coloured based on the assigned *Keilmesser* shape.

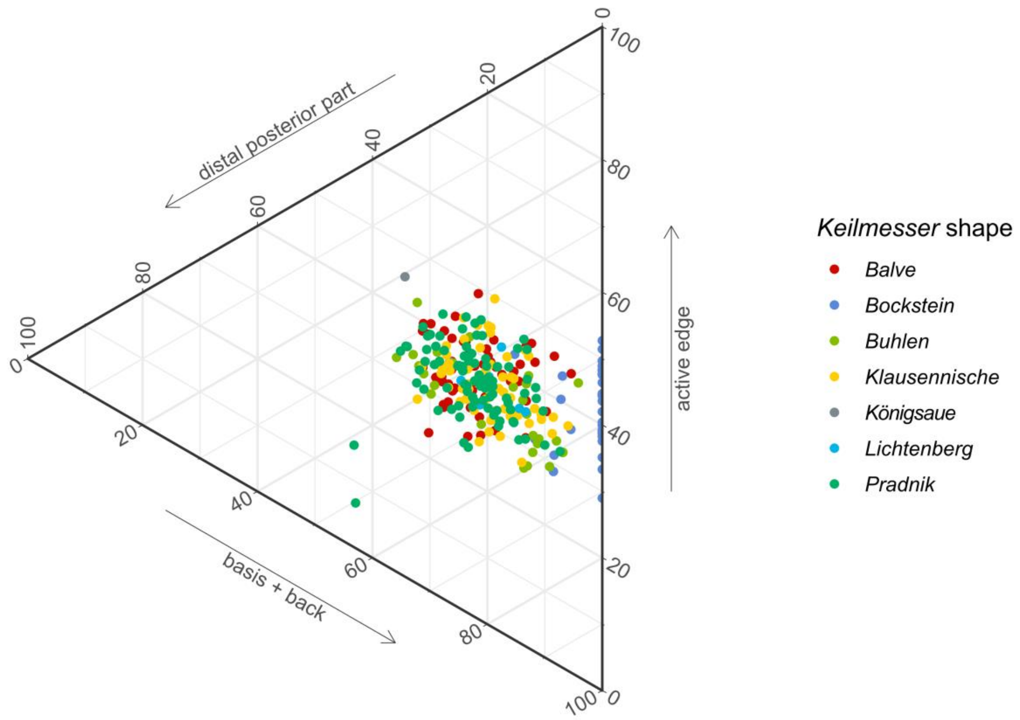

Fig. 101 Size-independent comparison of the shape variation in the perimeter of the complete *Keilmesser* from Buhlen, Balver Höhle and Ramioul, showing the ratio of the perimeter sections back and base, distal posterior part and active edge. The data points are coloured based on the assigned *Keilmesser* shape.

5.2.7 Application of the *Prądnik method*

The majority of the *Keilmesser* from the three sites Buhlen, Balver Höhle and Ramioul display a special modification in the distal part of the tool. The application of the so-called *Prądnik method* is evident by one or multiple negatives on the tool surface resulting from the removal of an elongated lateral spall. For this part of the analysis, only complete and not fragmented *Keilmesser* were considered.

Nearly three quarter (73.0%, n = 92) of the *Keilmesser* assemblage from Buhlen attests the edge modification by the application of the *Prądnik method* (**fig. 102**). Out of these, n = 77 display only one negative. It is therefore likely that the *Prądnik method* was applied only once. The remaining n = 15 artefacts of the assemblage are characterised by two or more superimposed negatives. A small amount of n = 26 *Keilmesser* show no evidence of a modification in the distal tool part. Some pieces are classified as undetermined. For these n = 8 artefacts it is not possible to approve the modification or not. In some of these cases, the artefacts are *Keilmesser tips*.

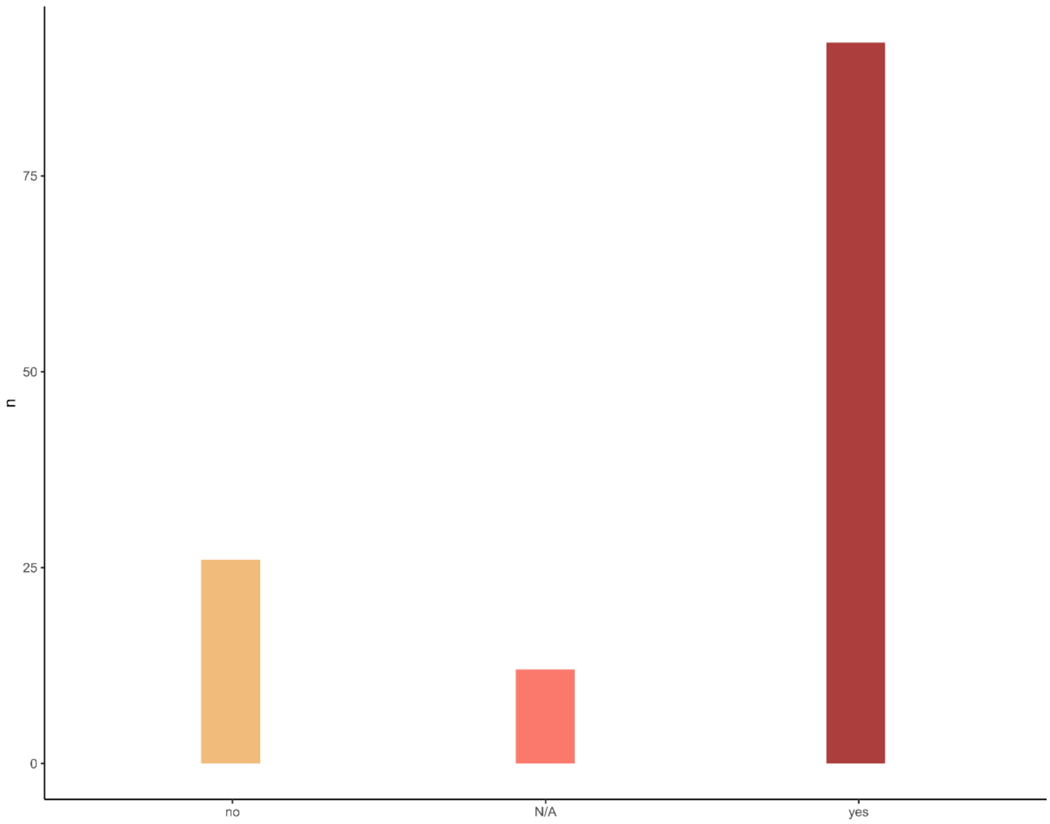

Fig.102 Tool modification by the application of the *Prądnik method* for the complete *Keilmesser* (n = 111) and *Keilmesser* tips (n =15) from Buhlen. In some cases (N/A), it was not possible to approve the application with certainty.

As mentioned above, also at Balve the *Prądnik method* was regularly applied to the *Keilmesser* (**fig. 103**). With n = 91 artefacts, this counts for half of the artefacts (50.8%). Recognisable by superimposed negatives, n = 8 of these tools show evidence for the repeated application. More *Keilmesser* than in Buhlen, n = 82, do not display a modification in the distal tool part. For n = 6 *Keilmesser*, a point could not be made.

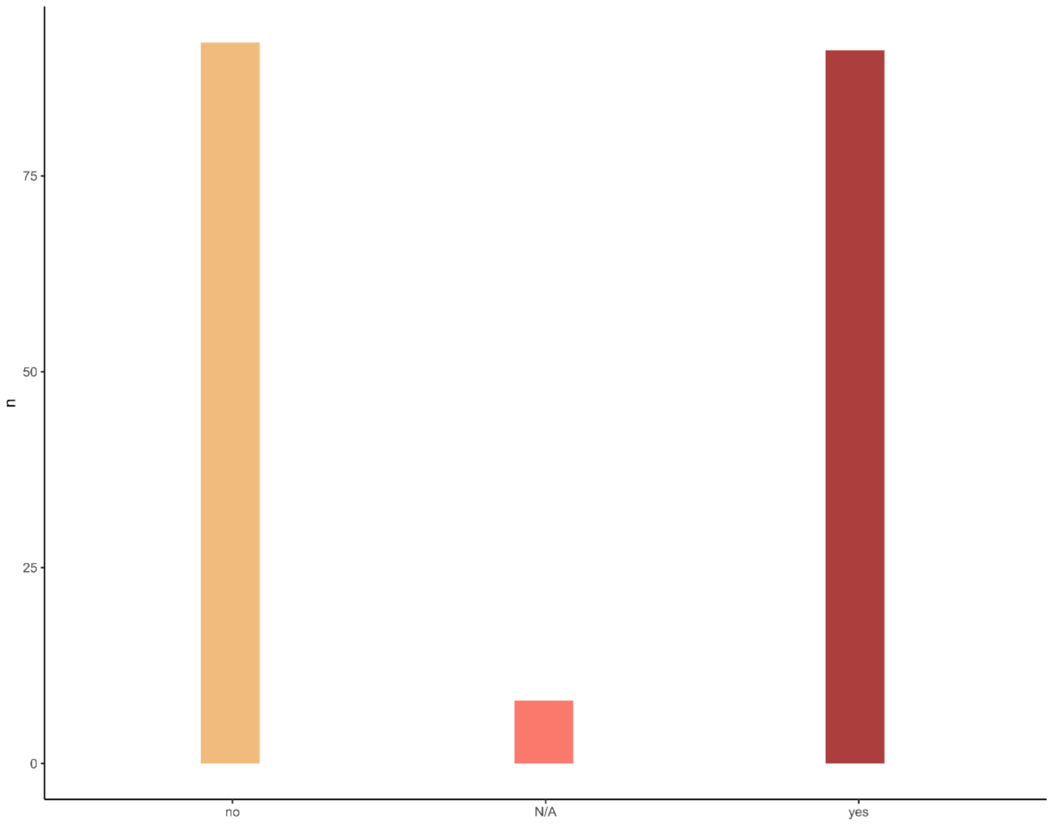

Fig. 103 Tool modification by the application of the *Prądnik method* for the complete *Keilmesser* (n = 158) and *Keilmesser* tips (n = 21) from Balver Höhle. In some cases (N/A), it was not possible to approve the application with certainty.

The same overall picture can be found in Ramioul (**fig. 104**). Almost all (n = 8) *Keilmesser* clearly document the application of the *Prądnik method*. One of these artefacts also displays a multiple application. Only one *Keilmesser* does not show a modification by the '*Prądnik method* in the distal area of the tool.

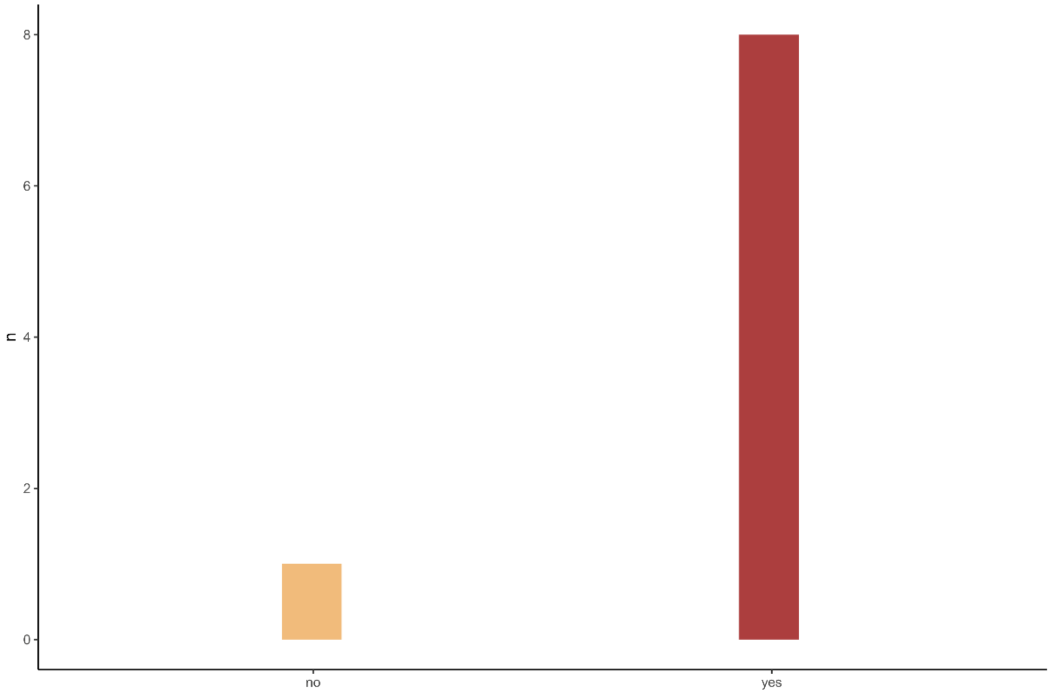

Fig. 104 Tool modification by the application of the *Prądnik method* for the complete *Keilmesser* (n = 9) from Ramioul.

The majority of *Keilmesser* from the three sites are bifacially retouched, but more interestingly regarding the edge design is the special modification in the distal area of the toll's active edge. The numbers taken together result in the following percentage distribution: 60.8% (n = 191) of all *Keilmesser* are modified by the *Prądnik method* whereas 34.7% (n = 109) are not (**fig. 105**). The reaming 4.5 % (n = 14) artefacts are undetermined regarding the application. A small percentage of 12.6 % (n =24) is clearly characterised be a repeated application, indicated by superimposed negatives.

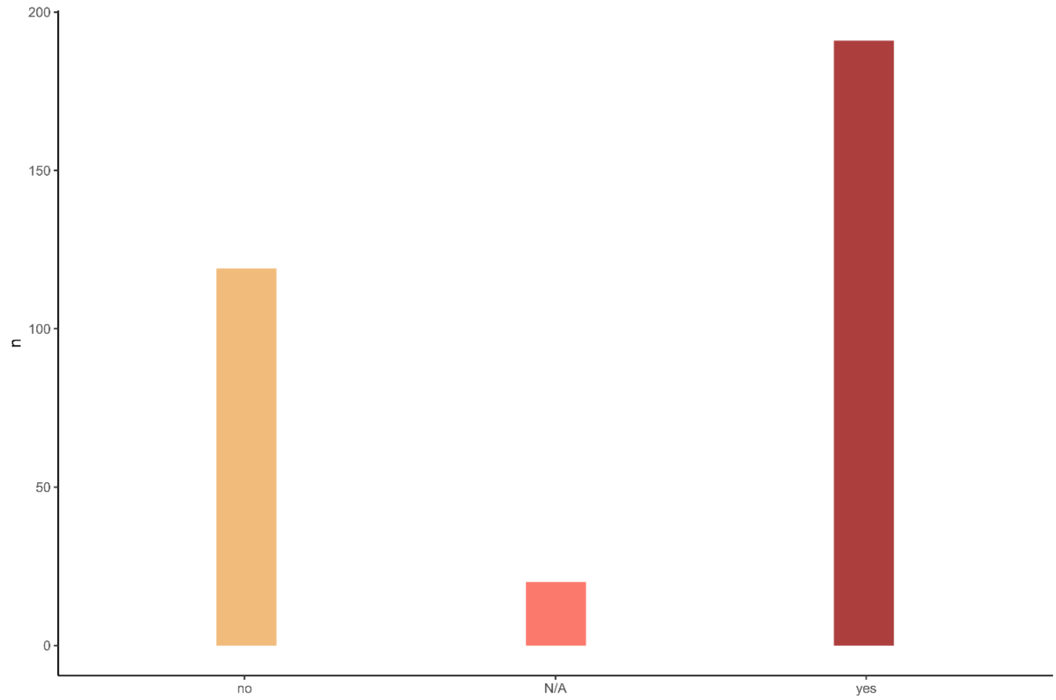

Fig. 105 Tool modification by the application of the *Prądnik method* for the complete *Keilmesser* and *Keilmesser* tips from Buhlen (n = 111, n = 15), Balver Höhle (n = 158, n = 21) and Ramioul (n = 9). In some cases (N/A), it was not possible to approve the application with certainty.

5.2.8 *Prądnik spalls*

The so-called *Prądnik spalls,* which result from the application of the *Prądnik method* on *Keilmesser* or *Prądnik scrapers,* are part of the studied inventories. In total, n = 159 *Prądnik spalls* were analysed. Due to the fact, that no *Prądnik spalls* from the assemblage in Ramioul could be selected for this study, this part of the analysis only focuses on the artefacts from Buhlen (n = 42) and Balve (n = 117).
The results presented in the following are based on a classification of the *Prądnik spalls* as primary or secondary spalls and the determination of the artefact laterality. In a further step, the dimensions of the *Prądnik spalls* will be addressed.

5.2.8.1 Morphometric quantitative analysis

The length, width and thickness of the *Prądnik spalls* was measured on the maximum extend, respectively.
Only n = 36 of the n = 42 studied *Prądnik spalls* from Buhlen are complete and thus relevant for the analysis. The other *Prądnik spalls* are either distal (n = 3) or proximal (n =3) fragments. The measurements of these pieces can be found in the appendix (see appendix I.). The complete *Prądnik spalls* can be classified in a size range from 21.0 mm to 56.0 mm length (**fig. 106, 109**). The arithmetic mean of the length is 35.1 mm. The minimum and maximum extension of the width are 8.0 mm and 31.0 mm, with an

arithmetic mean value of 16.0 mm (**fig. 110**). The thickness is ranging between 2.0 mm and 13.0 mm (**fig. 111**). The arithmetic mean amounts to 4.7 mm.

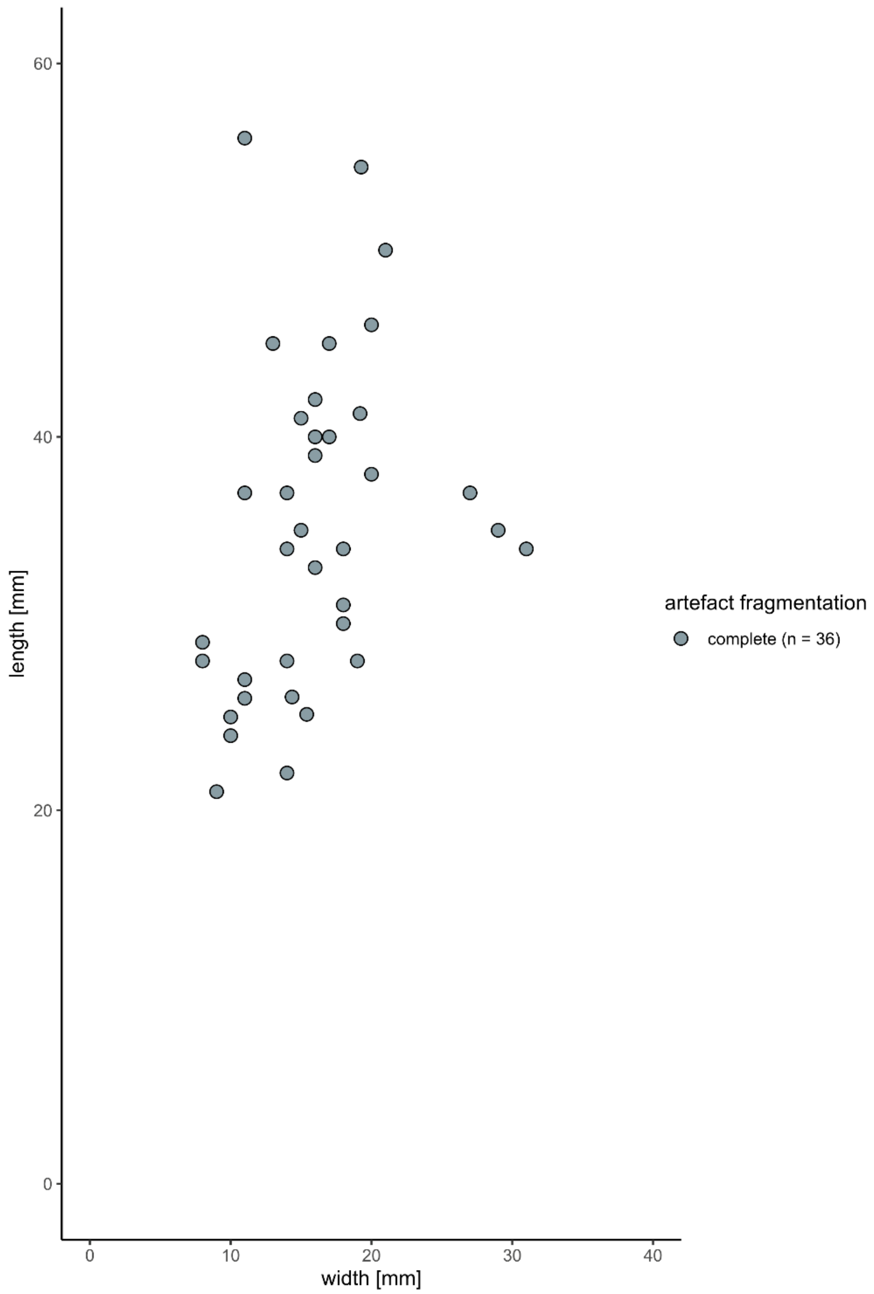

Fig. 106 Length-width ratio of the complete *Prądnik spalls* (n = 36) from Buhlen.

As in Buhlen, not all *Prądnik spalls* from Balve are complete pieces. While the majority of the *Prądnik spalls* are complete (n = 110), also n = 4 distal and n = 3 medial fragments belong to the *Prądnik spall* assemblage. In Balve, the complete *Prądnik spall* length ranges between 12.4 mm and 55.8 mm (**fig. 107, 109**). The arithmetic mean is 29.3 mm. The margin concerning the width is 7.0 mm and 29.3 mm with an arithmetic mean value of 17.4 mm (**fig. 110**). The minimum thickness of the *Prądnik spalls* is 2.14 mm and the maximum is 11.0 mm (**fig. 111**). The arithmetic mean amounts to 6.0 mm.

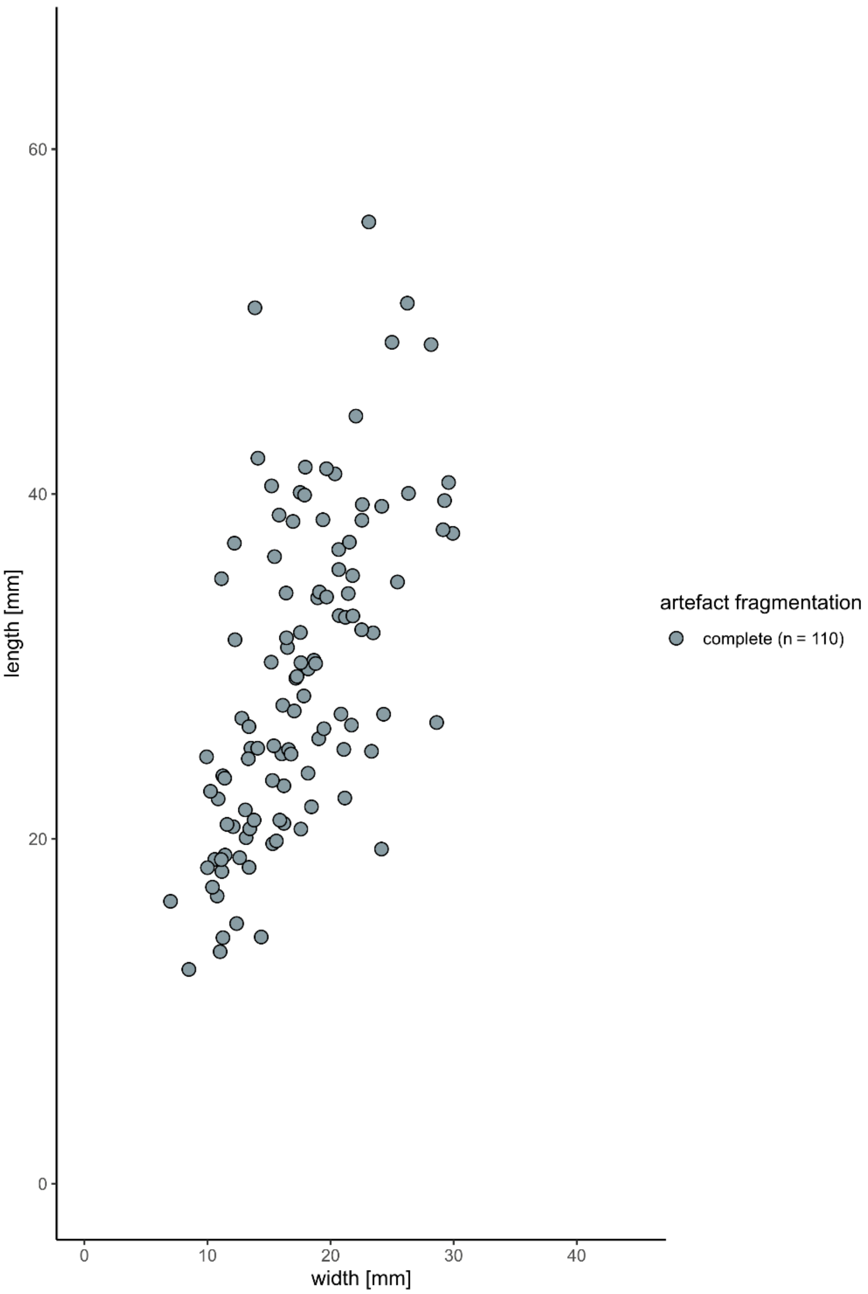

Fig. 107 Length-width ratio of the complete *Prądnik spalls* (n = 110) from Balver Höhle.

The data generated from the two sites shows, that the *Prądnik spalls* from Buhlen and Balve have comparable dimensions. To summarize, the analysed complete *Prądnik spalls* from the two sites together (n = 146) are between 12.4 mm and 56.0 mm long (**fig. 108, 109**). The arithmetic mean value thereby is 30.7 mm. The width extends from minimum 7.0 mm to maximum 31.0 mm with an arithmetic mean of 17.1 mm (**fig. 110**). The thickness is ranging between 2.0 mm and 13.0 mm (**fig. 111**). The arithmetic mean value for the thickness is 5.7 mm.

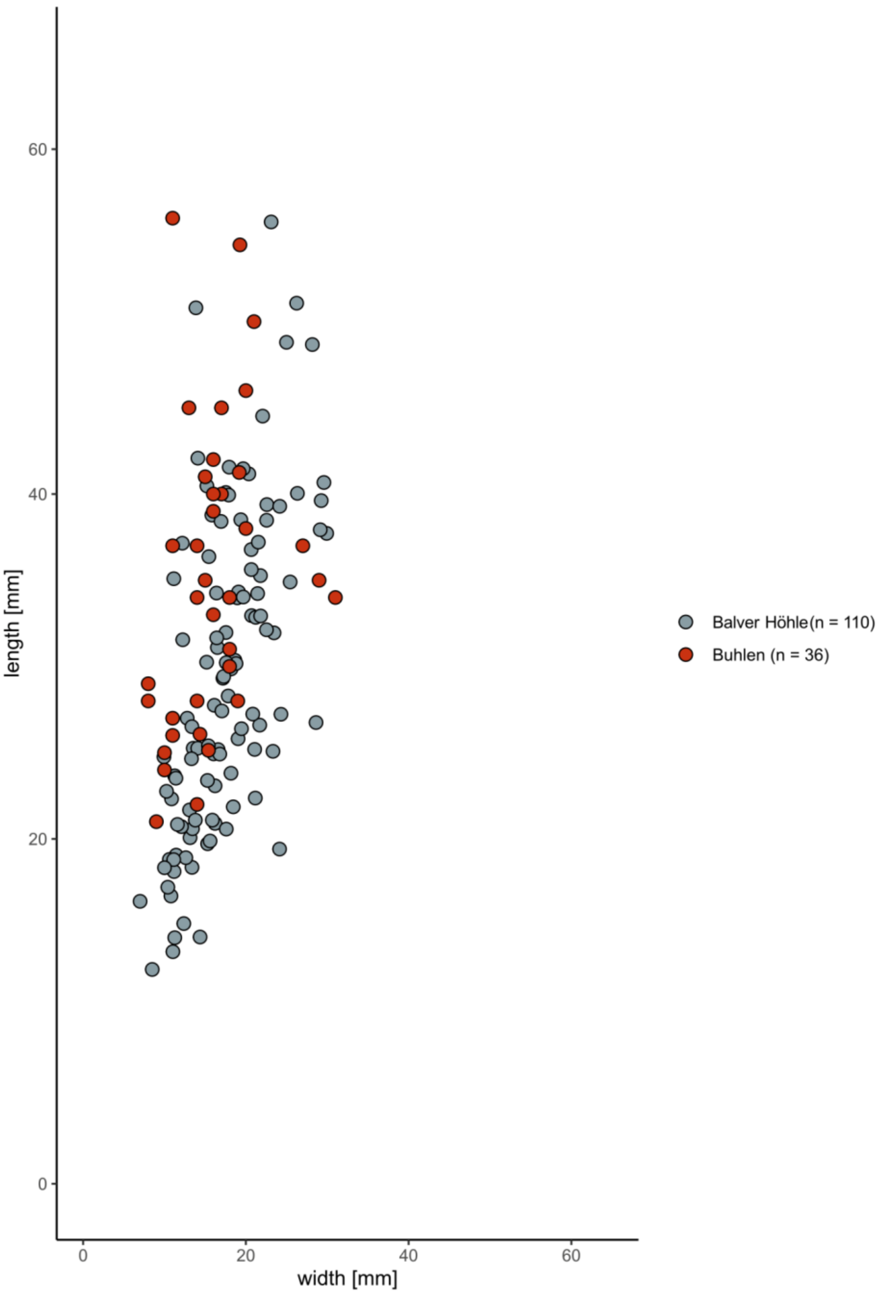

Fig. 108 Length-width ratio of the complete *Prądnik spalls* from Buhlen (n = 36) and Balver Höhle (n = 110).

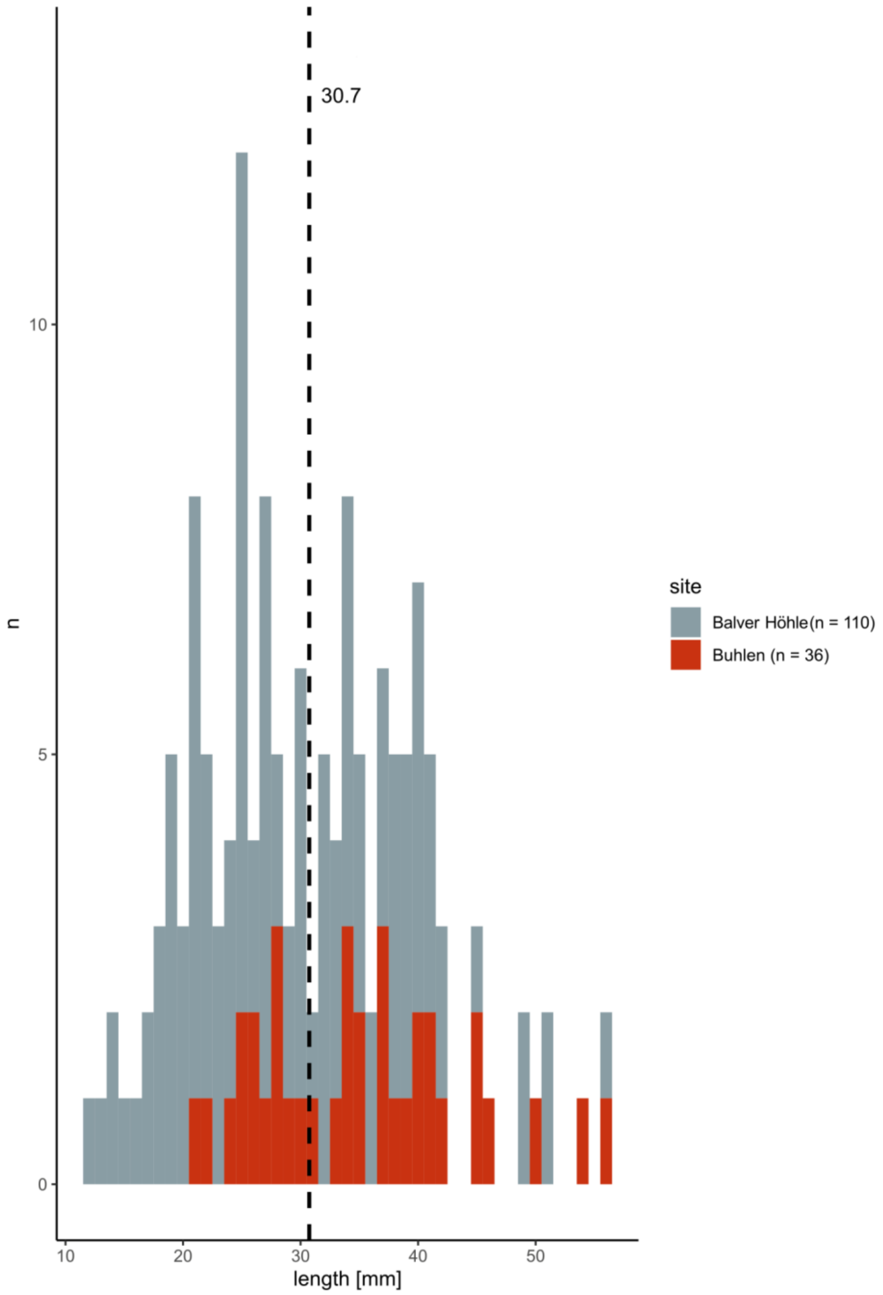

Fig. 109 Maximal length of the complete *Prądnik spalls* from Buhlen (n = 36) and Balver Höhle (n = 110). The dashed line indicates the arithmetic mean value.

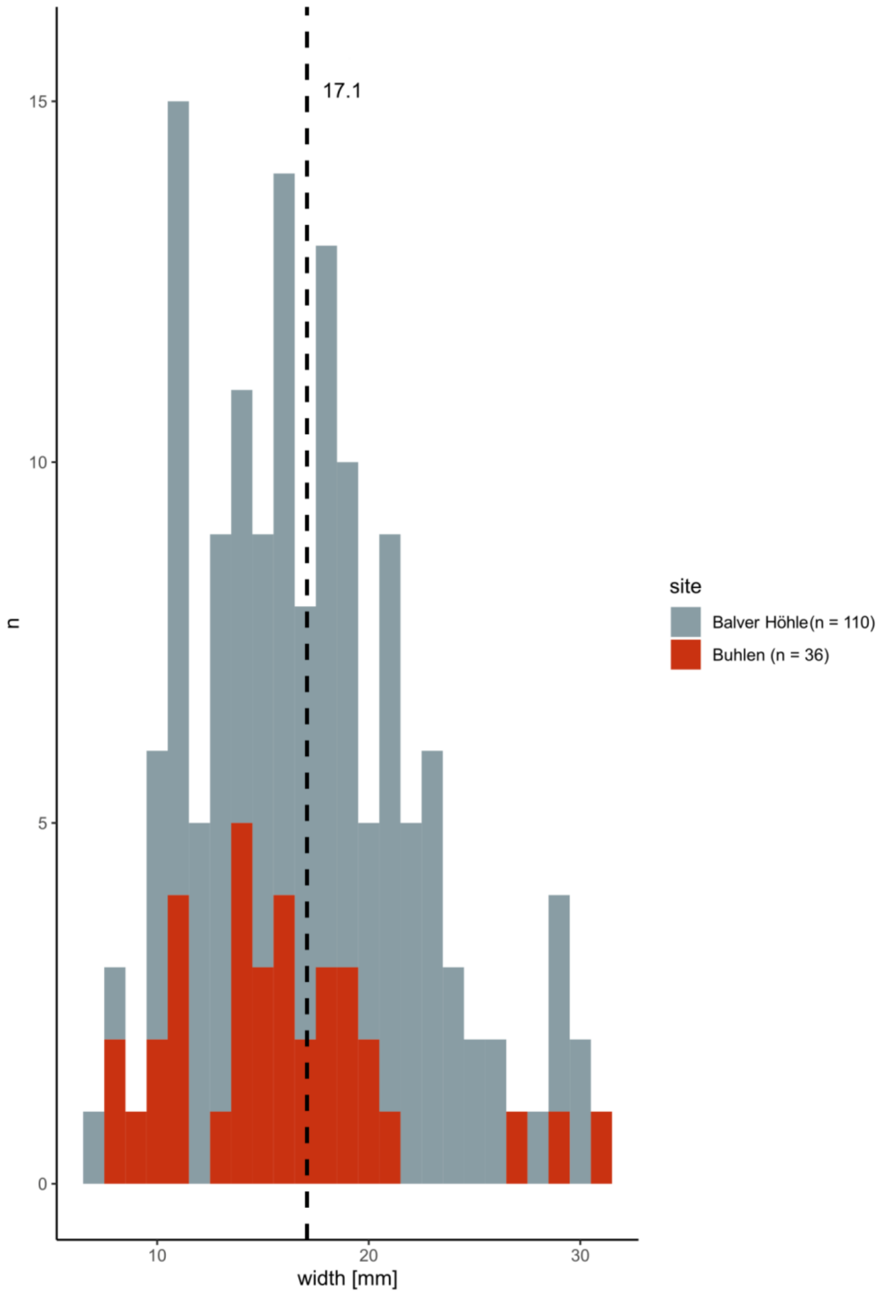

Fig. 110 Maximal width of the complete *Prądnik spalls* from Buhlen (n = 36) and Balver Höhle (n = 110). The dashed line indicates the arithmetic mean value of the complete and fragmented *Prądnik spalls* together.

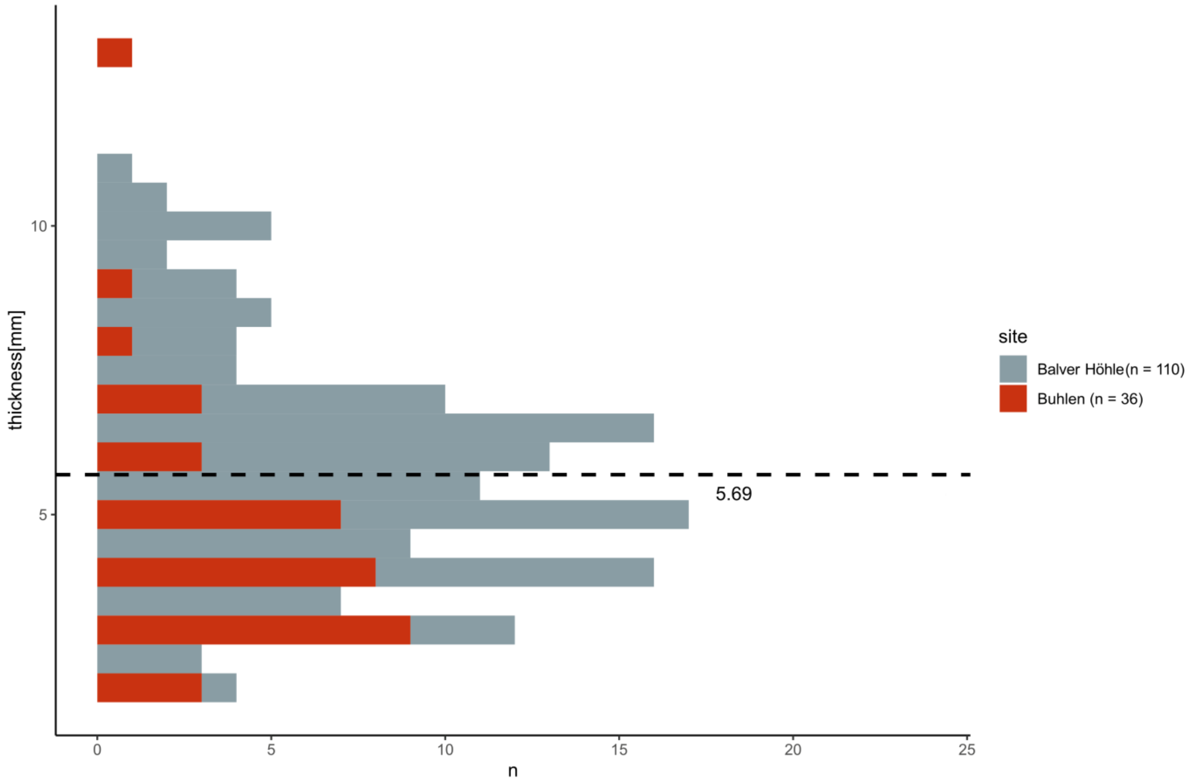

Fig. 111 Maximal thickness of the complete *Prądnik spalls* from Buhlen (n = 36) and Balver Höhle (n = 110). The dashed line indicates the arithmetic mean value of the complete and fragmented *Prądnik spalls* together.

5.2.8.2 Classification

The *Prądnik spalls*, which emerge by the application of the *Prądnik method*, can be subdivided in primary and secondary spalls. The n = 42 analysed *Prądnik spalls* from the Buhlen inventory can be separated in n = 29 primary and n = 12 secondary spalls (**fig. 112**). One artefact could not be attributed due to its fragmentation.

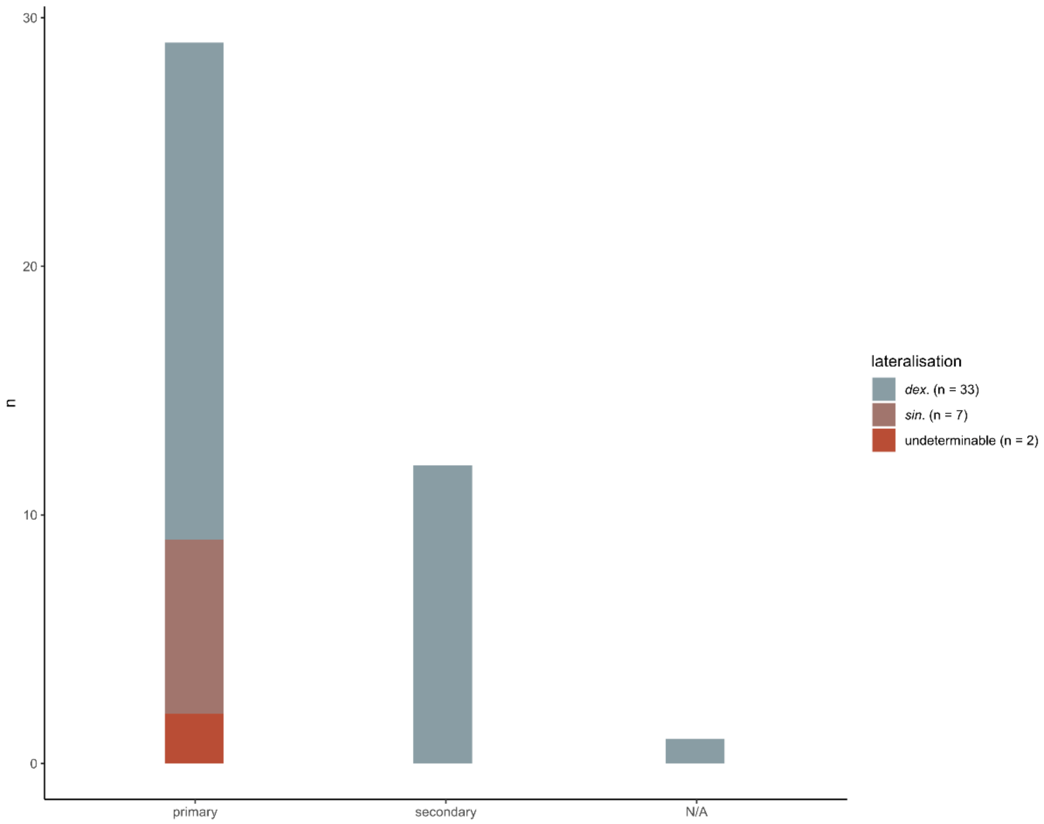

Fig. 112 Classification of the *Prądnik spalls* (n = 42) from Buhlen. The colours indicate the laterality of the artefacts.

In Balve, in total n = 117 *Prądnik spalls* were analysed (**fig. 113**). Here, the primary *Prądnik spalls* predominate with n = 89 pieces, too. Secondary *Prądnik spalls* are represented with n = 28 artefacts.

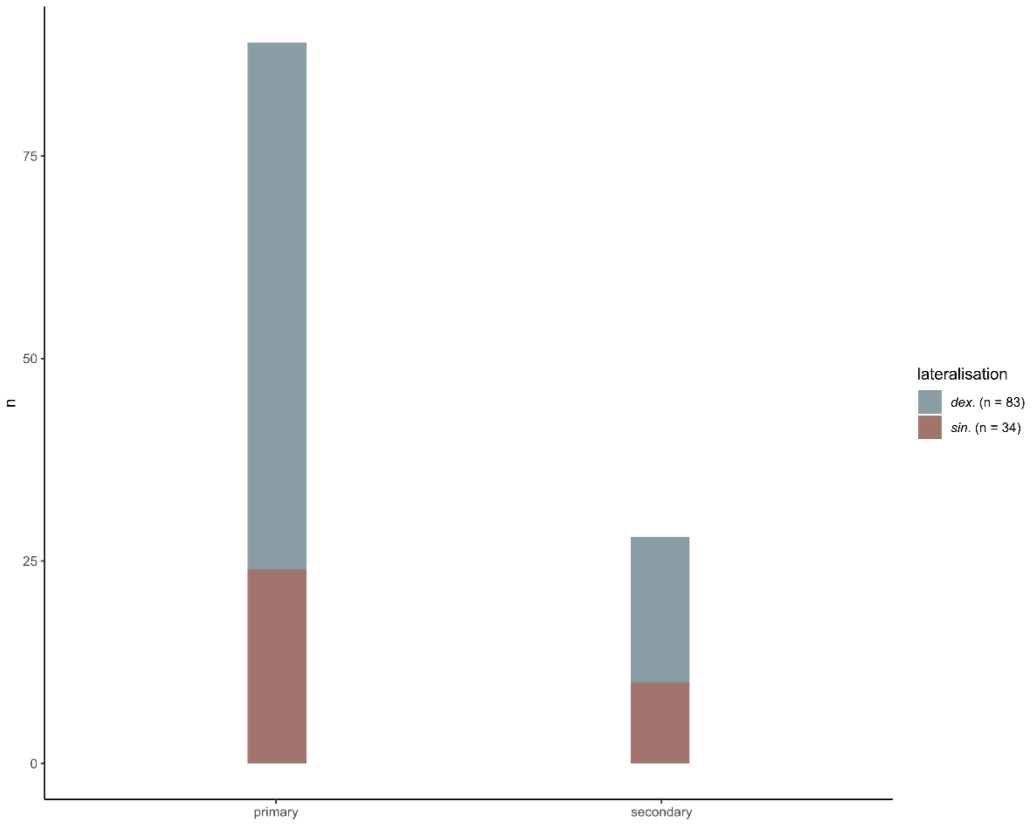

Fig. 113 Classification of the *Prądnik spalls* (n = 117) from Balver Höhle. The colours indicate the laterality of the artefacts.

The results from the two sites taken together lead to a percentage of 74.2% primary to 25.2% secondary *Prądnik spalls* (**fig. 114**).

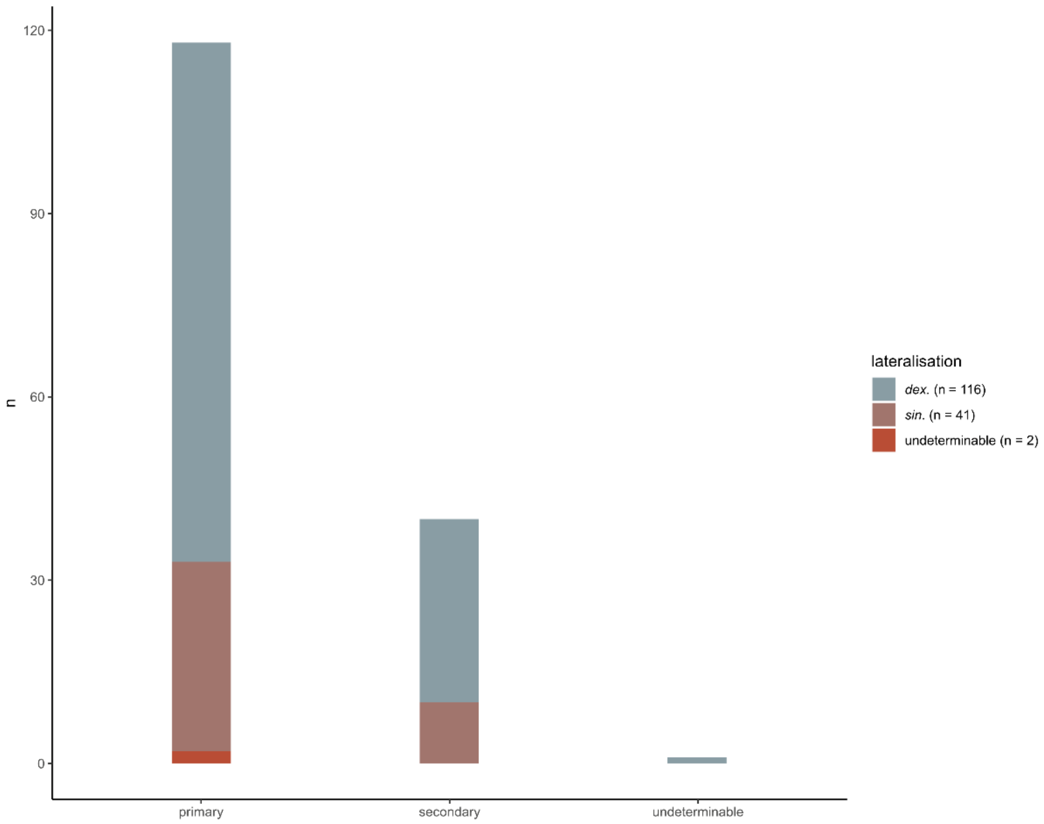

Fig. 114 Classification of the *Prądnik spalls* from Buhlen (n = 42) and Balver Höhle (n = 117). The colours indicate the laterality of the artefacts.

5.2.8.3 Lateralisation

Similar as for the *Keilmesser* and *Prądnik scrapers*, a lateralisation can also be determined for the *Prądnik spalls* removed from these tools (**tab. 14**).

site		*Prądnik spall*		
		sin.	*dex.*	total
Buhlen	n	13	29	**130**
	%	31.0	69.1	100.0
Balve	n	34	83	**117**
	%	29.1	70.9	100.0
total	**n**	**47**	**112**	**159**
	%	29.6	70.4	100.0

Table 14 Determination of the tool lateralisation of the *Prądnik spalls* from Buhlen and Balver Höhle.

As for the tools, the *Prądnik spalls* from Buhlen are by a majority right-sided spalls (**fig. 114**). Next to the n = 29 right-lateral artefacts, n = 13 pieces are documented as left-lateral. These left-lateral *Prądnik spalls* are without exception primary spalls. However,

the right-sided *Prądnik spalls* can be categorised as primary (n = 20) and secondary (n = 7) pieces.
A dominance of right-sided *Prądnik spalls* becomes also evident in the assemblage from Balve with n = 69 pieces. A description as left-lateral *Prądnik spalls* is possible for n = 28 artefacts. Both, right- as well as left-sided *Prądnik spalls* consist of primary and secondary spalls.
In total, 74.2% (n = 118) of the analysed *Prądnik spalls* from Buhlen and Balve are documented as primary spalls, whereas 25.2% (n = 40) of the pieces count as secondary spalls. The overall predominating right-sidedness of the *Keilmesser* and *Prądnik scrapers'* is also reflected in the laterality of the *Prądnik spalls.* 61.2% (n = 98) of the pieces are right-lateral, 25.8% (n = 41) are left-lateral.

5.3 Quantification of edge design

One relevant aspect concerning tool design is the edge angle. Edge angle measurements have been taken on selected artefacts. The sampling strategy thereby was explained in the previous method chapter (chapter 4.4), resulting in a sub-sample of n = 226 artefacts (**tab. 8**). Only complete artefacts were selected. These artefacts can be divided in n = 157 *Keilmesser*, n = 18 *Keilmesser* tips, n = 20 *Prądnik scrapers* and n = 21 *Prądnik spalls*. Also for the edge angle measurements, artefacts not belonging to the selected artefact categories were relevant. Thus, n = 8 scraper as well as n = 2 flakes were sampled for reference as outgroup. The edge angles here was measured with a semi-automated, script-based method. Hence, the n = 226 artefacts have been scanned with a 3D scanner (AICON smartScan-HE R8, Hexagon, Germany) in order to create 3D models for the application of the method.

5.3.1 Edge angle variability

The edge angles of the scanned tools were calculated in order to understand the variability of the angle along the entire tool edge. Moreover, the specific method was also applied to document the changes of the edge angle from the intersection of dorsal and ventral surfaces towards the middle of the artefact. As pointed out already earlier, one mean value *per* tool is thus not sufficient and does not allow for any interpretation concerning the internal variability of the edge design within and between tools. In order to explain the resulting data, certain arithmetic mean values need to be mentioned here, though. Every individual measured angle can be review on GitHub [https://github.com/lschunk/edge_angle_analysis]. There, the raw data, the derived data and a plot of each single artefact can be found and accessed.
For each scanned artefact, ten horizontal sections were defined. Starting at the edge of the tool, each section had a length of 12 mm towards both surfaces (ventral and dorsal) (**fig. 23 - 25**). Based on these horizontal sections, the measurements were taken in 1

mm steps starting at the intersection. Meaning, up to 12 measurements per section were taken.

As explained in the methods chapter, three different measurement procedures were applied for each tool. From earlier tests, which also have been done on objects with a known edge angle, it could be noticed, that the different measurement system led to slightly different results. While the '2-line' and the 'best-fit' procedures produce similar results, the results from the '3-point' procedure vary more strongly. It is likely that the '3-point' measurement procedure deals well with simple structures and smooth surfaces. For instance, the '3-point' procedure works perfectly well on the experimental standard samples. The other two measurement procedures seem to be more suitable and reliable for complex structures and surface irregularities.

The results for the different artefact categories involved is presented and illustrated exemplarily for the three different measurement procedures respectively in the following. The data is split in the usual artefact categories *Keilmesser*, *Prądnik scrapers*, *Prądnik spalls*, scrapers and flakes. Additionally, the *Keilmesser* are furthermore separated in *Keilmesser* with and without negative of the *Prądnik spall* removal and *Keilmesser* tips. The data calculated for the *Prądnik spalls* refers always to the edge on the dorsal surface, which was the former active edge of the *Keilmesser* or *Prądnik scraper* before the spall was detached (**fig. 115**). In order to make the herein explained quantity of data a little more comprehensible, only the results for the measurements at 2 mm, 5 mm and 10 mm distance to the intersection will be mentioned. Moreover, when analysing the data, it became obvious, that the results of the first section (distal) as well as the tenth section (proximal) most often deviate from the results of the other eight sections. The reason for that can likely be found in the length of the vertical polyline that follows the tool edge. This polyline often slightly extents toward the distal posterior part and the base of the tool. Meaning, these results would actually reflect not the edge angle measurements for the active edge, but rather for the adjacent perimeter section. Thus, to avoid any doubts, these two sections will be excluded when presenting the data. Whenever there will be a range discussed, it always refers to the range from the second (distal) to the ninth (proximal) horizontal section. The range does not necessarily reflect the minimum and maximum values. All mentioned edge angle values are in degrees.

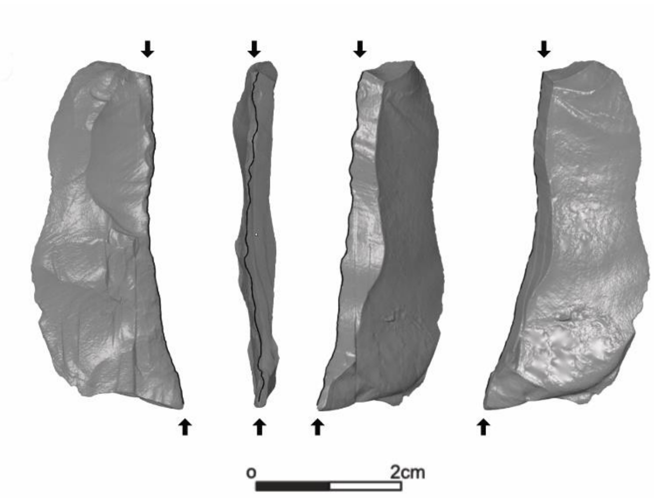

Fig. 115 3D scan of a secondary *Prądnik spall* from Buhlen (left: dorsal surface; middle: edge, right: ventral surface) illustrating on which edge (black line; indicated by the arrows) the angles have been calculated.

5.3.2 '3-point' procedure

First, the results from the '3-point' measuring procedure is presented. The results for the *Keilmesser* are based on n = 57 artefacts (**tab. 8**). To start with the 2 mm distance, the edge angle ranges from 86.8° to 92.2° (**tab. 15**). The measurements at 5 mm distance result in a range from 70.4° to 79.6°. At the 10 mm distance, the values are 51.4° to 66.8°. For these three distances, the arithmetic mean is 89.1°, 75.3° and 61.6° respectively.
Keilmesser with a negative from the application of the *Prądnik method* are with n = 100 pieces part of the analysis (**tab. 16**). These measurements result in lower edge angels. At a distance of 2 mm from the intersection, the measurements are ranging from 79.8° to 86.1°, with an arithmetic mean value of 82.9°. The range for the 5 mm distance is from 67.0° to 74.0°. The arithmetic mean is 71.0°. At the 10 mm distance, the measurements are 54.6° to 61.2° and the arithmetic mean is 59.7°.
The next category is the *Keilmesser* tips. N = 18 pieces were scanned and analysed for the edge angle measurements (**tab. 17**). The results for the *Keilmesser* tips are similar to the previously mentioned results. Interesting here is, that n = 10 of the *Keilmesser* tips also display a negative resulting from the application of the *Prądnik method*. At the 2 mm distance, the values are 83.8° to 83.0°. The range at 5 mm is from 67.3° to 71.0°. At a distance of 10 mm from the intersection, the values are 50.9 to 59.9°. The arithmetic mean values amount to 80.9°, 68.4° and 56.0°.
N = 20 *Prądnik scrapers* were included in the analysis (**tab. 18**). From 55.7° to 80.0° is the range at the 2 mm distance. The measurements ranging from 43.0° to 66.4° at the 5 mm distance. Significantly lower are the values at 10 mm. They range from 33.3° to 48.3°. This leads to arithmetic mean values of 70.0°, 55.1° and 42.4° per mentioned distance.

The analysed n = 21 *Prądnik spalls* result in measurements of 59.5° and 69.4° at 2 mm distance with an arithmetic mean of 67.4° (**tab. 19**). At a distance of 5 mm, the values are 38.8° to 42.1°. The arithmetic mean values for the 5 mm distance is 42.7°. The range for the 10 mm distance is 17.9° to 20.4°. The arithmetic mean is 19.9°.
Additionally, n = 9 scrapers and n = 2 flakes were analysed as outgroup (**tab. 20**). The scrapers range at the 2 mm distance from 93.7° to 85.2°. At the 5 mm distance, the values are 74.9° to 75.2°. The measurements for the 10 mm distance are 55.0° and 75.8°. These measurements result in arithmetic mean values of 94.8°, 77.0° and 59.8° per distance respectively.
The flakes have a range of 72.3° to 80.7° at the 2 mm distance with an arithmetic mean of 76.3° (**tab. 21**). The measurements at 5 mm distance reach from 58.5° to 71.9°. The arithmetic mean value is 60.9°. At the 10 mm distance, the values are lower and range from 47.1° to 61.6°. The arithmetic mean is 52.7°.

section	**distance to origin**			**mean per section** (2-5)	**mean per section** (all)
	2 mm [in degrees]	**5 mm** [in degrees]	**10 mm** [in degrees]		
1	89.5	73.6	57.4	73.5	72.9
2	86.8	70.4	51.4	69.5	69.4
3	88.2	73.0	60.4	73.9	73.4
4	86.1	72.1	61.5	73.2	72.6
5	89.1	75.9	65.0	76.7	76.1
6	88.6	76.1	58.6	74.4	75.6
7	87.6	75.9	63.5	75.7	75.7
8	94.4	79.4	65.4	79.7	78.9
9	92.2	79.6	66.8	79.5	78.8
10	98.4	84.2	67.5	83.4	82.3

Table 15 Edge angle arithmetic mean values for *Keilmesser* (n = 57). The edge angles are calculated with the '3-point' measurement procedure.

section	distance to origin			mean per section (2-5)	mean per section (all)
	2 mm [in degrees]	**5 mm** [in degrees]	**10 mm** [in degrees]		
1	81.7	65.2	50.8	65.9	65.1
2	79.8	67.0	54.6	67.1	66.5
3	80.7	67.6	54.9	67.7	67.1
4	76.3	68.2	57.8	67.4	67.4
5	80.4	71.8	62.2	71.5	71.0
6	85.9	72.4	62.3	73.5	72.8
7	86.7	73.8	63.1	74.5	74.2
8	87.2	72.9	61.7	73.9	73.4
9	86.1	74.0	61.2	73.8	73.0
10	98.8	81.1	64.9	81.6	80.4

Table 16 Edge angle arithmetic mean values for *Keilmesser* modified by the *Prądnik method* (n = 100). The edge angles are calculated with the '3-point' measurement procedure.

section	distance to origin			mean per section (2-5)	mean per section (all)
	2 mm [in degrees]	**5 mm** [in degrees]	**10 mm** [in degrees]		
1	68.3	66.1	49.9	61.4	65.1
2	83.8	67.3	50.9	67.3	66.5
3	79.2	64.9	52.3	65.5	67.1
4	80.0	67.6	55.8	67.8	67.4
5	76.5	64.5	57.0	66.0	71.0
6	81.2	69.4	56.0	68.9	72.8
7	80.7	71.0	58.9	70.2	74.2
8	82.7	71.2	57.4	70.4	73.4
9	83.0	71.0	59.9	71.3	73.0
10	85.3	66.5	53.9	68.6	80.4

Table 17 Edge angle arithmetic mean values for *Keilmesser tips* (n = 18). The edge angles are calculated with the '3-point' measurement procedure.

section	distance to origin			mean per section (2-5)	mean per section (all)
	2 mm [in degrees]	5 mm [in degrees]	10 mm [in degrees]		
1	65.6	42.2	31.6	46.5	45.7
2	55.7	43	33.3	44.0	44.2
3	53.4	46.0	38.5	46.0	46.2
4	63.0	51.7	42.6	52.4	52.4
5	76.4	59.3	43.1	59.6	59.4
6	75.7	54.7	42.3	57.6	56.7
7	81.4	57.0	44.6	61.0	59.9
8	74.4	62.9	46.2	61.2	60.6
9	80.0	66.4	48.3	64.9	63.9
10	85.8	67.8	49.2	67.6	65.8

Table 18 Edge angle arithmetic mean values for *Prądnik scrapers* (n = 20). The edge angles are calculated with the '3-point' measurement procedure.

section	distance to origin			mean per section (2-5)	mean per section (all)
	2 mm [in degrees]	5 mm [in degrees]	10 mm [in degrees]		
1	54.3	32.1	19.6	35.3	37.4
2	59.5	38.8	17.9	38.7	38.9
3	63.4	41.6	17.2	40.7	40.8
4	64.4	40.0	18.9	41.1	41.0
5	64.5	41.8	19.5	41.9	41.6
6	72.0	46.6	20.9	46.5	45.5
7	72.5	44.7	22.0	46.4	45.0
8	73.4	45.6	22.3	47.1	45.1
9	69.4	42.1	20.4	44.0	42.7
10	56.4	35.4	18.4	36.7	36.8

Table 19 Edge angle arithmetic mean values for *Prądnik spalls* (n = 21). The edge angles are calculated with the '3-point' measurement procedure.

section	distance to origin			mean per section (2-5)	mean per section (all)
	2 mm [in degrees]	5 mm [in degrees]	10 mm [in degrees]		
1	79.4	55.2	52.5	62.4	59.4
2	72.3	58.5	47.1	59.3	58.3
3	89.0	65.3	55.3	69.9	69.4
4	56.8	51.2	48.6	52.2	51.8
5	74.3	57.5	49.5	60.4	59.5
6	78.8	60.3	53.6	64.2	63.3
7	76.0	59.9	50.4	62.1	61.1
8	82.4	62.6	55.7	66.9	66.2
9	80.7	71.9	61.6	71.4	70.3
10	108.9	106.7	95.6	103.7	105.1

Table 20 Edge angle arithmetic mean values for scrapers (n = 9). The edge angles are calculated with the '3-point' measurement procedure.

section	distance to origin			mean per section (2-5)	mean per section (all)
	2 mm [in degrees]	5 mm [in degrees]	10 mm [in degrees]		
1	95.9	79.4	50.0	75.1	75.1
2	93.7	74.9	55.0	74.5	74.6
3	93.3	74.1	58.1	75.2	74.5
4	96.9	76.4	58.7	77.3	76.5
5	95.7	80.3	62.3	79.4	79.1
6	94.8	81.4	64.4	80.2	79.3
7	93.6	76.6	62.5	77.6	77.5
8	95.5	76.9	60.2	77.5	76.9
9	95.2	75.2	57.0	75.8	74.8
10	99.5	81.4	56.9	79.3	78.0

Table 21 Edge angle arithmetic mean values for flakes (n = 2). The edge angles are calculated with the '3-point' measurement procedure.

5.3.3 '2-lines' procedure

With the second measuring procedure, the so-called '2-lines' procedure, deviating edge angle values were calculated.

For *Keilmesser*, the range at 2 mm is from 73.7° to 78.4° (**tab. 22**). At a distance of 5 mm from the intersection, the values are 51.3° and 62.7°. The range at 10 mm is from 28.2° to 43°. The arithmetic means for these three distances are 75.4°, 59.3° and 41.5° respectively.

Keilmesser with a negative from the removed *Prądnik spall* do have slightly smaller values at the 2 mm and 5 mm distance compared to the beforehand mentioned results for the *Keilmesser* (**tab. 23**). At 2 mm distance, these *Keilmesser* have a range of 66.3° to 74.6 ° with a mean value of 70.5°. The measurements at 5 mm range from 52.9° to 59.9°. The arithmetic mean is 57.3°. At the 10 mm distance, the measurements are 30.9° to 41.9° and the arithmetic mean is 41.6°. Thus, the arithmetic means at the 10 mm distance for *Keilmesser* and *Keilmesser* with negative are nearly identical. It is likely that the negative often does not reach up to 10 mm width on the surface.

The measurements for the *Keilmesser* tips result in the following values (**tab. 24**). The range at the 2 mm distance from the intersection is 64.8° to 71.2°. For the measurements at the 5 mm distance, the values are 50.5° and 60.7°. At 10 mm distance to the intersection, the values ranging from 30.3° to 42.2°. The edge angle measurements lead to arithmetic mean values of 66.9°, 57.5° and 33.7° per mentioned distance.

The calculated edge angles for the *Prądnik scrapers* result in measurements of 42.3° and 64.8° at 2 mm distance with an arithmetic mean of 54.8° (**tab. 25**). At a distance of 5 mm, the values are 33.6° to 50.9°. The arithmetic mean values for the 5 mm distance is 40.0°. The range for the 10 mm distance is 15.8° to 16.2°. The arithmetic mean is 20.5°.

For *Prądnik spalls*, the values measured at the 2 mm distance are 44.4° and 50.7° (**tab. 26**). At the 5 mm distance to the intersection, a range from 20.7° to 14.9° could be calculated. The values at 10 mm are ranging from 21.4° to 16.1°. The arithmetic mean for these three distances are 47.6°, 18.5° and 18.8° respectively.

The measured scrapers display a range of 71.7° to 75.6° at the 2 mm distance with an arithmetic mean of 77.5° (**tab. 27**). The measurements at 5 mm distance reach from 53.7° to 52.2°. The arithmetic mean value is 55.2°. At the 10 mm distance, the values range from 22.9° to 25.8°. The arithmetic mean is 33.8°.

The flakes, also belonging to the selected outgroup, range at a distance of 2 mm to the intersection from 59.3° to 78.4° (**tab. 28**). The values displayed at the 5 mm distance are 39.7° and 52.7°. At the 10 mm distance, the measurements are 35.5° and 51.0°. For the three mentioned distances, the arithmetic means are 61.3°, 46.7° and 41.3°.

section	distance to origin			mean per section (2-5)	mean per section (all)
	2 mm [in degrees]	**5 mm** [in degrees]	**10 mm** [in degrees]		
1	76.5	53.9	28.2	52.9	52.6
2	73.7	51.3	28.2	51.1	49.5
3	71.9	59.2	39.2	56.8	55.9
4	72.3	58.4	45.0	58.6	58.4
5	74.3	60.8	47.0	60.7	61.1
6	77.3	59.3	45.7	60.8	59.9
7	73.7	62.8	43.8	60.1	59.7
8	81.3	60.2	40.6	60.7	60.8
9	78.4	62.7	43.1	61.4	61.9
10	83.9	66.1	43.9	64.6	63.0

Table 22 Edge angle arithmetic mean values for *Keilmesser* (n = 57). The edge angles are calculated with the '2-lines' measurement procedure.

section	distance to origin			mean per section (2-5)	mean per section (all)
	2 mm [in degrees]	**5 mm** [in degrees]	**10 mm** [in degrees]		
1	63.4	48.9	30.8	47.7	46.8
2	66.3	52.9	30.9	50.0	50.4
3	66.7	50.6	35.3	50.9	51.3
4	68.3	55.3	43.8	55.8	55.1
5	69.6	62.8	46.8	59.7	58.4
6	71.3	58.4	45.0	58.2	58.8
7	74.5	59.3	44.4	59.4	59.5
8	72.5	59.3	44.3	58.7	58.1
9	74.6	59.9	41.9	58.8	57.5
10	82.8	59.8	42.0	61.5	59.9

Table 23 Edge angle arithmetic mean values for *Keilmesser* modified by the *Prądnik method* (n = 100). The edge angles are calculated with the '2-lines' measurement procedure.

section	distance to origin			mean per section (2-5)	mean per section (all)
	2 mm [in degrees]	**5 mm** [in degrees]	**10 mm** [in degrees]		
1	65.0	41.6	28.5	45.0	46.8
2	64.8	50.5	30.3	48.5	50.4
3	62.8	52.1	32.1	49.0	51.3
4	68.2	54.7	34.2	52.4	55.1
5	64.6	60.9	31.7	52.4	58.4
6	68.2	57.3	33.2	52.9	58.8
7	64.9	66.1	31.6	54.2	59.5
8	70.3	57.8	34.3	54.1	58.1
9	71.2	60.7	42.2	58.0	57.5
10	61.9	47.2	35.4	48.2	59.9

Table 24 Edge angle arithmetic mean values for *Keilmesser* tips (n = 18). The edge angles are calculated with the '2-lines' measurement procedure.

section	distance to origin			mean per section (2-5)	mean per section (all)
	2 mm [in degrees]	**5 mm** [in degrees]	**10 mm** [in degrees]		
1	41.5	26.2	25.8	31.2	30.3
2	42.3	33.6	15.8	30.6	30.6
3	43.8	37.1	17.2	32.7	34.7
4	49.5	40.9	24.1	38.2	39.4
5	59.5	40.5	23.8	41.3	39.4
6	55.8	36.9	20.5	37.7	38.0
7	59.9	36.1	24.4	40.1	41.2
8	62.6	45.6	21.8	43.3	41.4
9	64.8	50.9	16.2	44.0	42.5
10	67.6	47.5	16.7	43.9	43.7

Table 25 Edge angle arithmetic mean values for *Prądnik scrapers* (n = 20). The edge angles are calculated with the '2-lines' measurement procedure.

section	distance to origin			mean per section (2-5)	mean per section (all)
	2 mm [in degrees]	**5 mm** [in degrees]	**10 mm** [in degrees]		
1	32.8	18.3	21.7	24.3	24.9
2	44.4	20.7	21.4	28.8	28.5
3	43.9	20.5	21.1	28.5	28.5
4	44.4	18.1	20.3	27.6	26.7
5	43.9	17.7	17.8	26.5	26.5
6	53.1	18.5	21.3	31.0	29.5
7	47.5	20.3	16.9	28.2	27.6
8	52.7	17.3	15.6	28.5	27.6
9	50.7	14.9	16.1	27.2	25.6
10	35.3	10.2	13.3	19.6	20.5

Table 26 Edge angle arithmetic mean values for *Prądnik spalls* (n = 21). The edge angles are calculated with the '2-lines' measurement procedure.

section	distance to origin			mean per section (2-5)	mean per section (all)
	2 mm [in degrees]	**5 mm** [in degrees]	**10 mm** [in degrees]		
1	74.4	42.4	18.7	45.2	44.4
2	71.7	53.7	22.9	49.4	51.0
3	74.9	52.2	36.8	54.6	54.0
4	78.5	51.8	36.5	55.6	54.9
5	83.3	55.7	43.7	60.9	59.2
6	81.3	58.8	41.5	60.5	60.3
7	76.5	59.5	32.9	56.3	57.1
8	78.2	57.5	30.1	55.3	54.1
9	75.6	52.2	25.8	51.2	51.3
10	83.1	56.4	14.5	51.3	49.0

Table 27 Edge angle arithmetic mean values for scrapers (n = 9). The edge angles are calculated with the '2-lines' measurement procedure.

section	distance to origin			mean per section (2-5)	mean per section (all)
	2 mm [in degrees]	5 mm [in degrees]	10 mm [in degrees]		
1	54.3	30.3	24.8	36.5	39.5
2	59.6	39.7	35.5	44.9	43.3
3	69.4	48.2	39.2	52.3	53.0
4	49.9	47.3	33.9	43.7	46.2
5	55.6	44.2	40.2	46.7	46.8
6	58.3	48.7	43.3	50.1	50.7
7	60.7	42.0	44.2	49.0	48.8
8	58.3	50.6	42.8	50.6	52.5
9	78.4	52.7	51.0	60.7	59.1
10	99.9	109.9	61.5	90.4	91.3

Table 28 Edge angle arithmetic mean values for flakes (n = 2). The edge angles are calculated with the '2-lines' measurement procedure.

5.3.4 'Best-fit' procedure

Lastly, the results from the 'best-fit' measurement procedure will be presented. These results are similar to the ones from the '2-lines' measurements. Since the two procedures are almost identical, except that the 'best-fit' procedure interpolates the points between the 2 mm line, the similarity between the results is not surprising.

The measurements for the Keilmesser display a range from 73.4° to 78.4° at the 2 mm distance to the intersection (**tab. 29**). At 5 mm distance, the values range from 54.6° to 62.6°. The measurements for the 10 mm distance are 27.8° and 46.8°. The arithmetic means for these three distances are 75.2°, 59.8° and 43.2°.

Keilmesser with a negative from the application of the *Prądnik method* result again in lower edge angle values than the *Keilmesser* without modification (**tab. 30**). At a distance of 2 mm from the intersection, the measurements are ranging from 66.4° to 74.3°, with an arithmetic mean value of 70.2°. The range for the 5 mm distance is from 54.9° to 59.9°. The arithmetic mean is 57.6°. At the 10 mm distance, the measurements are 35.2° and 43.7° and the arithmetic mean is 43.6°. Also, in this case, the arithmetic mean value at the 10 mm distance is similar to the one from the *Keilmesser* without modification while the mean values at 2 mm and 5 mm are lower.

The calculated edge angles for the *Keilmesser* tips result in measurements of 63.8° and 71.1° at 2 mm distance (**tab. 31**). At a distance of 5 mm, the values are 50.4° and 62.5°. The range for the 10 mm distance is 42.5° to 41.7°. The arithmetic mean values amount to 66.7°, 58.6° and 40.3°.

For the *Prądnik scrapers*, the following results were calculated with the 'best-fit' measuring procedure (**tab. 32**). At the 2 mm distance to the intersection, the values are 42.6° and 65.0° with an arithmetic mean of 55.1°. The measurements at 5 mm range from 34.0° to 51.7°. The mean value is 41.2°. At the 10 mm distance, the measurements are 19.9° and 19.4° and the arithmetic mean is 25.3°.

The analysed *Prądnik spalls* display at the 2 mm distance a range of 46.0° to 54.9° (**tab. 33**). At the 5 mm distance, the values range from 21.9° to 15.4°. The measurements at the 10 mm distance are 33.3° and 25.2°. The calculated arithmetic mean values of these three distances are 49.8°, 23.1° and 26.9°.

The scrapers, representing one artefact category of the sampled outgroup, display at the 2 mm distance measurements of 71.1° and 74.9° with an arithmetic mean value of 77.2 (**tab. 34**). The range for the 5 mm distance is from 67.8° to 52.1°. The arithmetic mean is 56.9°. At the 10 mm distance, the measurements are 23.1° and 43.8° and the arithmetic mean is 38.2°.

The measurements for the flakes result in a range of 60.5° to 77.2° at the 2 mm distance from the intersection (**tab. 35**). For the measurements at the 5 mm distance, the values are 40.7° and 53.5°. At 10 mm distance to the intersection, the values ranging from 35.9° to 52.3°. The edge angle measurements result in arithmetic mean values of 60.6°, 46.9° and 41.8° per mentioned distance.

section	**distance to origin**			**mean per section** (2-5)	**mean per section** (all)
	2 mm [in degrees]	**5 mm** [in degrees]	**10 mm** [in degrees]		
1	76.0	55.1	38.4	56.5	56.6
2	73.4	54.6	27.8	51.9	51.7
3	71.7	59.3	45.6	58.9	58.8
4	72.7	58.5	47.3	59.5	59.5
5	73.7	61.5	47.4	60.9	61.6
6	77.5	59.0	45.9	60.8	59.8
7	73.9	63.3	44.1	60.4	60.0
8	80.2	59.6	41.0	60.3	61.3
9	78.4	62.6	46.8	62.6	63.4
10	84.2	66.3	47.4	66.0	65.2

Table 29 Edge angle arithmetic mean values for *Keilmesser* (n = 57). The edge angles are calculated with the 'Best-fit' measurement procedure.

section	distance to origin			mean per section (2-5)	mean per section (all)
	2 mm [in degrees]	**5 mm** [in degrees]	**10 mm** [in degrees]		
1	63.4	50.0	30.8	48.1	49.5
2	66.4	54.9	35.2	52.2	53.0
3	66.3	51.2	37.1	51.5	52.3
4	67.6	56.0	44.5	56.0	56.9
5	69.4	63.2	48.6	60.4	59.9
6	71.4	57.9	50.5	59.9	59.4
7	74.4	59.0	44.0	59.1	59.9
8	71.9	59.0	45.3	58.7	59.2
9	74.3	59.9	43.7	59.3	58.3
10	82.8	59.6	43.7	62.0	60.8

Table 30 Edge angle arithmetic mean values for *Keilmesser* modified by the *Prądnik method* (n = 100). The edge angles are calculated with the 'Best-fit' measurement procedure.

section	distance to origin			mean per section (2-5)	mean per section (all)
	2 mm [in degrees]	**5 mm** [in degrees]	**10 mm** [in degrees]		
1	64.8	47.5	41.1	51.1	49.5
2	63.8	50.4	42.5	52.2	53.0
3	63.6	58.3	43.3	55.1	52.3
4	68.8	54.5	39.6	54.3	56.9
5	64.5	60.1	31.8	52.1	59.9
6	67.8	57.9	50.4	58.7	59.4
7	64.2	65.2	31.6	53.7	59.9
8	69.7	59.6	41.7	57.0	59.2
9	71.1	62.5	41.7	58.4	58.3
10	60.8	48.0	35.1	48.0	60.8

Table 31 Edge angle arithmetic mean values for *Keilmesser* tips (n = 18). The edge angles are calculated with the 'Best-fit' measurement procedure.

section	distance to origin			mean per section (2-5)	mean per section (all)
	2 mm [in degrees]	**5 mm** [in degrees]	**10 mm** [in degrees]		
1	41.0	27.6	30.0	32.9	37.3
2	42.6	34.0	19.9	32.2	33.7
3	44.0	37.5	22.1	34.5	37.1
4	50.3	46.1	27.1	41.2	42.1
5	58.5	40.6	30.2	43.1	43.4
6	57.7	36.4	24.8	39.6	38.5
7	61.0	37.5	29.2	42.6	43.9
8	61.3	45.5	30.0	45.6	43.2
9	65.5	51.7	19.4	45.5	43.7
10	66.3	47.3	74.6	62.7	50.2

Table 32 Edge angle arithmetic mean values for *Prądnik scrapers* (n = 20). The edge angles are calculated with the 'Best-fit' measurement procedure.

section	distance to origin			mean per section (2-5)	mean per section (all)
	2 mm [in degrees]	**5 mm** [in degrees]	**10 mm** [in degrees]		
1	37.0	19.3	23.9	26.7	34.0
2	46.0	21.9	33.3	33.7	36.6
3	43.4	20.6	23.7	29.2	31.0
4	53.5	27.5	34.0	38.3	38.7
5	43.6	18.8	27.3	29.9	32.0
6	54.0	33.6	32.0	39.9	36.6
7	47.7	19.8	24.4	30.6	33.0
8	55.1	27.3	15.6	32.7	35.0
9	54.9	15.4	25.2	31.8	33.8
10	47.4	21.0	38.3	35.6	28.0

Table 33 Edge angle arithmetic mean values for *Prądnik spalls* (n = 21). The edge angles are calculated with the 'Best-fit' measurement procedure.

section	distance to origin			mean per section (2-5)	mean per section (all)
	2 mm [in degrees]	**5 mm** [in degrees]	**10 mm** [in degrees]		
1	72.7	41.3	34.2	49.4	46.6
2	71.1	67.8	23.1	54.0	53.6
3	74.7	50.8	53.9	59.8	55.4
4	77.7	51.6	35.9	55.1	54.9
5	82.9	55.9	45.0	61.3	59.3
6	81.8	58.0	41.3	60.4	61.6
7	76.7	60.8	32.2	56.6	57.1
8	77.6	58.4	30.5	55.5	55.7
9	74.9	52.1	43.8	56.9	54.6
10	82.6	56.5	14.3	51.1	49.3

Table 34 Edge angle arithmetic mean values for scrapers (n = 9). The edge angles are calculated with the 'Best-fit' measurement procedure.

section	distance to origin			mean per section (2-5)	mean per section (all)
	2 mm [in degrees]	**5 mm** [in degrees]	**10 mm** [in degrees]		
1	54.5	33.2	25.4	37.7	39.6
2	60.5	40.7	35.9	45.7	43.2
3	71.3	48.7	39.4	53.1	53.1
4	48.9	48.0	33.6	43.5	46.8
5	53.7	44.5	41.1	46.4	46.8
6	56.1	48.7	45.6	50.1	50.7
7	61.3	40.7	43.3	48.4	48.9
8	55.7	50.2	43.0	49.6	52.5
9	77.2	53.5	52.3	61.0	59.2
10	96.0	109.1	60.7	88.6	91.8

Table 35 Edge angle arithmetic mean values for flakes (n = 2). The edge angles are calculated with the 'Best-fit' measurement procedure.

5.3.5 Edge angle data analysis

When taking all the data concerning the edge angle analysis into account, the differences in the results from the three measurement procedures are primarily noticeable. The differences between the '2-lines' and the 'best-fit' procedures are comparable small. The measurements at 2 mm and 5 mm distance from the intersection display a variance of 0.2° up to 3.6°. Only at the 10 mm distance, a difference of 8.1° is noticeable between the results of the '2-lines' and the 'best-fit' measurement procedures. The variance between these results and the results of the '3-point' measurement procedure is significantly higher. However, the results reflect the same tendencies and are not randomly different. Instead, the results calculated with the '3-point' procedure are always around 10° to 20° higher. Beforehand conducted, controlled tests with an artefact, an experimental flake and a calibrated standard angle (gauge block; edge angle known) led to the exact same conclusion. These tests were done in order to validate the reliability of the method. The results of the three measurement procedures reflect the same tendencies and patterns although the calculated edge angles with the '3-point' procedure are always higher. As mentioned earlier, it seems like the '3-point' measurement is leading to reliable results when edge angles of simple objects are measured. As soon as the object is more complex and does not have plain surfaces, the '2-lines' and the 'best-fit' procedures seem to lead to more precise data.

Another striking aspect regarding the data are the different results calculated for the three presented distances to the intersection. In general, the variance between the distances is for all artefact categories higher that the variance along the edge. When considering all artefact categories, especially the distance at 2 mm stands out. This is not entirely unexpected. Two aspects are relevant when interpreting the data. The first one is the resolution of the 3D model. The data can only be as good as the resolution of 3D model. In particular, the acute edges of the artefacts are often difficult to document with a 3D scanner. When zooming extremely into a 3D model, the edges of the models always appear curved instead of sharp. Therefore, the results calculated for the first probably 1 to 3 mm should likely be higher than the edge angle values calculated for the following distances. The second aspect is the human factor. Although the method is predominantly script- and algorithm-based, some steps need to be done manually. One of these steps is the digitalisation of the edge by defining a vertical polyline. Placing this polyline in the correct position is complicated when the edge of the scanned artefact is curved. Thus, it can happen that the line was placed for instance 1 mm too far towards one tool surface. As a result, the edge angle value will be higher than it would be in reality. To summarize, the measurements taken really close to the edge are likely to be affected by at least one of the described issues. This should be reflected by higher edge angle values at the first few distances from the intersection.

After highlighting some general aspects, aspects concerning specific artefact categories are discussed in the following. First of all, it has to be mentioned that not only the edge angles for the active edge were calculated. *Per* tool, two edges (E1 and E2) have been digitalised. In the case of *Keilmesser* often even three edges (E3). The distinction between a back and an active edge is mostly simple. *Keilmesser* in particular often have such a pronounced and thick back, that the back can only be defined by two edges. Nevertheless, the idea was to calculate the edge angles from all existing edges *per* artefact in order to be as objective as possible. The results of this second and/or third edge per tool can be found on GitHub [https://github.com/lschunk/edge_angle_analysis]. The graphic representation of the measured edge angles for each artefact also includes all edges. Since the focus, when presenting the data, was only on the active edge, the results for the *Keilmesser* edges representing the back will be addressed here only briefly. In general, there is no recognisable trend that shows the edge angle values change along the edge. There is a variance along the edge, but the values do not increase towards the proximal part of the tool. The edge angle values along the edge as well as the ones from the different distances seem to be slightly higher compared to the values from the *Keilmesser* active edge. Although edge angle values around 70° were calculated, also values above 100° were documented.

The second topic refers to the artefact morphology. The tool morphology seems to be reflected in the data. Tools including *Keilmesser* and *Prądnik scrapers* but also scrapers have deviating edge angle values at 5 mm and 10 mm distance, while *Prądnik spalls* and flakes display no remarkable differences between the measurements. Since bifacially worked tools or especially *Keilmesser* and *Prądnik scrapers* do not necessarily have flat surfaces, the curvature of the surface will be reflected by changing edge angle values with increasing distance to the intersection. The *Prądnik spalls* and flakes do not reflect this change between the measurements at 5 mm and 10 mm distance.

Another aspect is the edge angle variability along the edge of *Keilmesser* (**fig. 116, 118**). The data calculated for the *Keilmesser* (with and without modification) illustrates a change in the edge angle from the distal to the proximal part of the *Keilmesser* around approximately 10°. According to the data, the edge is on average more acute in the distal part of the tool than in the proximal area. The same is documented for the *Prądnik scrapers*.

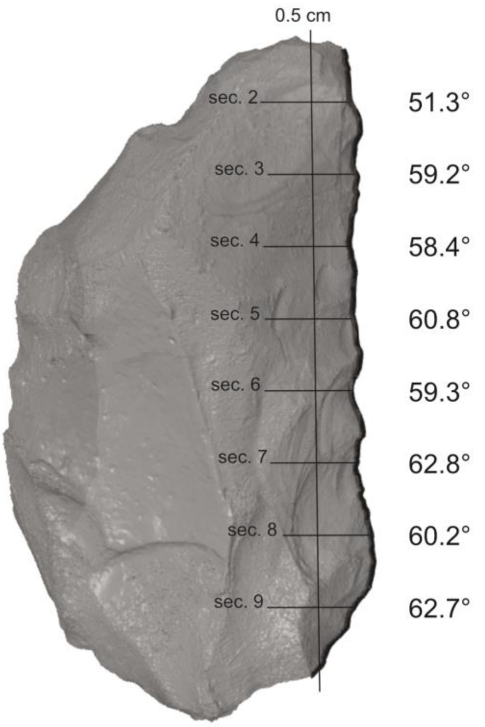

Fig. 116 Edge angle variability at 0.5 cm distance from the intersection for all measured *Keilmesser* (n = 57) without *Prądnik method* modification. The edge angle values display mean values calculated with the '2-lines' procedure. The 0.5 cm vertical line is only schematic. Normally, this line follows the shape of the digitalised active edge.

Additionally, the *Keilmesser* with a modification through the *Prądnik method* do display a lower, sharper edge angle in the distal tool area than *Keilmesser* without the modification (**fig. 117**). This difference is only small and does not exceed 10°.

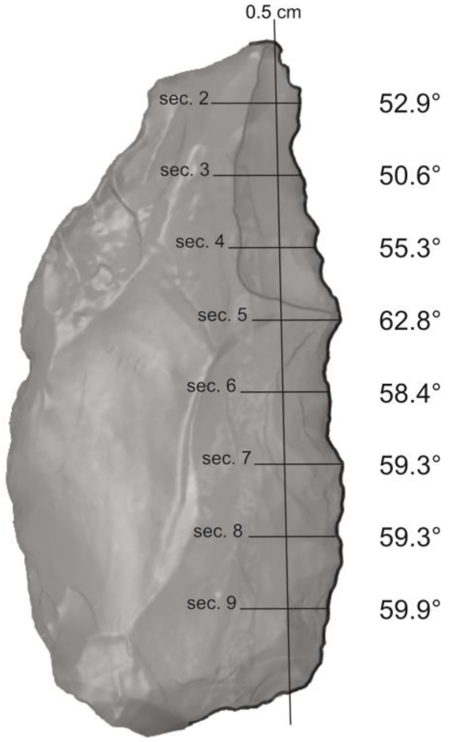

Fig. 117 Edge angle variability at 0.5 cm distance from the intersection for all measured *Keilmesser* (n = 100) with *Prądnik method* modification. The edge angle values display mean values calculated with the '2-lines' procedure. The 0.5 cm vertical line is only schematic. Normally, this line follows the shape of the digitalised active edge.

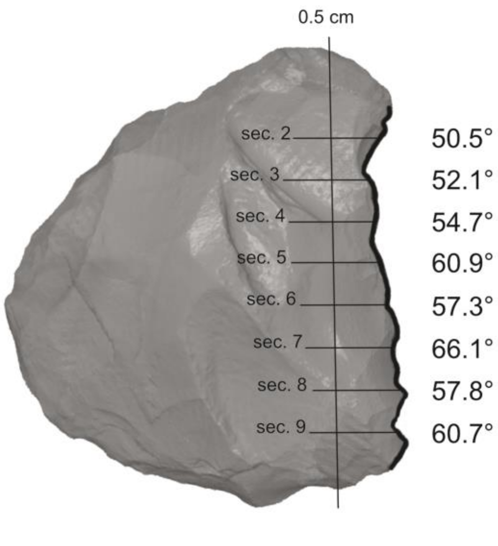

Fig. 118 Edge angle variability at 0.5 cm distance from the intersection for all measured *Keilmesser* tips (n = 18). The edge angle values display mean values calculated with the '2-lines' procedure. The 0.5 cm vertical line is only schematic. Normally, this line follows the shape of the digitalised active edge.

Prądnik scrapers do have more acute edge angles than *Keilmesser* (**fig. 119**). The calculated edge angles for the *Prądnik scraper* are on average 20° lower.

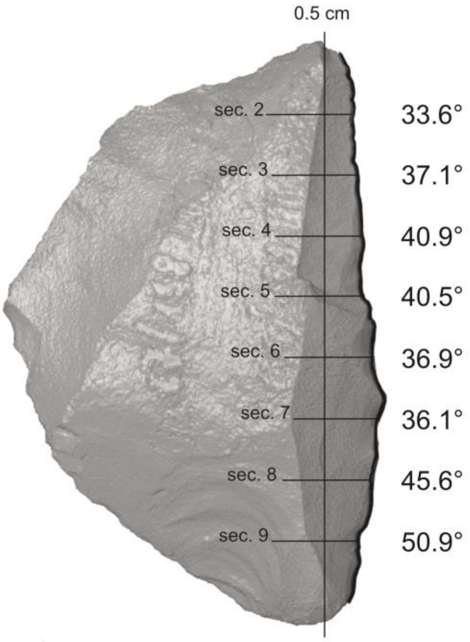

Fig. 119 Edge angle variability at 0.5 cm distance from the intersection for all measured *Prądnik scrapers* (n = 20). The edge angle values display mean values calculated with the '2-lines' procedure. The 0.5 cm vertical line is only schematic. Normally, this line follows the shape of the digitalised active edge.

The *Prądnik spalls*, when excluding the measurements at the 2 mm distance to the intersection for the mentioned reasons, display significantly lower edge angles values compared to the tools (**fig. 120**). The values range between 20° and 25°. Additionally, the edge angle values for the *Prądnik spalls* display in general only a small variance (~ 5°) and are in comparison more constant along the edge and towards the surface.

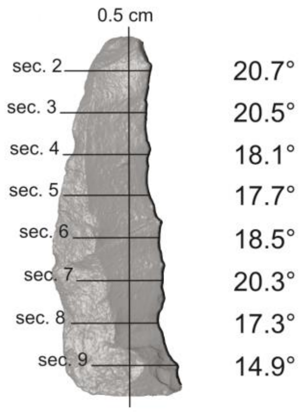

Fig. 120 Edge angle variability at 0.5 cm distance from the intersection for all measured *Prądnik spalls* (n = 21). The edge angle values display mean values calculated with the '2-lines' procedure. The 0.5 cm vertical line is only schematic. Normally, this line follows the shape of the digitalised active edge.

The last aspect to address is the result from the outgroup. A small quantity of scrapers (**fig. 121**) and flakes (**fig. 122**) were included in the edge angle measurements in order to have a possibility to put the results from the *Keilmesser* and *Prądnik scraper* in context. The variability along the edge with the tendency of an increasing edge angle towards the proximal part of the tool as noticed for the *Keilmesser* and *Prądnik scraper* cannot be documented for the scrapers and flakes. Moreover, the edge angle values are in general lower. In particular, the flakes with edge angle values between 30° and 40° have more acute edges than *Keilmesser*. However, these values are similar to the measurements from the *Prądnik scrapers*.

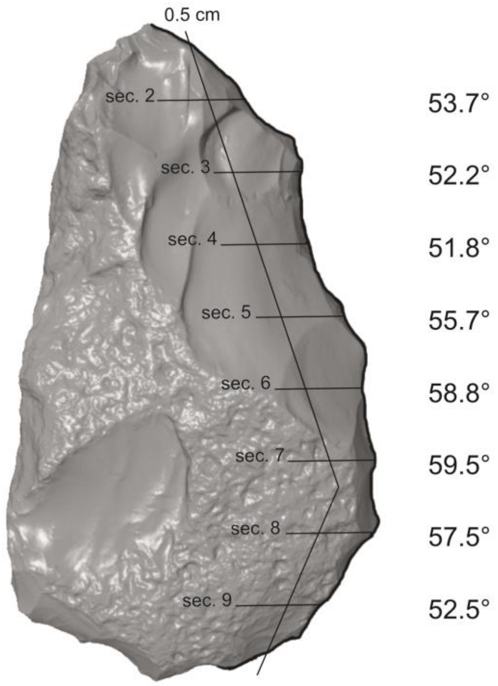

Fig. 121 Edge angle variability at 0.5 cm distance from the intersection for all measured scraper (n = 9). The edge angle values display mean values calculated with the '2-lines' procedure. The 0.5 cm vertical line is only schematic. Normally, this line follows the shape of the digitalised active edge.

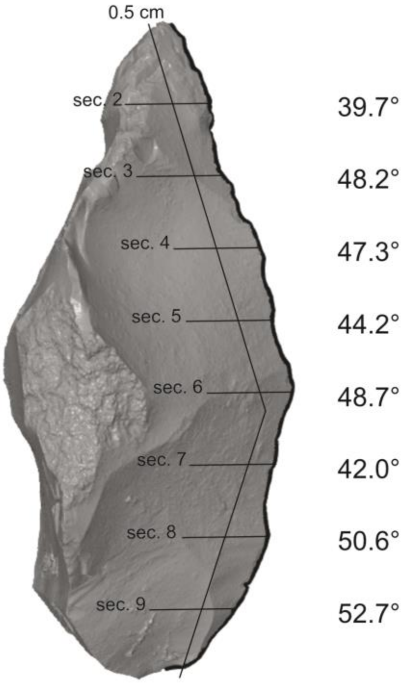

Fig. 122 Edge angle variability at 0.5 cm distance from the intersection for all measured flakes (n = 2). The edge angle values display mean values calculated with the '2-lines' procedure. The 0.5 cm vertical line is only schematic. Normally, this line follows the shape of the digitalised active edge.

5.4 Use-wear analysis

This subchapter addresses the results of the conducted use-wear analysis. First, the results of the qualitative assessment are presented. This includes the location, the orientation and the description of the use-were traces. Subsequently, the results of the quantitative use-wear are addressed.

5.4.1 Qualitative use-wear analysis

Use-wear analysis is a time-consuming approach. For that reason, a sub-sampling of the assemblage under study was needed. The sampling was done during the techno-typological analysis. The base for the sampling was thereby the research question. Since the research question focusses on specific tools – *Keilmesser* and *Prądnik scrapers* – these tools were predominantly selected. Also relevant in order to address the research question are the *Prądnik spalls*, which have been removed from the *Keilmesser* and *Prądnik scrapers* at a certain stage within the use-life history of the tools. In order to be able to put the results in relation with other artefact categories afterwards, some other tools were additionally sampled. A small number of scrapers and flakes was selected as outgroup. Only complete and well-preserved artefacts from the three archaeological assemblages were chosen for the use-wear analysis and all *Keilmesser* shapes were selected.

Having this as a prerequisite, with n = 200 artefacts, more than one third of the entire assemblage was sampled for the qualitative use-wear analysis (**tab. 9**). These n = 200 sampled artefacts divide in n = 119 *Keilmesser*, whereas n = 10 of these are *Keilmesser* tips, n = 23 *Prądnik scrapers* as well as n = 39 *Prądnik spalls*. This means, more than one third (36.1%) of the entire *Keilmesser* assemblage was part of the qualitative use-wear analysis, while nearly half of the *Prądnik scrapers* (42.6%) have been studied. *Prądnik spalls* were less frequently involved in this analysis with 24.5%. less frequently. The outgroup consist of n = 17 scrapers and n = 2 flakes. The n = 200 artefacts are not sampled equally from the three archaeological sites. Since the assemblage from Ramioul is comparatively small, the entire n = 20 samples were included for the qualitative use-wear analysis. The macroscopic preservation (e.g. no edge damage) in Buhlen seemed better than the one in Balve. Therefore, more artefacts from Buhlen were sampled. Thus, the sampled artefacts are to 50.5% (n = 101) from Buhlen, to 39.5% (n = 79) from Balve and to 10.0% from Ramioul.

The samples were studied with an upright light microscope (ZEISS Axio Scope.A1 MAT) under a 5 x, 10 x and 20 x magnification. By doing so, traces could be found on n = 150 pieces out of the sampled n = 200 artefacts (**tab. 36**). Although Buhlen was samples most numerously, the artefacts from Buhlen displayed the fewest use-wear traces. On only n = 65 artefacts traces could be documented. The preservation for the material from Balve was estimated as poorer and therefore less suitable for a use-wear analysis. Surprisingly, n = 68 out of n = 79 selected pieces displayed use-wear traces. The complete studied assemblage from Ramioul (n = 20) was selected for the use-wear analysis. The material from Ramioul appeared as less well preserved. Most of the edges and higher micro topographical areas seemed rounded and affected. Moreover, the light coloured, almost white flint made the detection of use-wear traces more complicated. Nevertheless, on n = 17 artefacts traces could be documented.
The tool areas displaying use-wear traces were documented as EDF stitching images with a digital microscope (ZEISS Smartzoom 5) by using a 1.6 x objective and 34-x zoom. All use-wear traces are illustrated as figures in the supplementary material.

sites	use-wear	artefact category						
		Keilmesser	*Keilmesser tip*	*Prądnik scraper*	*Prądnik spall*	scraper	flake	total
Buhlen	with traces [n]	34 (33.6%)	7 (6.9%)	12 (11.9%)	11 (10.9%)	1 (1.0%)	0 (0.0%)	65 (64.3%)
	without traces [n]	24 (23.8%)	1 (1.0%)	3 (3.0%)	7 (6.9%)	1 (1.0%)	0 (0.0%)	36 (35.7%)
Balve	with traces [n]	40 (50.6%)	2 (2.5%)	2 (2.5%)	16 (20.3%)	8 (10.1%)	0 (0.0%)	68 (86.1%)
	without traces [n]	2 (2.5%)	0 (0.0%)	3 (3.8%)	5 (6.3%)	1 (1.3%)	0 (0.0%)	16 (13.9%)
Ramioul	with traces [n]	8 (40.0%)	0 (0.0%)	3 (15.0%)	0 (0.0%)	5 (25.0%)	1 (5.0%)	17 (85.0%)
	without traces [n]	1 (5.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	1 (5.0%)	1 (5.0%)	3 (15.0%)
total	with traces [n]	82 (41.0%)	9 (4.5%)	17 (8.5%)	27 (13.5%)	14 (7.0%)	1 (0.5%)	150 (75.0%)
	without traces [n]	27 (13.5%)	1 (0.5%)	6 (3.0%)	12 (6.0%)	3 (1.5%)	1 (0.5%)	50 (25.0%)

Table 36 Numbers of artefacts per site and artefact category studied with a qualitative use-wear analysis. The percentages in brackets relate to the number of artefacts per assemblage.

5.4.1.1 Analysis use-wear traces and spatial pattern recognition

During the performance of the qualitative use-wear analysis, all traces were documented in the beforehand described scheme (see chapter 4.5.3.1; **fig. 26**). Hence, not only the location of each trace on the artefacts was recorded, but also, if possible, the type (polish, striation or impact marks) and the orientation (perpendicular, parallel or oblique to the edge). After performing the qualitative use-wear, all documented traces of the n = 150 artefacts with use-wear were sorted and visually categorised (**appendix II. and III.**). Important criteria for the categorisation were the appearance of the traces, their extension, their orientation as well as the abrasiveness on the surface. In this way, nine types of traces were defined (described below).
The different types were named in a simple way by giving, as soon as a category was defined, a letter as a name, starting with the letter 'A'. When two categories were nearly identical, but for instance, only the orientation of the striations was different, the addition '2' was given. In three cases, no clear category could be given. These traces appeared like a combination out of two already defined categories. Therefore, next to the seven categories, also 'C/E', 'C/D' and 'C/A' exist.
Afterwards, a reordering of these types was done in order to make the descriptions more comprehensible and the order more logical. However, the former names of the categories are additionally given since these names also appear in the plots. A description of the traces is given in the following (**fig, 123**, **tab. 37**).

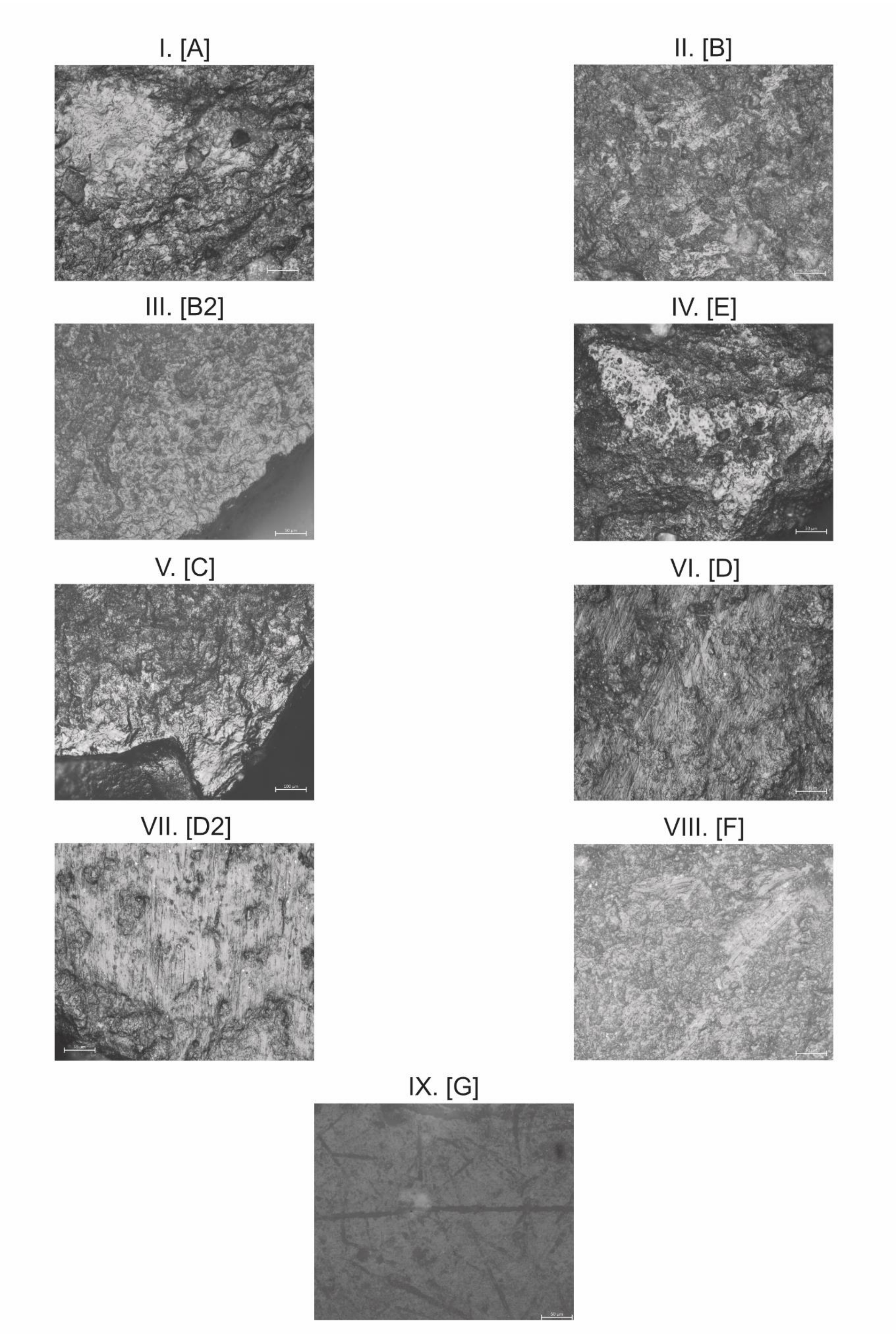

Fig. 123 Documented qualitative use-wear types (all images are taken with a 20x optical objective).

type	main features	description	topographical location
I. [A]	polish	small & bright polished circle	highest micro topography
II. [B]	polish	small & bright area of polish	highest micro topography
III. [B2]	polish	extended area of polish	highest micro topography
IV. [E]	polish	small areas of smooth & compact polish	highest micro topography
V. [C]	polish	extensive & continues and bright & shiny polish	lowest and highest micro topography
VI. [D]	polish & striation	smooth polish with randomly orientated striations; small area	lowest and highest micro topography
VII. [D2]	polish & striation	smooth polish with orientated striations; small area	lowest and highest micro topography
VIII. [F]	striation	small & orientated striations	lowest and highest micro topography
IX. [G]	polish, furrows & groves	dull & abrasive polish, deep furrows and groves	lowest and highest micro topography

Table 37 Description of the documented use-wear traces including their topographical location.

I. The first category is characterised by small polished spots. These spots appear as bright, intact circles. The polish is only slightly abrasive and affects only the highest micro topography. An orientation is indeterminable. [A]

II. The second category is also a polish. This time the polish is not limited to a spot, instead it is extended to a small area. Again, only the highest topographical locations are affected. The abraded, polished areas appear bright and slightly scattered. The polish can be parallel or perpendicular to the tool edge or without clear orientation. [B]

III. The third type of polish is in its appearance identical to the second category (II/B), but the distribution is more extensive. The polished areas occur most often parallel to the tool edge. [B2]

IV. The fourth category is another type of polish. The polish is smooth and distinctly more compact. In terms of the extension, the polish is comparable with the second category (II/B) and only appears in small, sometimes elongated areas. Despite the compact appearance, the polish can be found only on the highest topographical locations. This polish has either no orientation or is parallel to the edge orientated. [E]

V. The fifth category is again a polish. The polish is extensive and continual and appears as bright and shiny. Not only the highest topographical locations are abraded, but also lower topography. The orientation is most often indeterminable or otherwise parallel to the edges. [C]

VI. Category six combines a smooth polish with randomly orientated striations. The traces are not selected, instead they are extended over small areas. The polish is abrasive, affects all topographical locations, the highest and the lowest topography. The striations do not reach deeper than the polish. In the majority, the traces do not have an orientation. [D]

VII. The seventh category is identical to the category described before (VI/D). The only difference can be found in the orientation. The striations are not randomly orientated, they are orientated towards one direction. Since the striations do have an orientation, it was also possible to define the orientation of the traces in general. Most often, the traces are orientated perpendicular to the tool edges. [D2]
VIII. The eighth category can be described by orientated striations, which are not extensive and limited in their dimensions. The linear scratches affect the lowest as well as the highest topographical locations. These traces can be either parallel, perpendicular or oblique towards the edges. [F]
IX. The ninth and thus the last category displays a dull and abrasive polish. The polish is additionally combined with shallow or deep furrows and groves. The linear striations are randomly orientated and sometimes reach deeper than the polish. These traces are extensive and cover big areas of the surface while affecting all topographical locations, causing a surface deformation. The orientation is indeterminable. The category can be found close to the edge, but also extending towards the surface. [G]

Although the studied silicified schist samples clearly outnumber the flint samples, the mentioned use-wear types were documented on silicified schist as well as on flint samples. The categories do not differ depending on the raw material. However, one type was only documented on silicified schist, not on flint. This is type II. (B). However, type III. (B2) was documented and only differs concerning the extension of the trace.

artefact category	**use-wear type** [n]										
	I. (A)	**II.** (B)	**III.** (B2)	**IV.** (E)	**V.** (C)	**VI.** (D)	**VII.** (D2)	**VIII.** (F)	**IX.** (G)	**V. /** IV.	**V. /** VI.	**total**
Keilmesser	38	19	2	15	89	9	8	6	3	5	1	**195**
Prądnik scraper	9	0	0	0	19	0	1	0	3	1	0	**33**
Prądnik spall	7	4	0	0	33	2	0	2	0	5	0	**53**
scraper	4	3	1	5	18	0	2	2	4	1	0	**40**
total	**58**	**26**	**3**	**20**	**159**	**11**	**11**	**10**	**10**	**12**	**1**	**321**

Table 38 Number of documented use-wear traces on artefacts from Buhlen, Balver Höhle and Ramioul per use-wear type and artefact category.

In qualitative use-wear analysis, the first step is the recognition and the characterisation of use-wear types on the analysed artefacts. The aim of a use-wear analysis is to identify the observed traces in order to gain a functional interpretation of the different tools. In a qualitative use-wear analysis, this is solely based on visual identifications and characterisation. It is known that not only the worked material (Keeley, 1980; Haslam et al., 2009; Rots, 2013), but also the raw material, the use intensity and the performed task haven an impact on the formation of the use-wear traces (Buc, 2011; Marreiros et al., 2020). Without a widespread and highly reliable reference collection, the aim of a

functional interpretation of the observed use-wear traces can barley be observed. For silicified schist, there is no such reference collection existing yet. Thus, the aspiration of identifying the use-wear traces based on a qualitative use-wear analysis will not be fulfilled within this project.
Despite this, one single interpretation regarding the described use-wear categories will be made. The interpretation refers to the ninth category (IX/G). The described features of the traces are distinctly different from the other categories. These features do not look like use-wear traces, instead, they will be interpreted as post-depositional traces.
After analysing the artefacts, observing, categorising and describing the traces, the location of these traces was transformed from the manually filled scheme into a geographical information system (QGIS, version 3.14.16). Each use-wear trace was illustrated by a coloured point. The points were coloured according to the use-wear type categorisation.
The results of this graphical representation are presented in the following organised by artefact categories. Before doing so, one issue needs to be explained. Per tool category, one outline was used in order to locate the use-wear traces. These outlines were divided into areas, whereas A and B always displayed the dorsal and D and C the ventral surface of the tool. The orientation of these areas changed when looking at a left sided instead of a right sided tool. Since the specific lateralisation of the artefacts had no priority in the context of the location of the use-wear traces, all use-wear traces from left sided artefacts were transferred to the right sided scheme in order to fit a uniform scheme.

For *Keilmesser*, all described nine use-wear categories were documented (**fig. 124**). Surface modifications in the sense of use-wear or post-depositional traces could be documented on in total n = 195 locations (**tab. 38**). Although the surfaces of the tools were checked entirely, most of the use-wear traces can be found along the active edge. This counts for 77.4 % (n = 151) of the traces. The ventral surface shows thereby slightly more traces (n = 80) than the dorsal surface (n = 71). The traces are of all documented types, but the majority (n = 37) can be categorised as V. (C). Conspicuously often (n =26) along the edge is also the category I. (A). A third category, type II. (B), sticks out a little with n = 9 documented spots. The remaining categories could be documented on one to five locations.

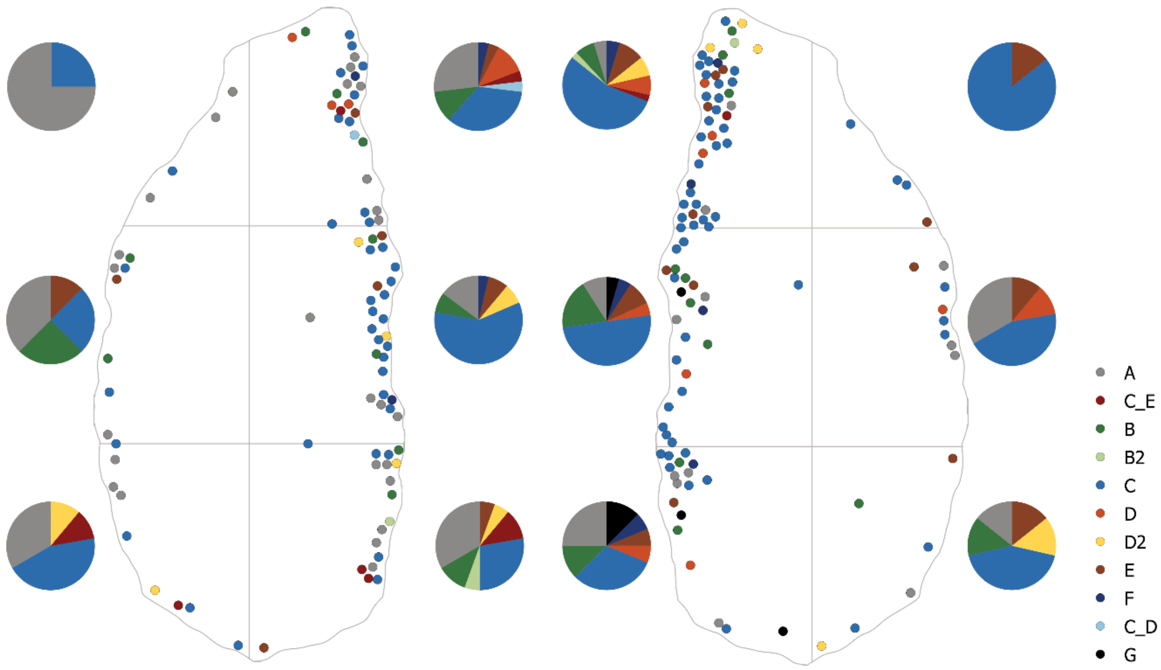

Fig. 124 Distribution of all the use-wear traces documented on *Keilmesser*. The left side illustrates the dorsal surfaces of the tool, the right side the ventral tool surface. The colours indicate the use-wear types.

These results differ when looking at the plotted traces from the three studied sites individually. All the aforementioned observations concerning the location of the use-wear traces is still valid. However, the occurrence of the documented use-wear types differ from site to site. The diversity of use-wear types reflected on all analysed *Keilmesser* together is not present on the *Keilmesser* from Buhlen only (**fig. 125**). Besides a few exceptions in the proximal part of the tools on the dorsal surface, the *Keilmesser* from Buhlen display solely use-wear traces of the category I. (A) or V. (C).

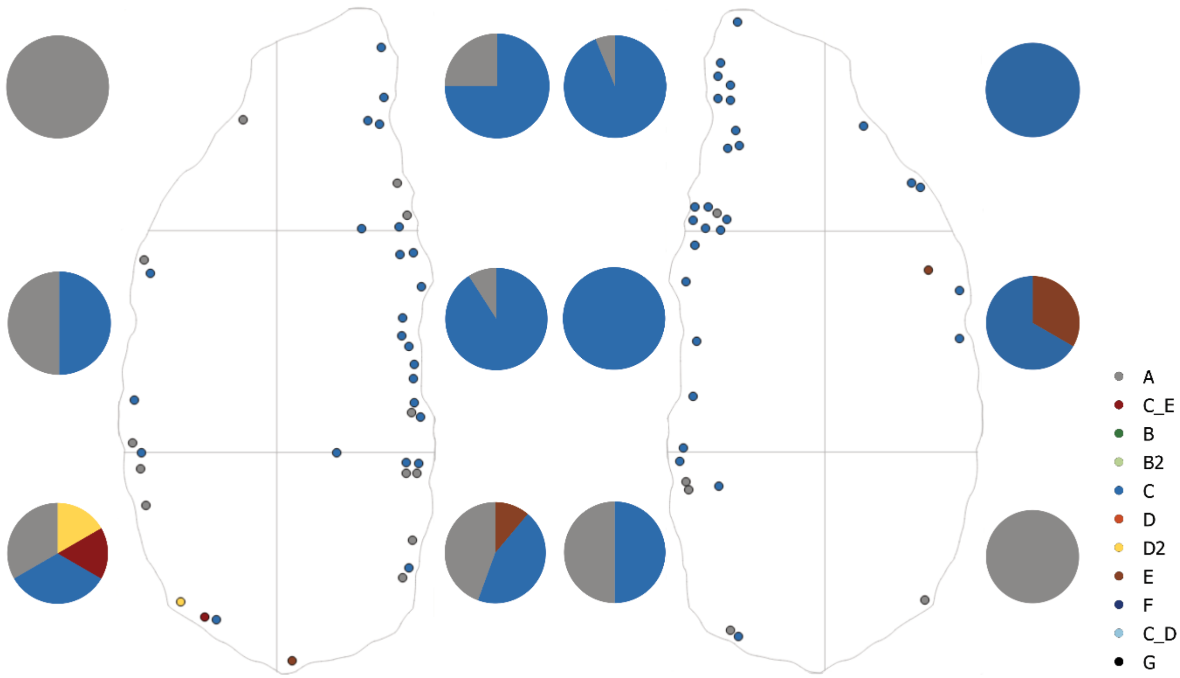

Fig. 125 Distribution of all the use-wear traces documented on *Keilmesser* from Buhlen. The left side illustrates the dorsal surfaces of the tool, the right side the ventral tool surface. The colours indicate the use-wear types.

The documented traces on the artefacts in Balve do reflect the variety of use-wear types noticed for all *Keilmesser* from the three sites together (**fig. 126**). Eight of the nine use-wear categories can be found on the *Keilmesser* from Balve. The only missing category is type IX. (G), the type interpreted as post-depositional trace.

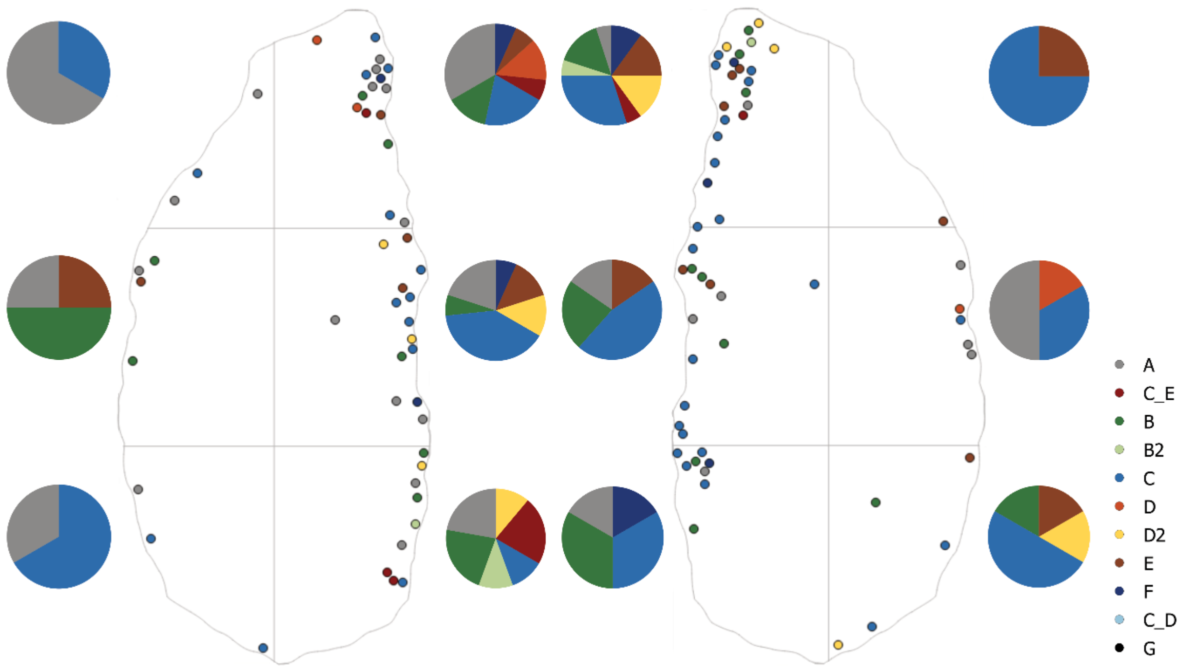

Fig. 126 Distribution of all the use-wear traces documented on *Keilmesser* from Balver Höhle. The left side illustrates the dorsal surfaces of the tool, the right side the ventral tool surface. The colours indicate the use-wear types.

Despite the small quantity of analysed *Keilmesser* from the site Ramioul, the variety of documented use-wear traces is nearly comparable to the results from Balve (**fig. 127**). The observed traces are located only along the active edge. Except for the three use-wear categories I. (A), III. (B2) and VIII. (D2), all other types could be documented on the artefacts.

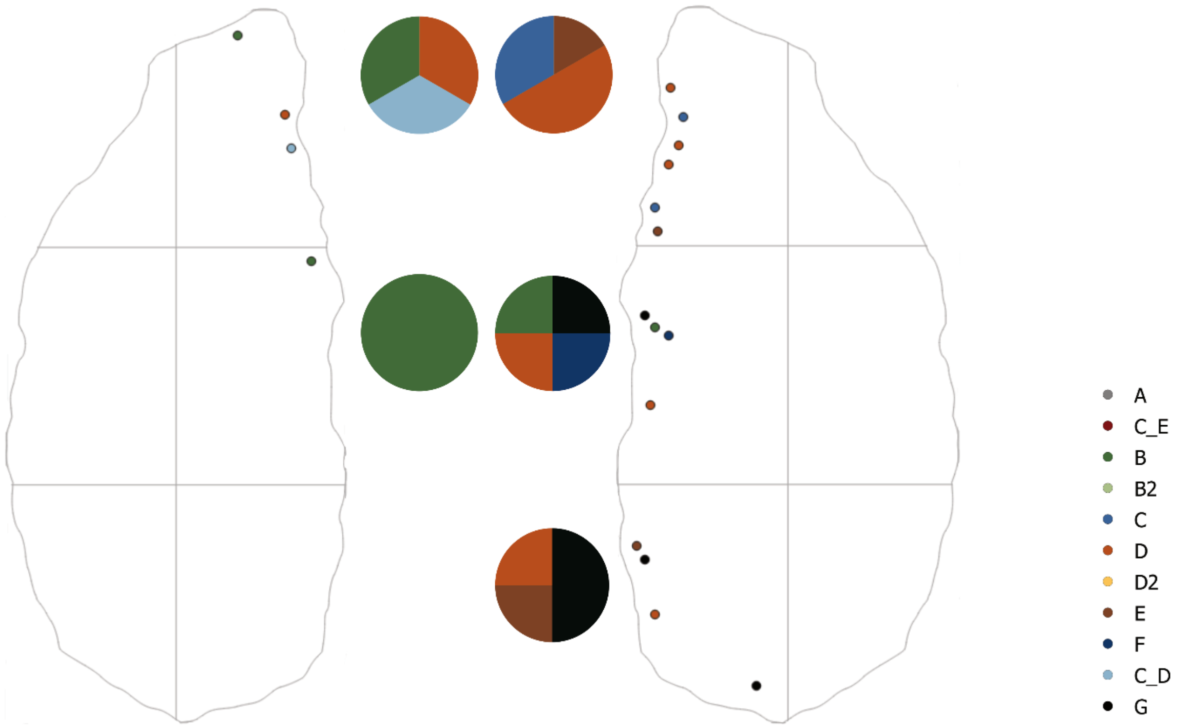

Fig. 127 Distribution of all the use-wear traces documented on *Keilmesser from Ramioul*. The left side illustrates the dorsal surfaces of the tool, the right side the ventral tool surface. The colours indicate the use-wear types

The results for the analysed *Prądnik scrapers* do look different (**fig. 128**). First of all, not many traces (n = 33) could be documented as measured by the smaller number of tools, compared to the *Keilmesser*. Most of the traces could be found again along the active edge (n = 25) with a majority of traces on the ventral surface (n = 14). Moreover, the diversity of use-wear types is also different. The surface modifications on *Prądnik scrapers* can be attributed to 84.9 % (n = 27) to the types V. (C) and I. (A), but type V. clearly predominates (n = 19). Three times, the category IX., interpreted as post-depositional traces, was found on two tools.

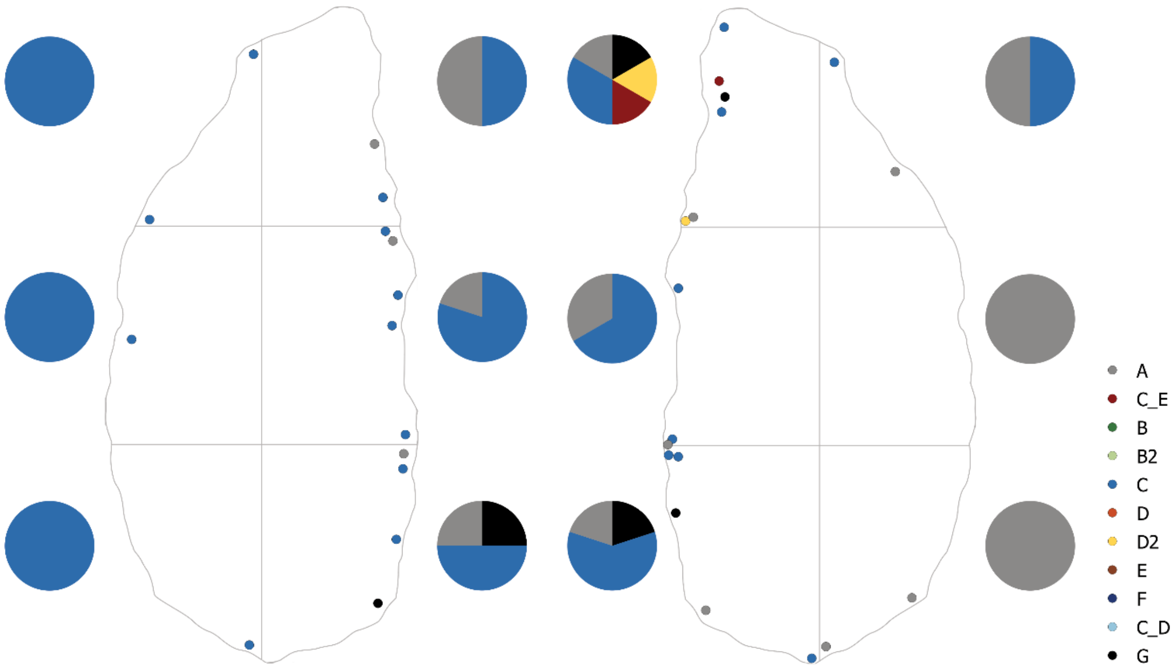

Fig. 128 Distribution of all the use-wear traces documented on *Prądnik scrapers*. The left side illustrates the dorsal surfaces of the tool, the right side the ventral tool surface. The colours indicate the use-wear types.

Within the qualitative use-wear analysis, n = 39 *Prądnik spalls* were microscopically checked for surface modifications. In total, n = 53 traces on n = 27 artefacts could be documented (**fig. 129**). The variance is higher than documented for the *Prądnik scrapers*, but not as high as for the *Keilmesser*. Five of the nine categories were found on the *Prądnik spalls*. The main frequency of the use-wear types is the same as for *Keilmesser*. Category V. is again the most often documented use-wear type with n = 33 locations. The frequency of type I. (n = 7) is also slightly higher compared to other types as well as type II. (n = 4). The combination of category V. and category IV. was also documented for n = 5 locations. The distribution of the traces is not as clear as described for *Keilmesser* and *Prądnik scrapers*. The traces are still most often orientated along the active edge (former active edge of the tool) but also the number of traces along the opposite edge is proportionally high. The percentage distribution is 52.8 % for the active edge to 47.2 % for the opposed edge.

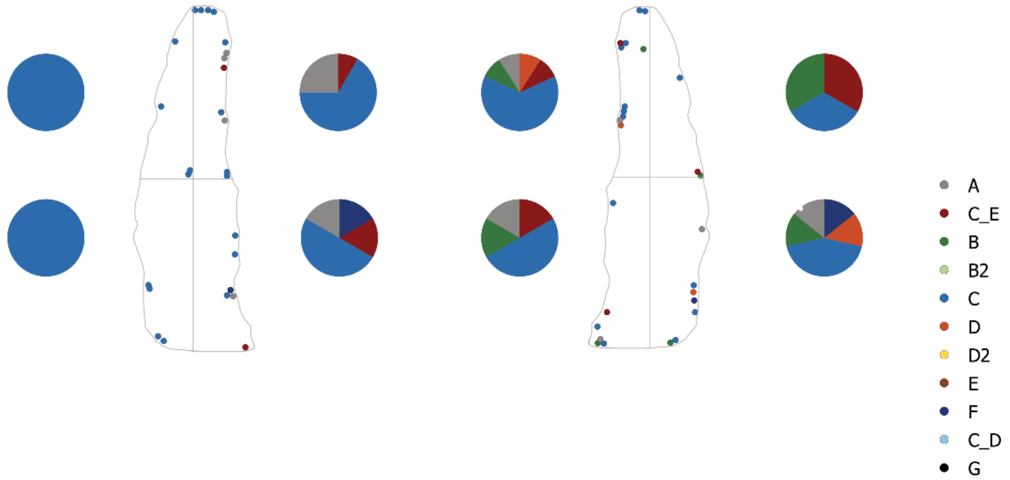

Fig. 129 Distribution of all the use-wear traces documented on *Prądnik spalls*. The left side illustrates the dorsal surfaces of the tool, the right side the ventral tool surface. The colours indicate the use-wear types.

Additionally, the orientation of the striations on *Keilmesser*, *Prądnik scarpers* and *Prądnik spalls* was reviewed. This was done in order to see, whether the striations can support or contradict the interpreted tool lateralisation. To do so, only striations along the active edge with a clear orientation (type VII. and VIII.) can provide information. Furthermore, these striations have to be oblique towards the edge. Oblique striations could reflect the tool handling of the tool during its action in the sense of which surface was used. Therefore, striations of left-lateral tools should be thereby mirrored, compared to the ones on right-lateral tools. Unfortunately, none of the documented striations with an oblique orientation is located along the edge. Thus, the tool laterality cannot be correlated with results of the qualitative use-wear analysis.

The results of the analysed scrapers illustrate again a different picture (**fig. 130**). For the small number of analysed tools with some surface modification (n = 14), the quantity of documented traces is comparably high (n = 37). Additionally, the variance of use-wear types is also high. Seven of the nine categories are displayed on the scrapers. Although the most frequent category is again type V. (n = 18), there is no other prominent use-wear type. The other categories are all present with one to five locations. The distribution of these traces is more even towards all edges, although the traces along the active edge still prevail slightly (n = 25).
The only flake with use-wear traces displayed type V. on three different locations.

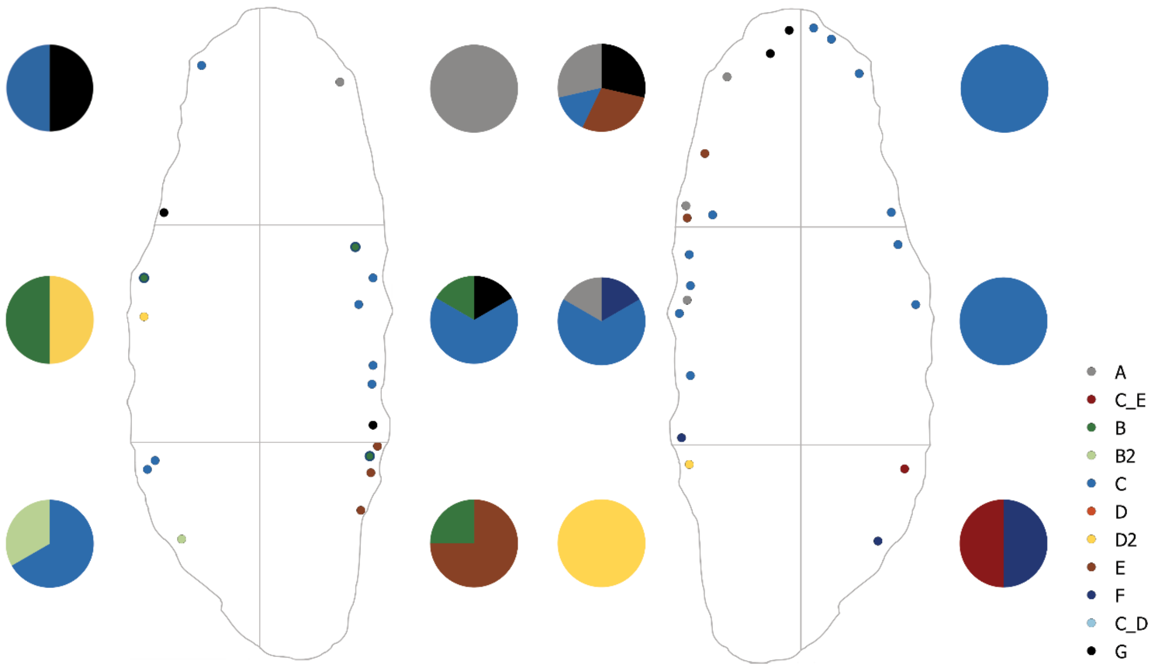

Fig.130 Distribution of all the use-wear traces documented on scrapers. The left side illustrates the dorsal surfaces of the tool, the right side the ventral tool surface. The colours indicate the use-wear types.

For all artefact categories from the three archaeological sites together, the following picture emerges. The traces clearly prevail along the active edges. About 38.9 % (n = 125) of the traces can be found close to the active edge on the ventral surface, 34.6 % (n = 111) on the dorsal surface. The remaining 26.5 % of the traces are located on the edge opposed to the active edge, the posterior part, either on the ventral (n = 45) or on the dorsal surface (n = 40). The quantity of traces decreases in all areas (A to D) from the distal and medial to the proximal tool part. While the quantity of traces in the medial and proximal part is more or less equally distributed in the areas A, B and C, the frequency of traces in area D is considerably higher in the distal part of the tool (n = 66; medial n = 37, proximal n = 22).
Regarding the type of traces, there is also one category that clearly stands out. Out of the n = 321 in total documented traces on all tools, 49.5 % (n = 159) of the traces are ascribed as category V. The next more frequent category is I. with 18.1 % (n = 58). Worth mentioning are also use-wear type II. and IV., documented on 8.10 % (n = 26) and 6.2 % (n =20) of the cases. The remaining categories are rarely present on the tools and make only up to 4 % of the traces respectively.
Some additional aspects should be highlighted which are a consequence of the distribution and the occurrence of the different traces. As mentioned before, *Keilmesser* (Buhlen as an exception) display all of the aforementioned described use-wear categories. The only other artefact category that displays nearly all use-wear types too, are the scrapers. Interestingly, category VI. only appears on *Keilmesser* and *Prądnik spalls*. In general it seems the distribution of the use-wear types on *Prądnik spalls* are very similar to the distribution on *Keilmesser.* This makes sense when assuming that the traces result from tool use before the *Prądnik spalls* have been removed from the

Keilmesser. At the same time, the traces on *Prądnik spalls* can be found on all edges, what makes it impossible to only be a consequence of a *Keilmesser* use. *Prądnik scrapers*, however, do not share these similarities with *Keilmesser* and *Prądnik spalls*. The use-wear types on *Prądnik scrapers* reflect almost no diversity and can be summarised be they types V. and I.

5.4.2 Quantitative use-wear analysis

The second part of the use-wear analysis was the quantitative use-wear analysis with the aim to acquire 3D surface topography data to measure and characterise the micro surface texture of the identified use-wear traces. The samples for the quantitative use-wear analysis have been selected based on the results from the previously performed qualitative use-wear analysis. From the n = 150 artefacts that displayed in total n = 321 traces, n = 50 traces provide the subsample for the quantitative use-wear analysis (**tab. 39**). These sampled traces correspond to n = 37 spots on *Keilmesser*, n = 3 on *Prądnik scrapers*, n = 4 on *Prądnik spalls* and n = 6 traces on scrapers. This subsample does not only display the different artefact categories, but also the different use-wear types. Since the predominant use-wear type found on the artefacts was category V., this type was selected by a majority (n = 13). The remaining use-wear types were selected on the premise, that, if possible, the minimum number of use-wear types were represented by three samples. Each use-wear trace was measured three times. These measurements were taken at nearby but non-identical spots within the trace in order to review the homogeneity within each trace. Hence, n = 150 measurements were performed in total. As explained in the method chapter, the data was acquired with an upright light microscope coupled with a laser-confocal microscope (ZEISS Axio Imager.Z2 Vario + ZEISS LSM 800 MAT).

site		**artefact category**						
		Keilmesser	***Keilmesser* tip**	***Prądnik* scraper**	***Prądnik* spall**	**scraper**	**flake**	**total**
Buhlen	n	4	0	1	1	0	0	**6**
	%	66.7	0.0	16.7	16.7	0.0	0.0	100.1
Balve	n	25	2	0	3	3	0	**33**
	%	75.8	6.1	0.0	9.1	9.1	0.0	100.1
Ramioul	n	6	0	2	0	3	0	**11**
	%	54.6	0.0	18.1	0.0	27.3	0.0	100.0
total	n	**37**	**2**	**3**	**4**	**6**	**0**	**52**
	%	71.2	3.9	5.8	7.7	11.5	0.00	100.1

Table 39 Selected artefacts from Buhlen, Balve and Ramioul for the quantitative use-wear analysis.

5.4.2.1 Surface micro texture data analysis

The acquired data was analysed according to the ISO 25178-2 parameters. Based on this international standard, n = 21 ISO 25178-2 parameters, n = 3 furrow parameters, n = 3 texture direction parameters, n = 1 texture isotropy parameter and the scale-sensitive fractal analysis (SSFA) parameters *epLsar, NewEplsar, Asfc, Smfc, HAsfc9 and HAsfc81* were calculated on each surface (**fig. 11;** further information about these parameters can be found in the 'surface metrology guide' from Digital Surf; see Digital Surf, Besançon, France). Only one parameter, *Str*, could not be calculated on a small number of surfaces and is thus missing for n = 9 measurements. However, the parameter *isotropy* (texture direction parameter) is identical to the ISO 25178-2 *Str* parameter. The ConfoMap templates, the resulting data including plots for each measured parameter can be found on GitHub. In order to present the data here, nine out of the 34 parameters were considered. These nine parameters spanning the different categories of field parameters (Blateyron, F., 2013) and some additional isotropy, furrow and SSFA parameters. The areal parameters separate in the three categories areal field, areal-scale and length-scale analysis. To start with the areal field parameters, *Sq* was chosen as an amplitude parameter expressing the root mean squared height. Thus, *Sq* is a measure of surface roughness. The higher the *Sq*, the higher the surface roughness. *Std*, a spatial parameter, calculates the main direction of the surface texture (texture direction). The parameter is defined relative to the y-axis. Thus, a surface with an orientation along the y-axis will return a *Std* of 0 degrees. Only when a surface is anisotropic, this parameter is of relevance or can be calculated. Interesting is, that *Std* can be used to detect the presence of a preliminary surface modification process, which is to be removed (succeeding modifications that lead to different texture directions). As a volume parameter of the areal field parameters, *Vmc* stands for the volume of the material. *Vmc* can be useful to understand how much material may be worn away for a given depth. *Sxp* is another functional parameter describing the peak extreme height. *Sxp* is a measure for the height differences between the average height of the surface and the highest peak by excluding 2.5% of the highest points. High *Sxp* values indicate the existence of high peaks. A field parameter belonging to the category of areal scale analysis is the hybrid parameter *Sdr*. *Sdr* is a measure of surface complexity. The higher the value, the more complex the surface. Meaning, a value close to 0% is equitable to a flat and smooth surface. Moreover, for the texture isotropy and periodicity the *isotropy* on surface was selected. The higher the *isotropy* value, the more the surface resembles itself in every direction. In other words, the *isotropy* decreases with an increasing directionality of the surface. For the furrow analysis, the *mean density of furrows* was selected as a parameter for detecting and characterising furrows on the surface. The last category are parameters of the fractal analysis. One of these parameters is *HAsfc9*. *HAsfc9* displays the heterogeneity of areal-scale fractal complexity. A high HAsfc9 value indicates a high-degree within-surface variation across different scales. EpLsar is another parameter of the fractal analysis, categorised as length-scale analysis. The parameter reflects the anisotropy of a texture and it thus the reverse of isotropy. The *epLsar* values increase with increasing directionality. To summarise, for the quantitative characterisation of the surface micro texture these variables were considered: surface roughness, surface directionality, volume, height, surface complexity, isotropy, heterogeneity and anisotropy.

Based on these selected variables, representative for the different categories of parameters, some results are explained. Prior to this, it should be mentioned again that quantitative use-wear analysis is a comparable new approach in archaeology although the interest is clearly increasing (e.g. Martisius et al., 2018; Galland et al., 2019; Stemp, Macdonald and Gleason, 2019; Álvarez-Fernández, 2020; Bradfield, 2020; Martisius et al., 2020; Pedergnana et al., 2020b; Pedergnana, Ollé and Evan, 2020). Following the international standards (ISO 25178-2) offers a secure way to analyse the data. However, which parameters are relevant or the most important ones to analyse use-wear traces on lithics, especially on silicified schist, is not sufficiently known yet. Quantitative use-wear analysis is a very promising approach with the great potential to be straightforward when explored and applied more regularly (Calandra et. al, 2019b; Martisius et al., 2020; Pedergnana et al., 2020b). Large archaeological assemblages, such as the one presented here, have not been part of a qualitative use-wear analysis yet.

To check the results, the scatterplots (**fig. 131 - 139**) of all measurements plotted *per* parameter give a first overview on the distribution of the values. The scatterplots show the measured values separated per artefact. Information about the raw material and the location (A to D, 1 to 3) are given. The data points are coloured based on the interpreted use-wear types. In this way, different results within or between the raw materials, the artefact categories, the use-wear type classification and the locations can be compared. Unfortunately, the measured parameters lead to no obvious diagnostic results. No direct pattern between the results and the aforementioned variables is apparent. However, four measurements stand out. These measurements (MU-199 C3_01_a, MU-202 D2_01c, BU-173 C2-01_a and BU-173 C2-01_b) are noteworthy. Here, it should be pointed out again that from each trace, three measurements were taken in order to make an identification of measuring errors possible. The results of these three measurements *per* trace should be similar, otherwise the measurement is likely unreliable. However, this is the case for the four aforementioned samples. The variability within the results of the three measurements per traces respectively is conspicuous. A review of the four measurements could clearly identify them as outliers. When processing the data, existing noise is removed by a threshold. This data is interpreted as non-measured points. In a further step, such missing data gets filled. This is necessary in order to calculate some of the ISO and the SSFA parameters. In the case of the four outliers, the following happened: The measured areas were marginal and located closed to the tool edge. When scanning the surface, a small area beyond the edge was also included in the scan. Meaning, this area is treated as non-measured points. In order to calculate the parameters, the missing data needed to be filled in and the final results do not reflect the actual measured surfaces. Thus, these four measurements appear as outliers and should therefore be excluded when interpreting the data.

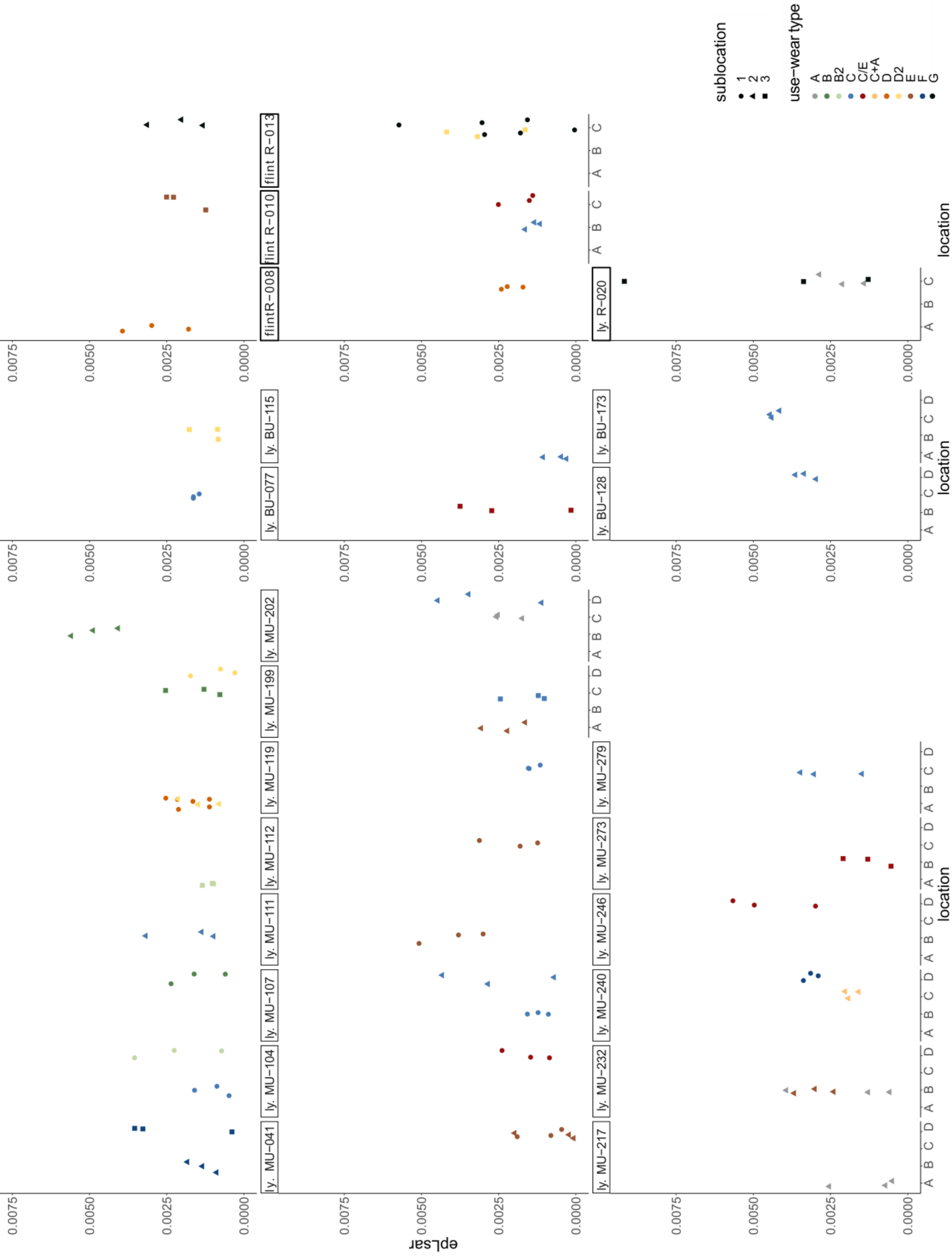

Fig. 131 *EpLsar* values for each analysed artefact (raw material (flint or ly. = lydite) plus ID). The parameter reflects the anisotropy of the texture. The epLsar value increases with increasing directionality. The plot indicates the location of the use-wear on the tool (A & B = dorsal, D & C = ventral) plus the sublocation (1, 2 or 3; sublocation stands for the number of use-wear traces *per* location). The three measurements per location and sublocation represent the three measurements *per* use-wear taken at non-identical but nearby spots. The data points are coloured based on the interpreted use-wear types.

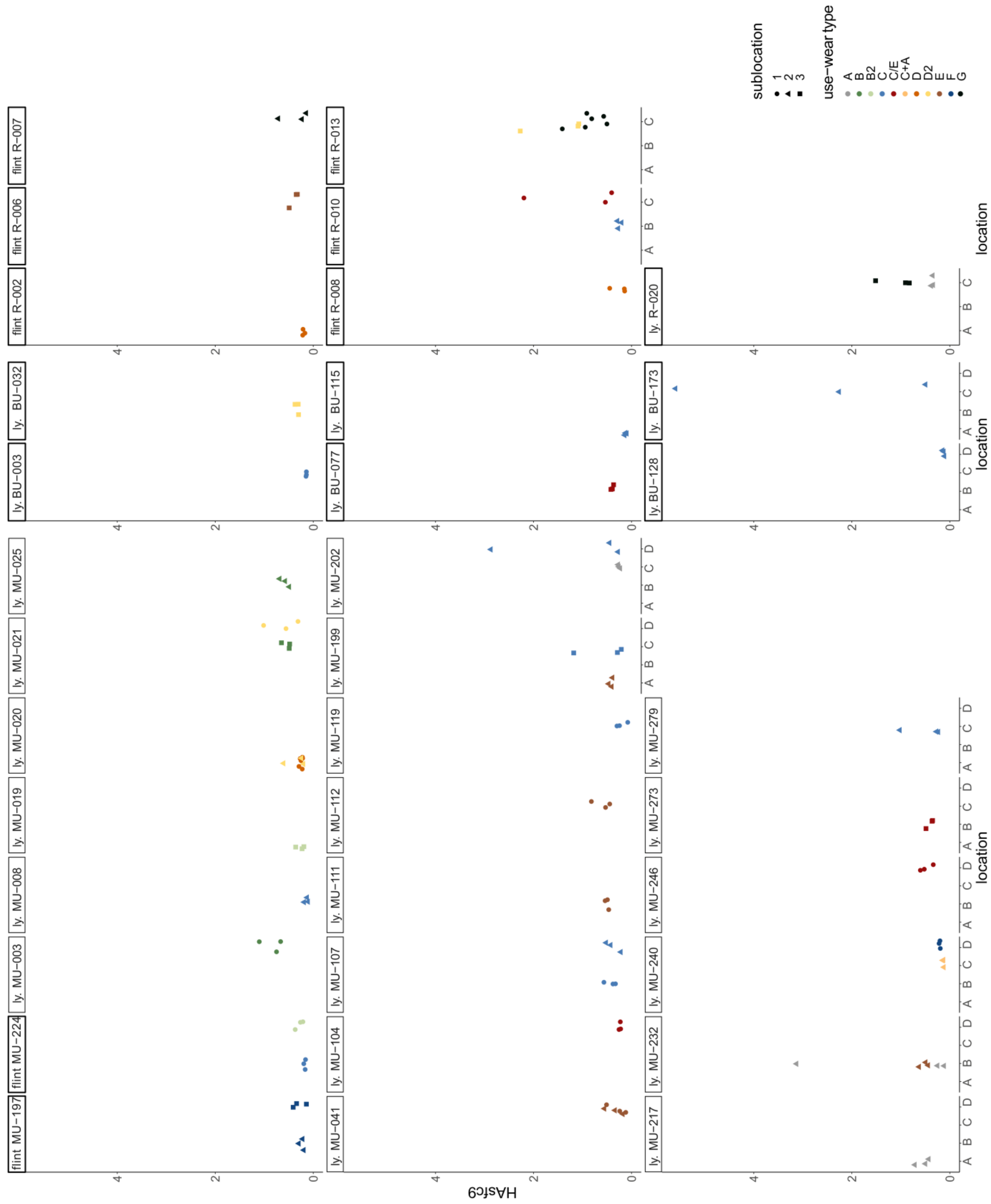

Fig. 132 *HAsfc9* values for each analysed artefact (raw material (flint or ly. = lydite) plus ID). HAsfc9 displays the heterogeneity of areal-scale fractal complexity. The plot indicates the location of the use-wear on the tool (A & B = dorsal, D & C = ventral) plus the sublocation (1, 2 or 3; sublocation stands for the number of use-wear traces *per* location). The three measurements per location and sublocation represent the three measurements *per* use-wear taken at non-identical but nearby spots. The data points are coloured based on the interpreted use-wear types.

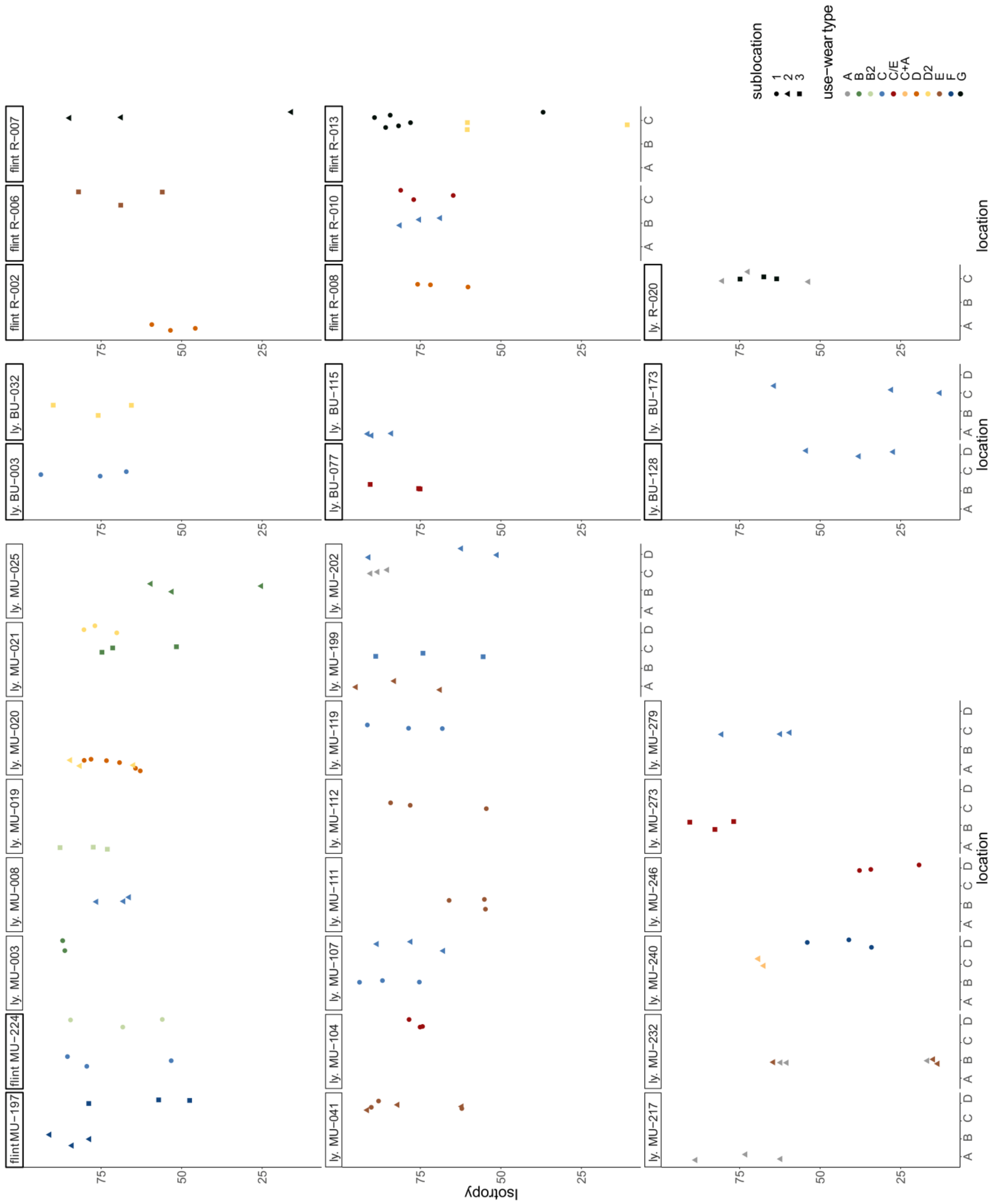

Fig. 133 *Isotropy* values for each analysed artefact (raw material (flint or ly. = lydite) plus ID). *Isotropy* reflects surface directionality. The value decreases with an increasing directionality of the surface. The plot indicates the location of the use-wear on the tool (A & B = dorsal, D & C = ventral) plus the sublocation (1, 2 or 3; sublocation stands for the number of use-wear traces *per* location). The three measurements per location and sublocation represent the three measurements *per* use-wear taken at non-identical but nearby spots. The data points are coloured based on the interpreted use-wear types.

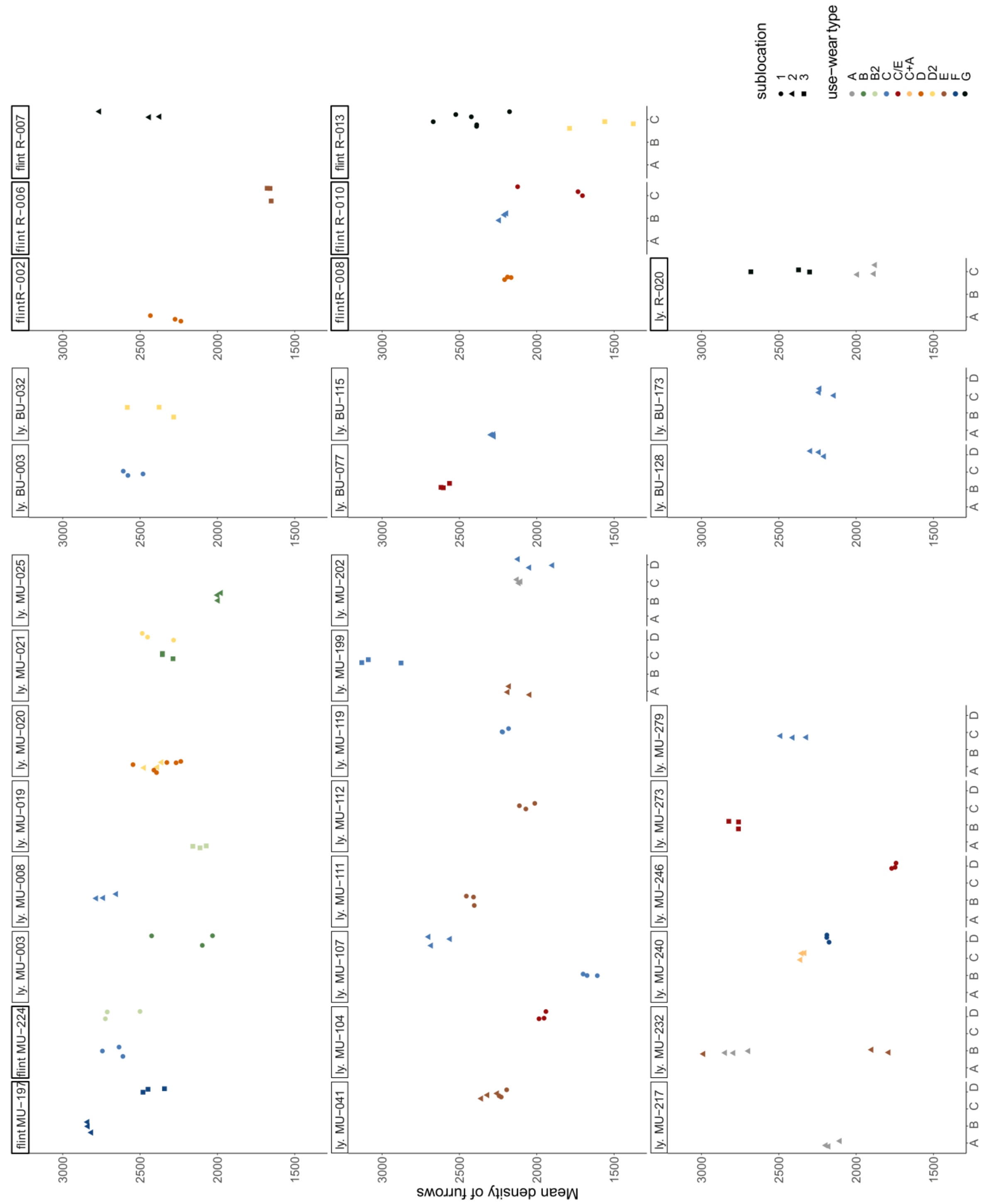

Fig. 134 *Mean density of furrow* values for each analysed artefact (raw material (flint or ly. = lydite) plus ID). *Isotropy* reflects surface directionality. The value reflects furrows on the surface. The plot indicates the location of the use-wear on the tool (A & B = dorsal, D & C = ventral) plus the sublocation (1, 2 or 3; sublocation stands for the number of use-wear traces *per* location). The three measurements per location and sublocation represent the three measurements *per* use-wear taken at non-identical but nearby spots. The data points are coloured based on the interpreted use-wear types.

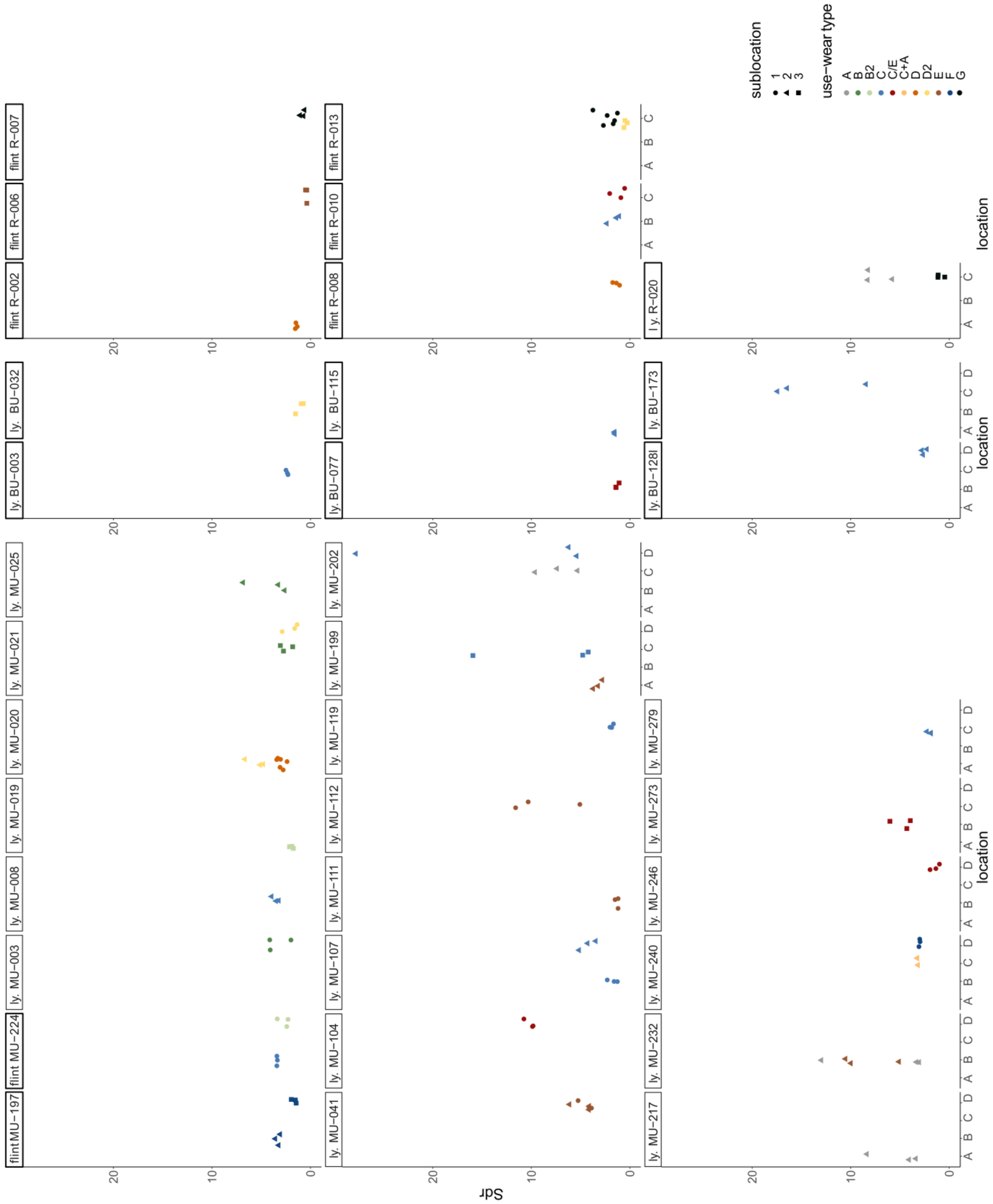

Fig. 135 *Sdr* values for each analysed artefact (raw material (flint or ly. = lydite) plus ID). *Sdr* is a measure of surface complexity. The higher the value, the more complex the surface. The plot indicates the location of the use-wear on the tool (A & B = dorsal, D & C = ventral) plus the sublocation (1, 2 or 3; sublocation stands for the number of use-wear traces *per* location). The three measurements per location and sublocation represent the three measurements *per* use-wear taken at non-identical but nearby spots. The data points are coloured based on the interpreted use-wear types.

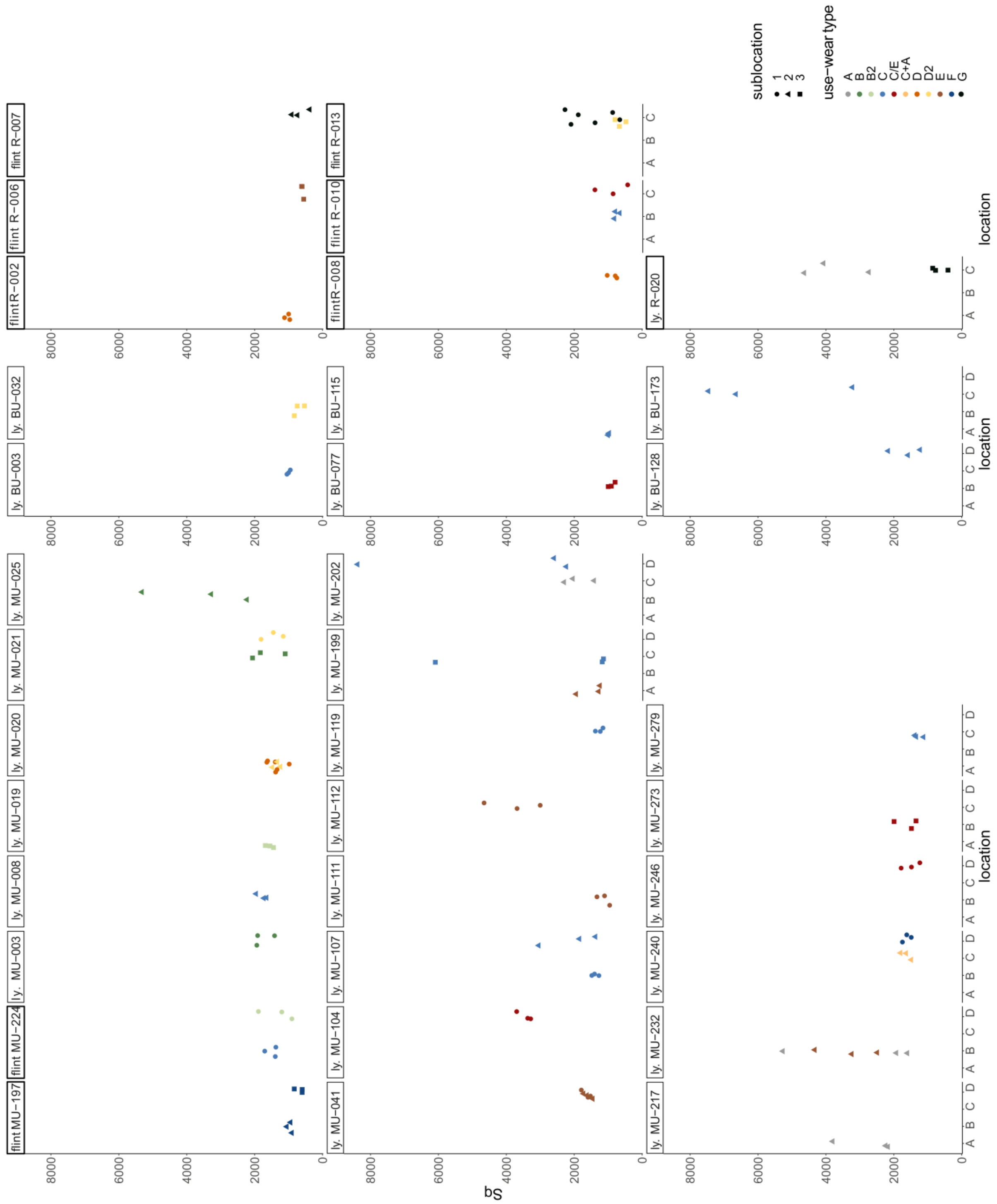

Fig. 136 *Sq* values for each analysed artefact (raw material (flint or ly. = lydite) plus ID). *Sq* is a measure of surface roughness. The higher the *Sq* value, the higher the surface roughness. The plot indicates the location of the use-wear on the tool (A & B = dorsal, D & C = ventral) plus the sublocation (1, 2 or 3; sublocation stands for the number of use-wear traces *per* location). The three measurements per location and sublocation represent the three measurements *per* use-wear taken at non-identical but nearby spots. The data points are coloured based on the interpreted use-wear types.

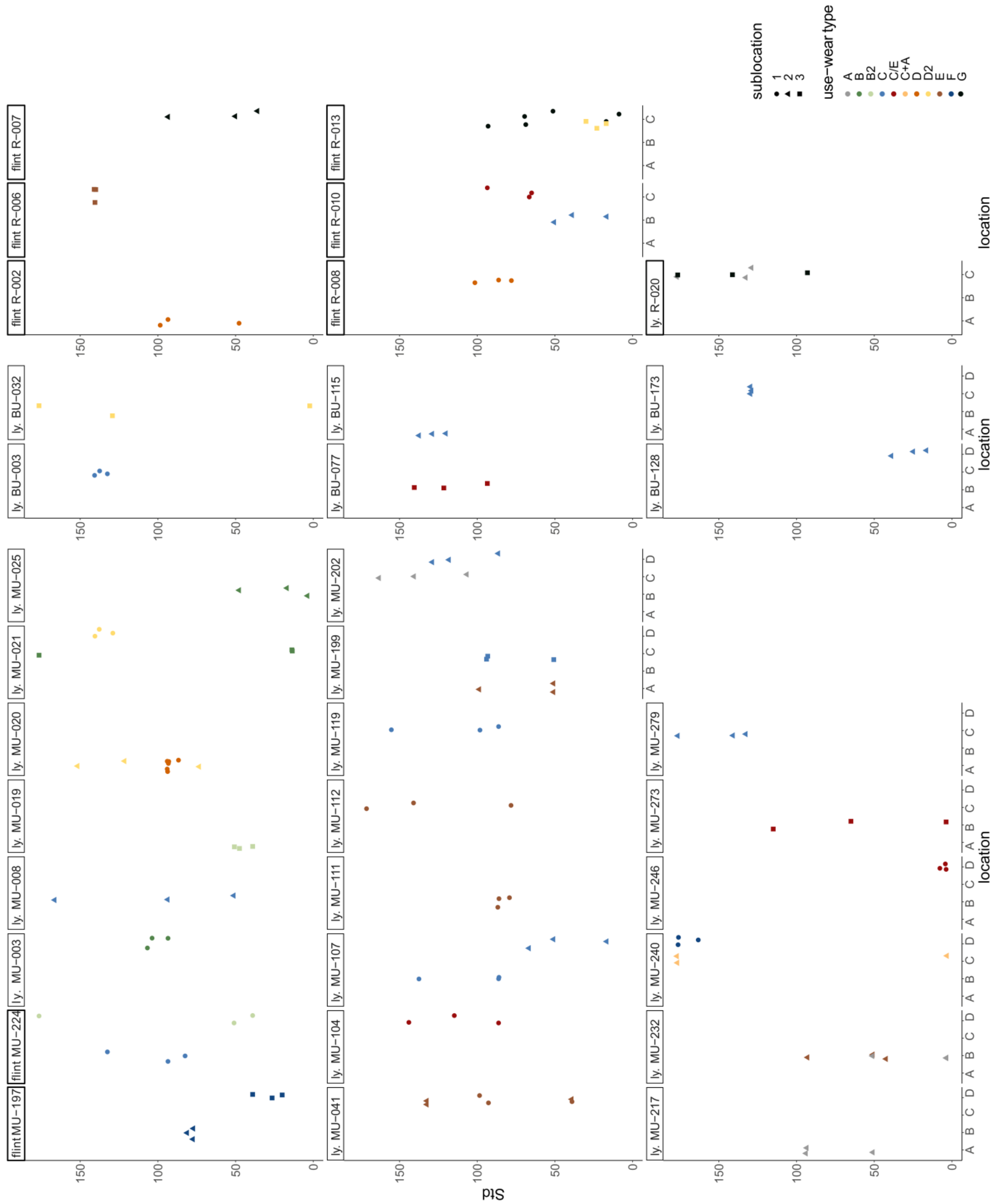

Fig. 137 *Std* values for each analysed artefact (raw material (flint or ly. = lydite) plus ID). *Std* reflects the main direction of the surface texture. The plot indicates the location of the use-wear on the tool (A & B = dorsal, D & C = ventral) plus the sublocation (1, 2 or 3; sublocation stands for the number of use-wear traces *per* location). The three measurements per location and sublocation represent the three measurements *per* use-wear taken at non-identical but nearby spots. The data points are coloured based on the interpreted use-wear types.

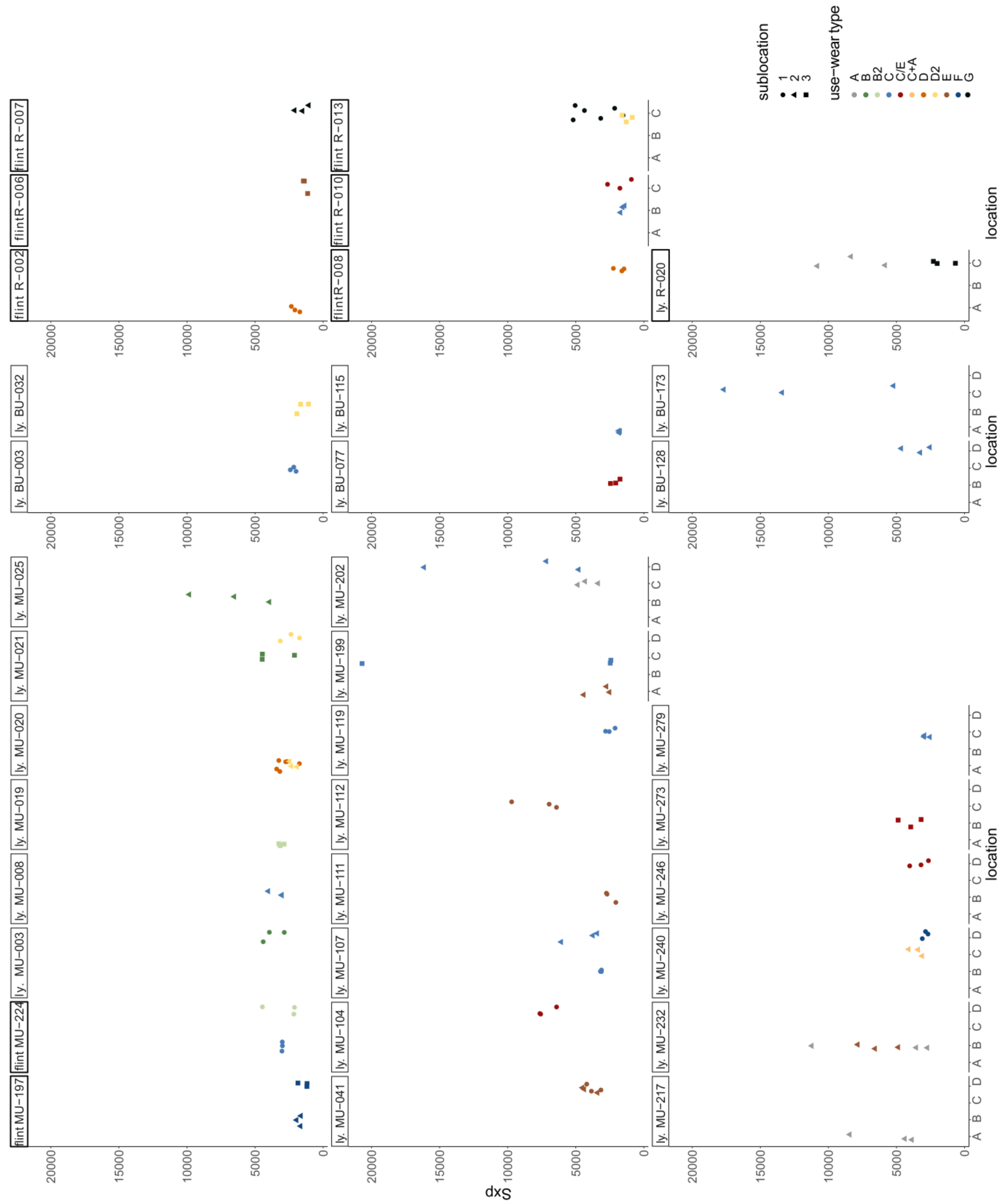

Fig. 138 *Sxp* values for each analysed artefact (raw material (flint or ly. = lydite) plus ID). *Sxp* is a measure for the height differences between the average height of the surface and the highest peak by excluding 2.5% of the highest points. The plot indicates the location of the use-wear on the tool (A & B = dorsal, D & C = ventral) plus the sublocation (1, 2 or 3; sublocation stands for the number of use-wear traces *per* location). The three measurements per location and sublocation represent the three measurements *per* use-wear taken at non-identical but nearby spots. The data points are coloured based on the interpreted use-wear types.

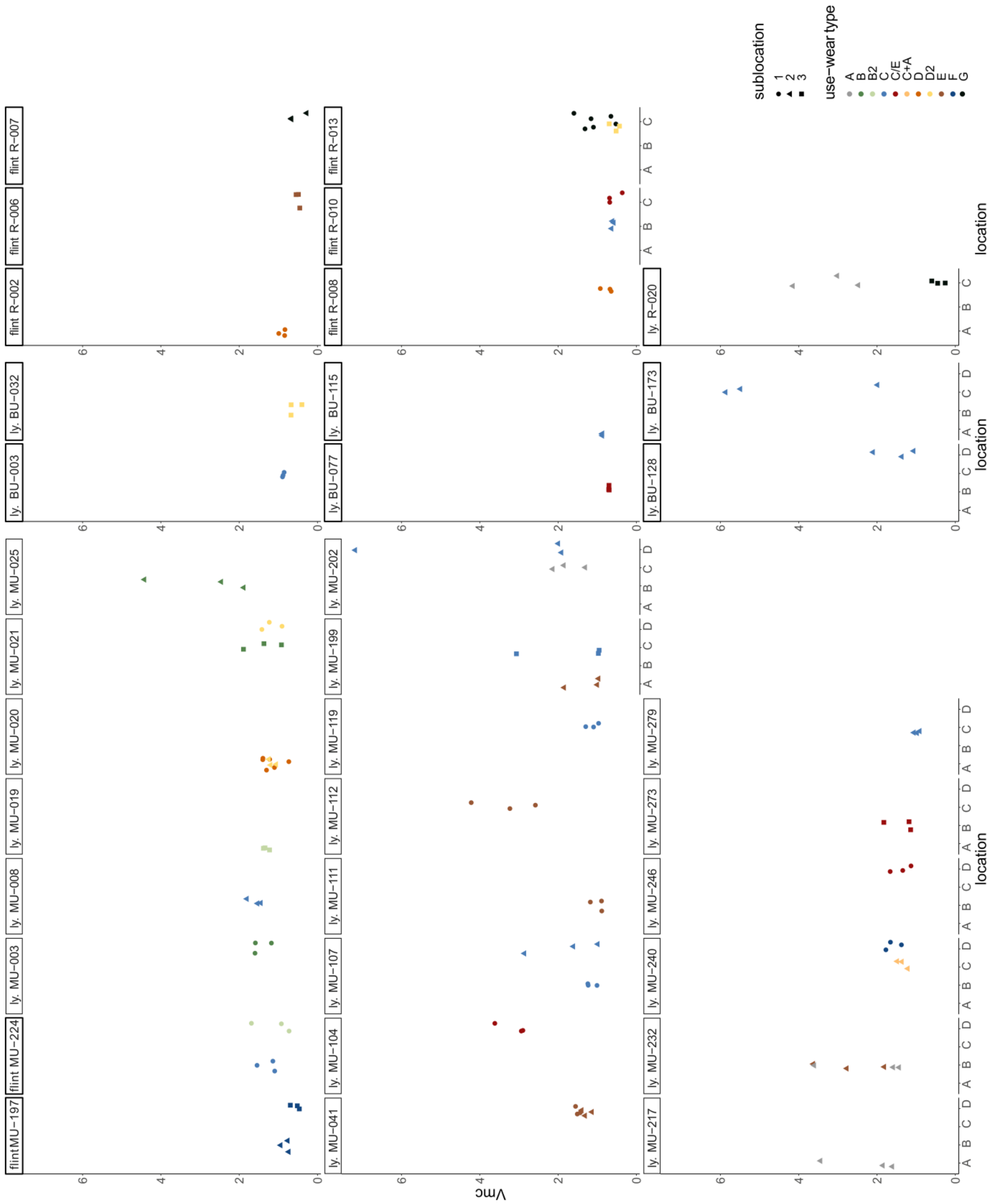

Fig. 139 *Vmc* values for each analysed artefact (raw material (flint or ly. = lydite) plus ID). *Vmc* stands for the volume of the material. The plot indicates the location of the use-wear on the tool (A & B = dorsal, D & C = ventral) plus the sublocation (1, 2 or 3; sublocation stands for the number of use-wear traces *per* location). The three measurements per location and sublocation represent the three measurements *per* use-wear taken at non-identical but nearby spots. The data points are coloured based on the interpreted use-wear types.

Although the data results in no immediately identifiable pattern, some aspects can be pointed out. The first aspect concerns the surface roughness (*Sq*). The *Sq* values calculated on flint are lower than the ones from lydite (**fig. 136**). The arithmetic mean

values for flint is 98.6 µm while the mean value for lydite is 189.2 µm. It needs to be noted that the arithmetic mean value for lydite (n = 111) is based on more measurements than the flint (n = 39) one. When looking at the use-wear types, some can be categorised by higher *Sq* values then others. The surface roughness for the use-wear type I., II. and IV. seems slightly rougher compared to the other types. Contrary to that, the use-wear type V. appears to be smoother, which is reflected by lower *Sq* values. In general, the three mentioned use-wear types I., II. and IV. differ from the other types not only concerning the surface roughness, but also concerning volume, height and surface complexity.
In order to bring the data a little more into question, the data was plotted in additional ways. For all these additional plots, the four measurements identified as outliers were excluded. Histograms of the use-wear types plotted *per* parameter support the aforementioned aspect (**fig. 140**). By a majority, the use-wear type V. displays are comparably low roughness based on the parameter *Sq*. Moreover, the observations that the types I., II. and IV. differ from other types, is also visible in the histograms.

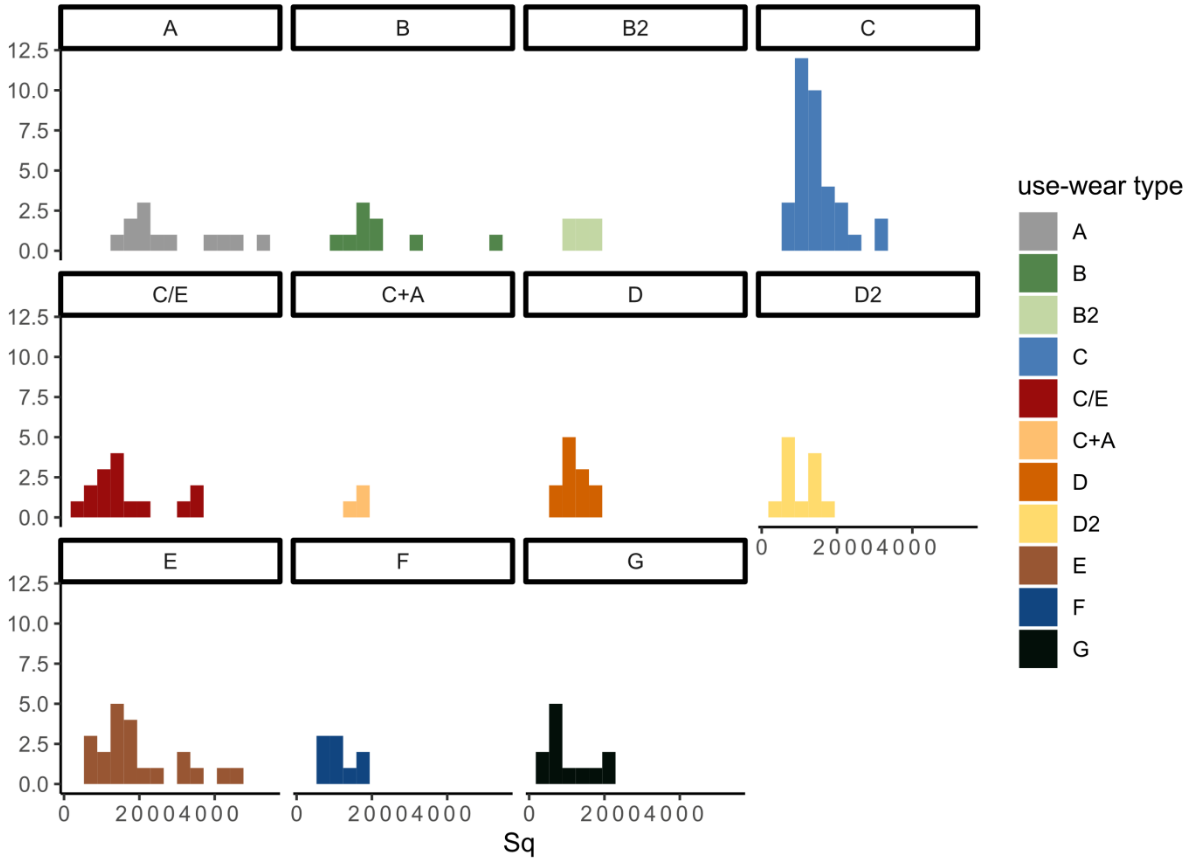

Fig. 140 *Sq* values and their frequency for the use-wear traces (n = 50) on the artefacts, categorised and coloured according to the interpreted use-wear types.

The last mentioned aspect is also illustrated by the boxplots of the use-wear types plotted again per parameters (**fig. 141**). The boxplots include the information about the artefact category. Interestingly, the data measured on the scrapers set off against the other artefact categories.

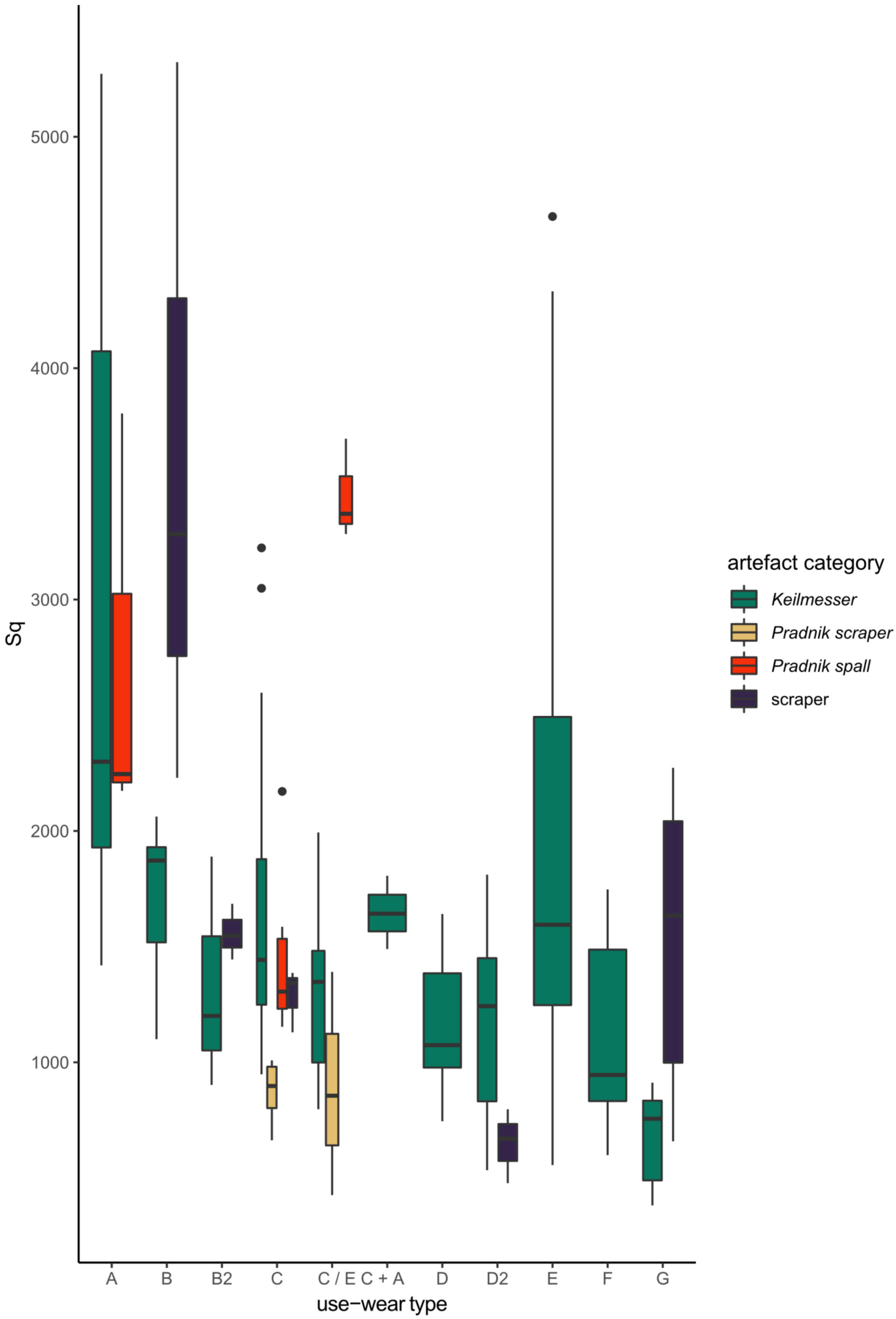

Fig. 141 Distribution of *Sq* values for the measured use-wear traces (n = 50) on the artefacts. The data is categorised according to the interpreted use-wear types and coloured based on the artefact type.

Two parameters, *Vmc* and *Sq* were selected in order to plot the results of these parameters against each other in a scatterplot. In one plot, the data was coloured based on the interpreted use-wear types (**fig. 142**). The data points align in one direction without any significant correlation. The same can be reported for the second plot, in which the data points were coloured based on the two plotted artefact categories *Keilmesser* and *Prądnik scrapers* (**fig. 143**). The data representing the *Keilmesser* spread more over the plot, but is numerically also more represented. Other parameters were plotted in the similar way. The parameters are *epLsar* and *Asfc* (**fig. 144**) as well as *Mean density of furrows* against *mean depth of furrows* (**fig. 145**). The plots reflecting the different use-wear types lead to no new insights. However, in the plot *epLsar* against *Asfc* a separation of the use-wear types I. (A) and IV. (E) is visible. These two types do not cluster differently, but the data points spread further towards a higher *Asfc* value.

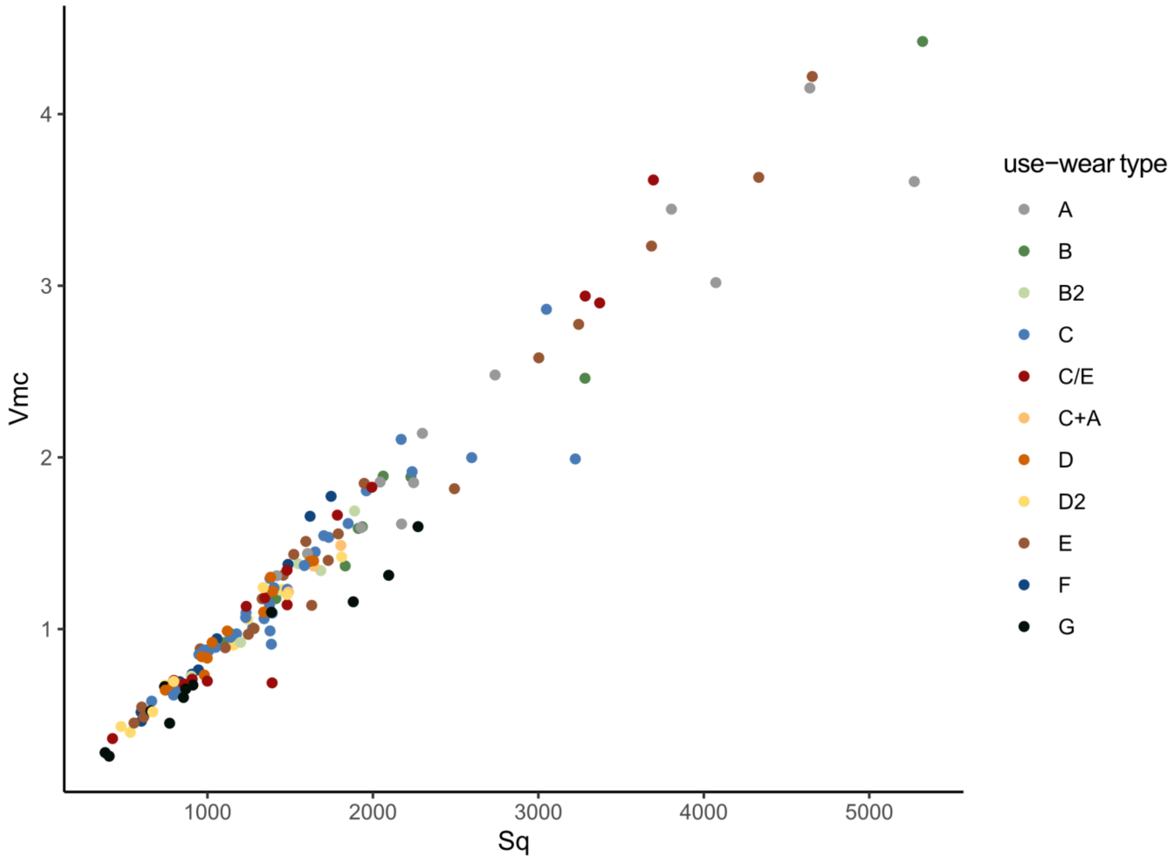

Fig. 142 *Vmc* and *Sq* values of the measured use-wear traces (n = 50) on the artefacts plotted against each other. The data points are coloured according to the interpreted use-wear type.

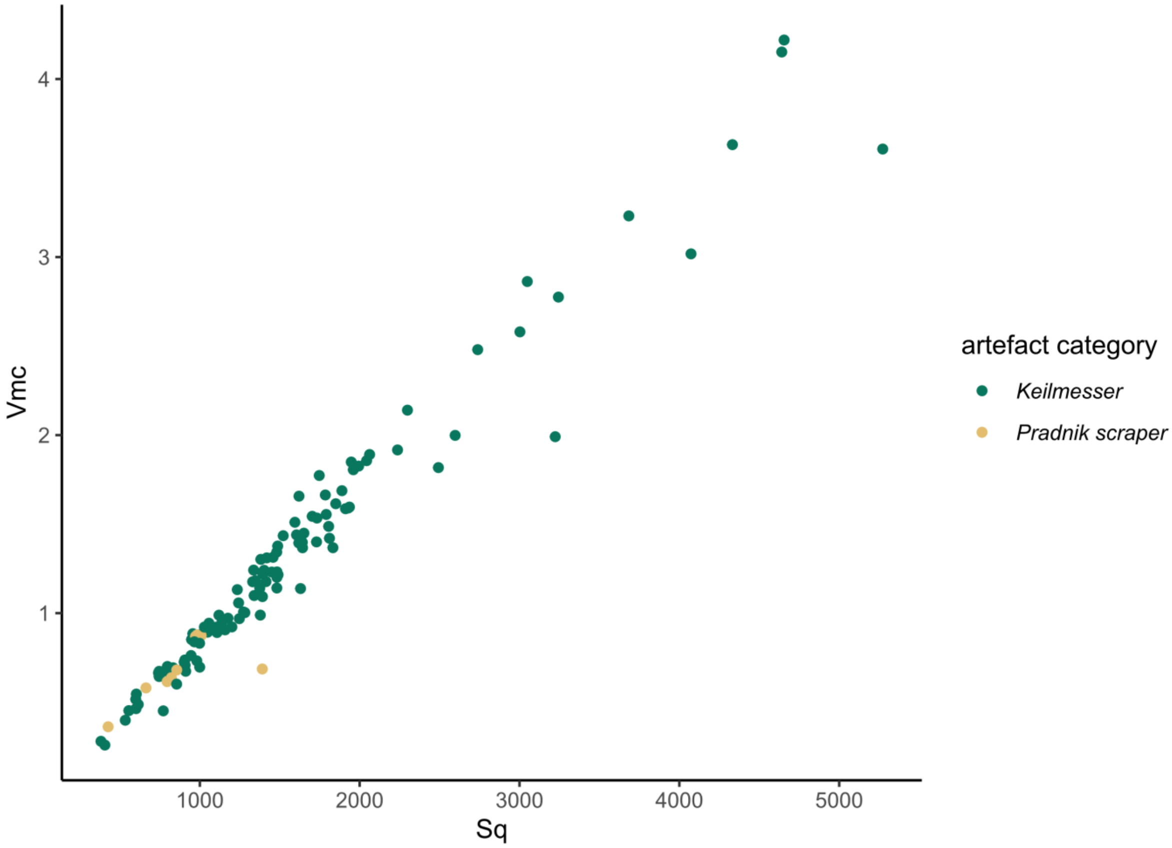

Fig. 143 *Vmc* and *Sq* values of the measured use-wear traces (n = 50) on the artefacts plotted against each other. The data points are coloured according to the artefact category.

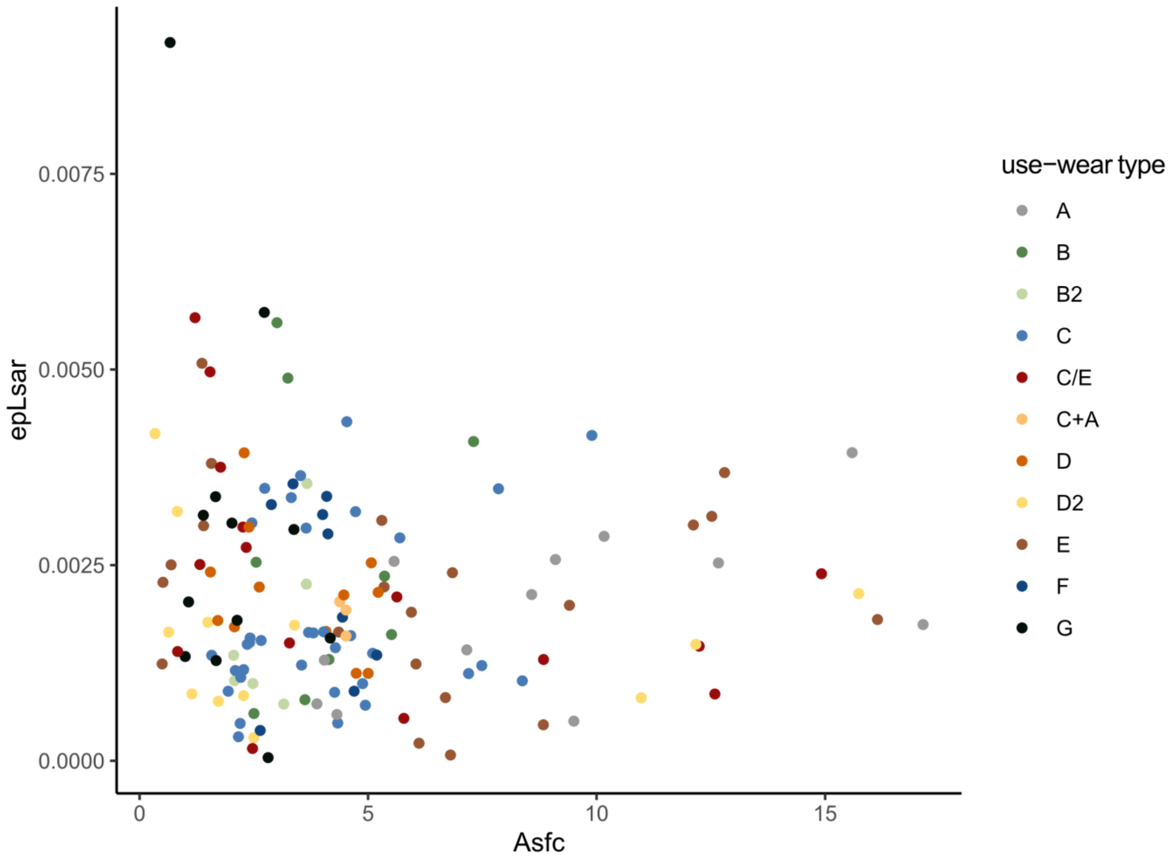

Fig. 144 *EpLsar* and *Asfc* values of the measured use-wear traces (n = 50) on the artefacts plotted against each other. The data points are coloured according to the interpreted use-wear type.

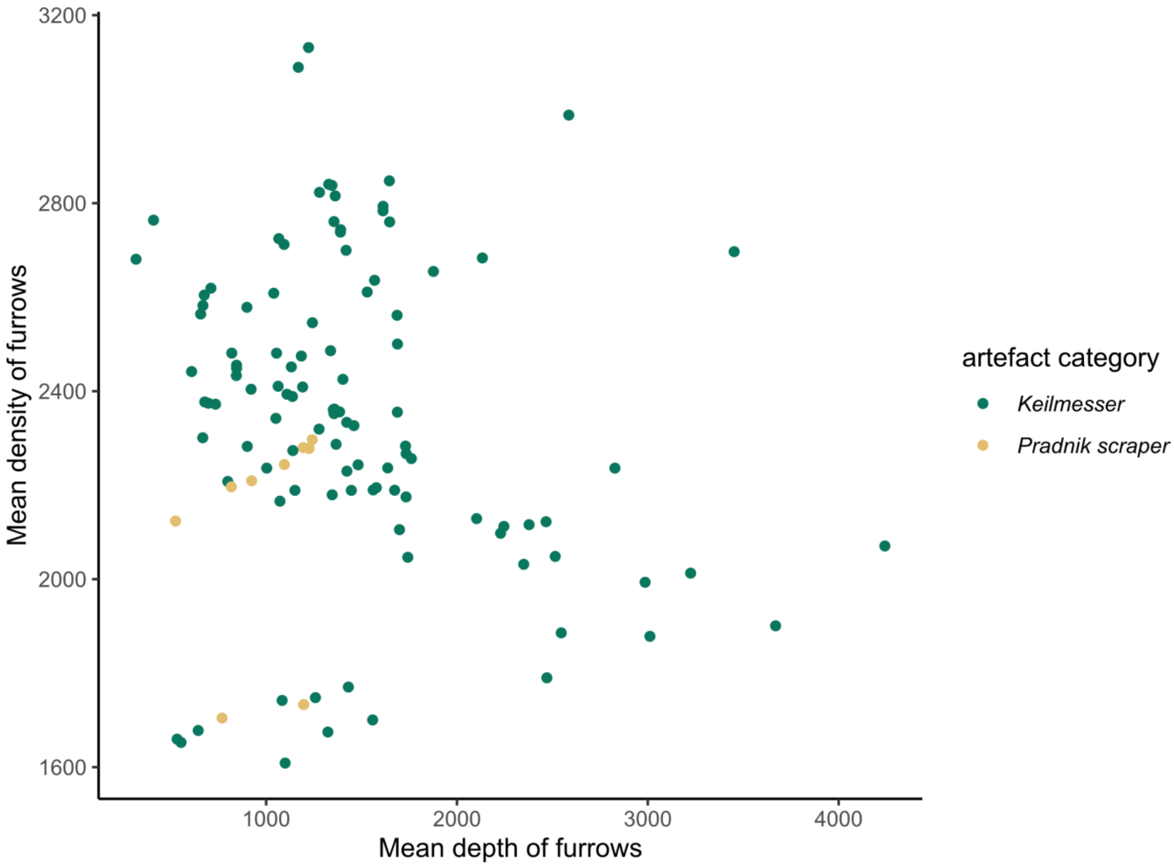

Fig. 145 *Mean density of furrows* and *Mean depth of furrows* values of the measured use-wear traces (n = 50) on the artefacts plotted against each other. The data points are coloured according to the artefact category.

A last attempt to explore the data was done by a principal component analysis (PCA). A first PCA was applied on seven components reflecting the variance in the artefact categories (**fig. 146**). These components are the parameters *Sq, Ssk, Vmc, Mean density of furrows, Isotropy, Asfc* and *HAsfc9*, spanning the different categories of field parameters. The variance in *Sq, Vmc* and *Asfc* is represented by Principal Component 1 (PC1), which accounts for 38.55 %. Principal component 2 (PC2) reflected 21.29 % of the explained variance with *Ssk, Mean density of furrows, Isotropy* and *HAsfc9*. This dimensionality reduction illustrates an overlap of the data with the data scattering mainly on the right half of the PC1 axis. The data cluster from the four different artefact categories – *Keilmesser*, *Prądnik scraper*, *Prądnik spall* and *scraper* - clearly overlap, whereas the data points from the *Keilmesser* spread the most. The cluster built by the data points from the *Prądnik spacers* do differ from the other data.

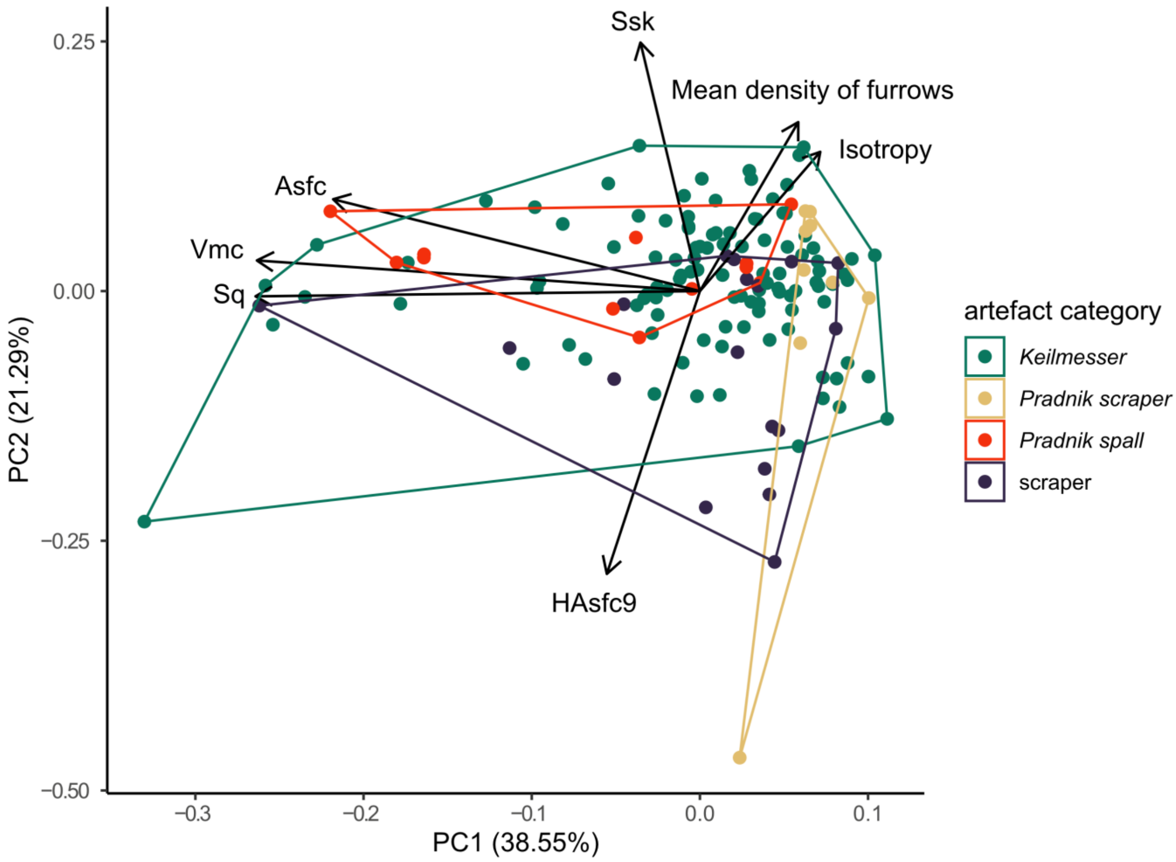

Fig. 146 Principal component analysis applied on the measured use-wear traces (n = 50) of the artefacts, reflecting variation regarding the artefact category.

A second PCA visualises the variance of the different use-wear types based on the same seven components (**fig. 147**). Again, the data scatters mainly on the right part of the PC1 axis. However, the clusters illustrating the use-wear types I. (A), II. (B), IV. (E) and also the combination of V. (C) and IV. (E) stretch towards the left PC1 axis. In particular use-wear type I. (A) varies from the other clusters and does not overlap with the use-wear types III. (B2), VI. (D) and IX. (G).

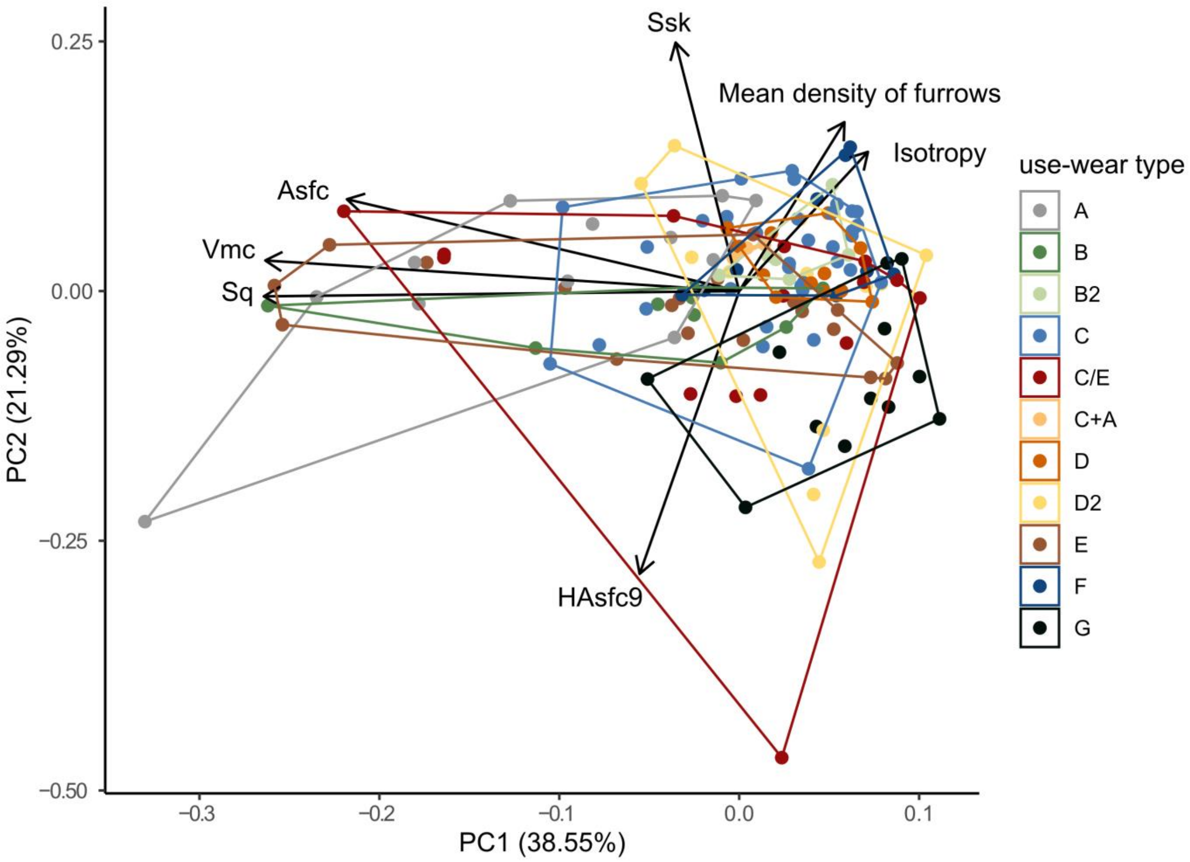

Fig. 147 Principal component analysis applied on the measured use-wear traces (n = 50) of the artefacts, reflecting variation regarding the interpreted use-wear types.

Although the interpretation of these data enters a new field in archaeology and needs to be explored in more detail, the quantitative use-wear analysis proved to have the potential to complement and improve qualitative use-wear analysis. Based on the presented data, it can be noticed that *Sq* as a parameter for the surface texture roughness indicates differences when combined with the defined use-wear types. Some use-wear types (e.g. type V.) seem to reflect a lower surface-roughness than other types. However, the parameters associated with the surface directionality (e.g. *isotropy, epLsar* or *NewEpLsar*) are more complex and thus, the combination between the results of the qualitative and this quantitative use-wear analysis might be more complicated.

5.5 Controlled experiments

The last subchapter refers to the results from the conducted so-called controlled or *second generation experiments* (*sensu* Marreiros et al., 2020). These experiments aimed at understanding the influence of specific, individually tested variables. These independent variables were the raw material and the edge angle of the standard samples, the contact material and the performed task. In order to test the effect-causation of these variables within a complex system, a mechanical device, the modular material tester SMARTTESTER®, was used to perform defined actions. Designed as sequential experiments, this also allowed for investigating the mechanics affecting tool performance and the formation of-use wear traces. Together, the execution of the experiments aimed at understanding the tool design of *Keilmesser* from a mechanical and practical point of view. At the same time, they were meant to test the possibility of successfully performing the two tasks, cutting and carving, with a specific edge design. In the following subchapter, the results are presented in the exact order, the experiments have been conducted: initial experiment, 'artificial VS. natural' experiment and tool function experiment.

5.5.1 Data analysis - Initial experiment

The first in the sequence of experiments was the so-called initial experiment (**fig. 36**). The purpose of this experiment was to test the experimental setup and to receive a first impression on the influence of the chosen variables within the setup. In total n = 7 standard samples (3x silicified schist 40°, 2x silicified schist 60°, 1x flint 40°, 1x flint 60°) were tested in a linear cutting movement on an artificial bone plate. Each sample had to perform in four cycles. Based on the uniform documentation of the standard samples before and after each cutting cycle it is possible to reveal precisely at which stage and location alteration in the sense of material loss, fractures, retouch etc. occur throughout the sequential experiment. In general, alteration has been documented via 3D scans and EDF images taken with a digital microscope as well as measurements based on the weight and the volume. However, the volume could not be calculated in the case of the samples from the initial experiment. The proximal part of the standard samples were fixed in a metal sample holder (**fig. 148**). This was done in order to guarantee that the samples can be fixed easily and cannot move in the sample holder of the SMARTTESTER®. During the course of the initial experiment, the metal attachment turned out as a weak point in the experimental setup. Thus, the metal attachment was slightly modified for the second experiment. After testing it on a few samples again, it was finally discarded. It became evident that an additional sample holder was not needed. Whenever a sample had this additional metal attachment, it was difficult to scan this area due to the high reflections of the material. Most of the time, the metal area was covered with a black fabric during the scanning process so that it was excluded from the documentation. Hence, the 3D models from the standard samples are missing their base. 3D models, which do not have an entirely closed mesh, are unsuitable for calculating the volume.

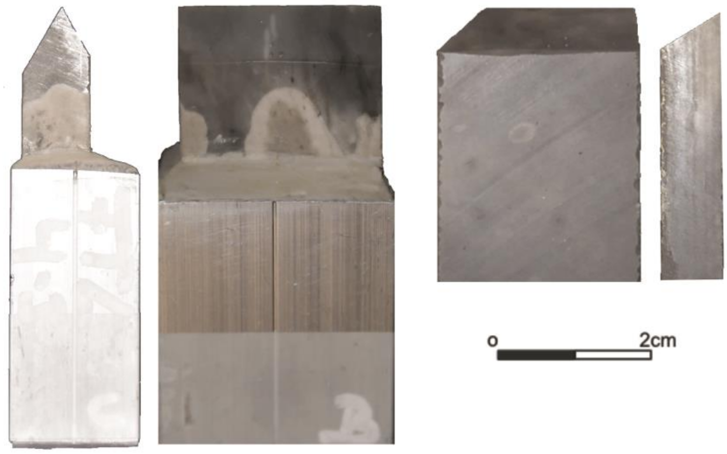

Fig. 148 Design of two standard sample (flint) illustrating the changes in design from the initial experiment to the later ones. The sample on the left side is fixed in a metal sample holder as used during the initial experiment. Moreover, the sample is bifacially cut. The sample on the right has no sample holder and is only unifacially cut. Additionally, this sample is modified by a 45° chamfered edge.

One important characteristic of a *second generation experiment* is the repeatability of the experiment and with thus the reproducibility of the data. As explained beforehand, the SMARTTESTER® was connected to five sensors throughout the experiments. In this way, the predetermined factors velocity, acceleration and force were sensor recorded. Two additional sensors measured the penetration depth and the friction. The initial experiment was meant to test the reliability of these controlling mechanisms. Thus, the data was checked frequently. The data set can be found on GitHub [https://github.com/lschunk/Initial_experiment-sensor_recording]. As shown by the data plot (**fig. 149**), force, friction, velocity (including acceleration) and depth are controlled throughout the experiment. Shown here are the measurements for one cycle of 50 strokes made with one standard sample (LYDIT1-2). Except for a few outliers in the force plot, the lines displaying each stroke are always following the same pattern. The data produced by the depth sensor at the bottom right, documents the increased depth of penetration by the standard sample with every cut.

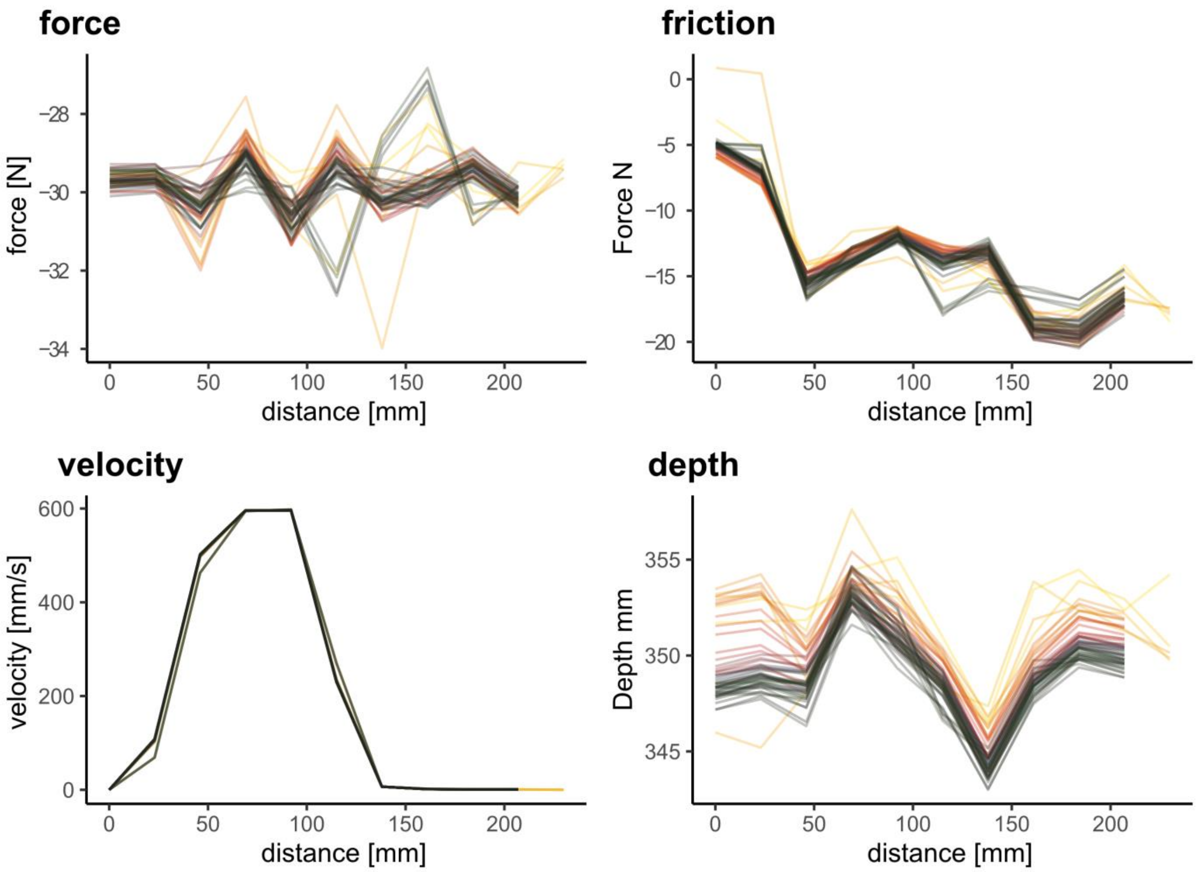

Fig. 149 Sensor data from a cycle of 50 cutting strokes performed with the SMARTTESTER® using the sample LYDIT4-2. Each line reflects one cutting stroke. The first stroke is in yellow and with increasing stroke number, the colour of the line turns darker. The graph illustrates that the predetermined factors force, friction and velocity stayed constant (as set) throughout the experiment. The graph in the lower right corner (depth) displays the achieved penetration depth, which increases throughout the 50 performed cutting stokes.

All seven samples were used to perform the four cycles. Within these cycles of in total 2000 cutting strokes, the progressive alteration of the standard sample surfaces is recognisable (**fig. 150**). When looking at the samples with the 40° edge angle, the tool damage on the flint specimen is lower than the damage on the lydite samples. The material loss is also reflected in the weight measurements. In fact, one lydite sample (LYDIT1-4) performed only 1368 strokes instead of the targeted 2000 strokes. The cycle had to be ended at that point, because the sample could not perform the task anymore due to a breakage. Standard samples with the 60° edge angle do not show this difference between the raw materials. Only minor edge fragmentation (barley macroscopically visible) could be documented in both raw materials. Higher fragmentation changes the edge angle as well as the tool performance. Tool performance was only assessed based on visual estimations. As defined, tool performance describes how well a task, here the cutting, was accomplished. This can be assessed by correlating the cutting depth with the material loss on the standard sample and on the contact material. Since one factor, the calculation of the material loss based on the standard sample volume was not possible, this was not done for this initial experiment. Nevertheless, the tool performance can be partially assessed based on the contact material, the artificial bone plate. The first aspect that can be noticed is the quality of the cuts. The first three cuts on the bone plate are made by lydite samples, the fourth by a flint sample (**fig. 151**). All four samples had a 40° edge angle. While the flint sample cut appears as a thin line, the cut created with the lydite samples are broader and less fine. The same can be noticed for cuts produced with the 60° samples. The lydite cuts are not only wider they also achieve a greater cutting depth. A new line needed to be used for one sample (LYDIT3-2) during the last cycle. After 1000 strokes, the generated cutting depth was nearly equal to the thickness of the bone plate. In order to avoid a damage of the mechanics below the bone plate, a new cutting track was started. Visually judged, this above mentioned lydite sample was not the only sample creating a deep cut. It seems as if the cutting depth generated by the lydite samples in general is deeper than the ones from the flint samples. Likely, this aspect can be combined with the edge angle changes of the samples.

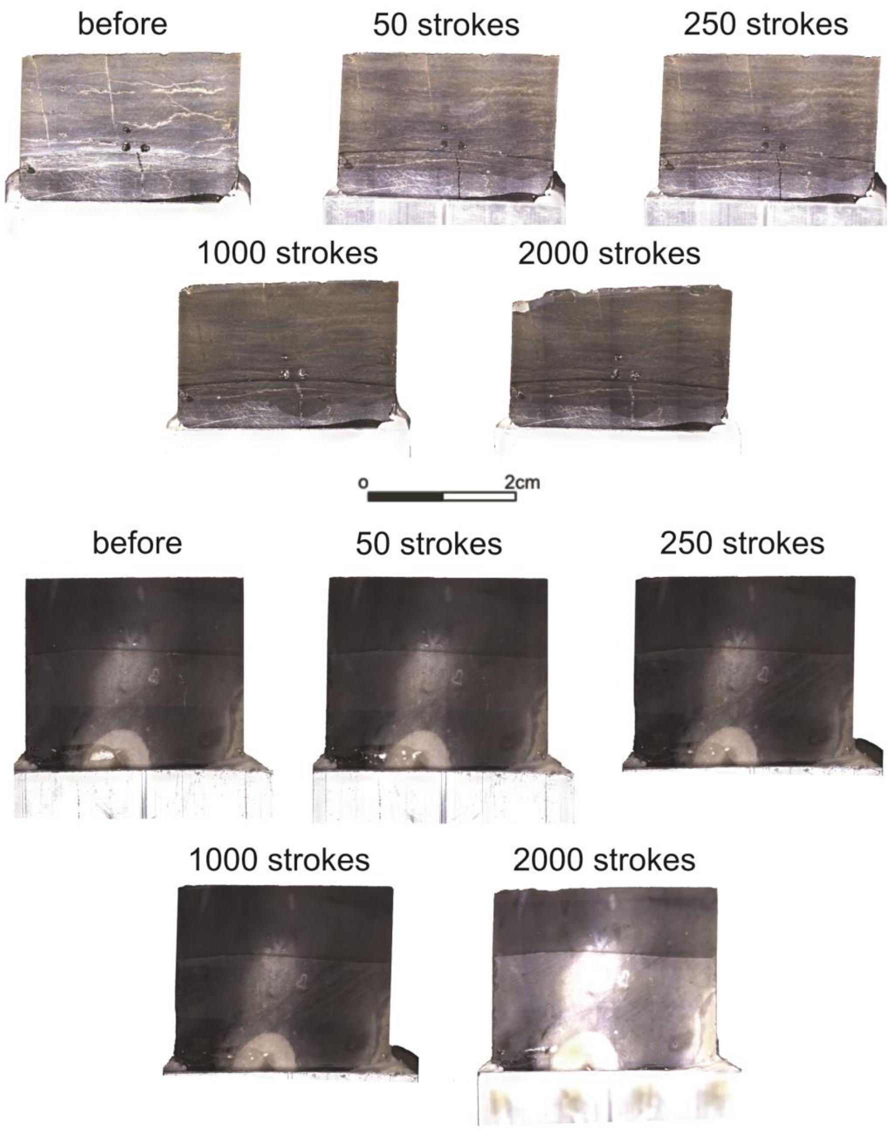

Fig. 150 Standard samples made of lydite (row one and two) and flint (row three and four) illustrating the alteration experience throughout the sequential experiment.

Fig. 151 3D scan of the artificial bone plate used during the initial experiment. The left side shows the plate before the use, the right side after 2000 strokes performed with seven standard samples.

The edge angles of all samples were calculated before and after each cycle. This was done based on the 3D models, as previously explained. Although the edge angles were calculated with the three different measurement procedures respectively, only the results from the '3-point' procedure will be presented here (**fig. 152**). The entire dataset can be found on GitHub [https://github.com/lschunk/edge_angle_experiments]. The data as well as the plot illustrates clearly, that the 40° and 60° flint samples change the edge angle in the course of the experiment only insignificantly. The same counts for the two 60° lydite samples. The change of the edge angles in these samples is about maximum 3° and thus also in the threshold of the expected inaccuracy of the measurement method. The 40° lydite samples did change more significantly. Throughout the first 250 strokes, the edge angles of the three lydite samples altered only slightly as described for the other samples. Distinct changes occurred during the penultimate and especially during the last cycle. While this means a difference of about 10° from the initial 40° edge angle in two lydite samples, one sample altered much more. The edge angle of the sample LYDIT1-4 changed from 40° to roughly 50° after 1000 strokes and above 100° throughout the last cycle.

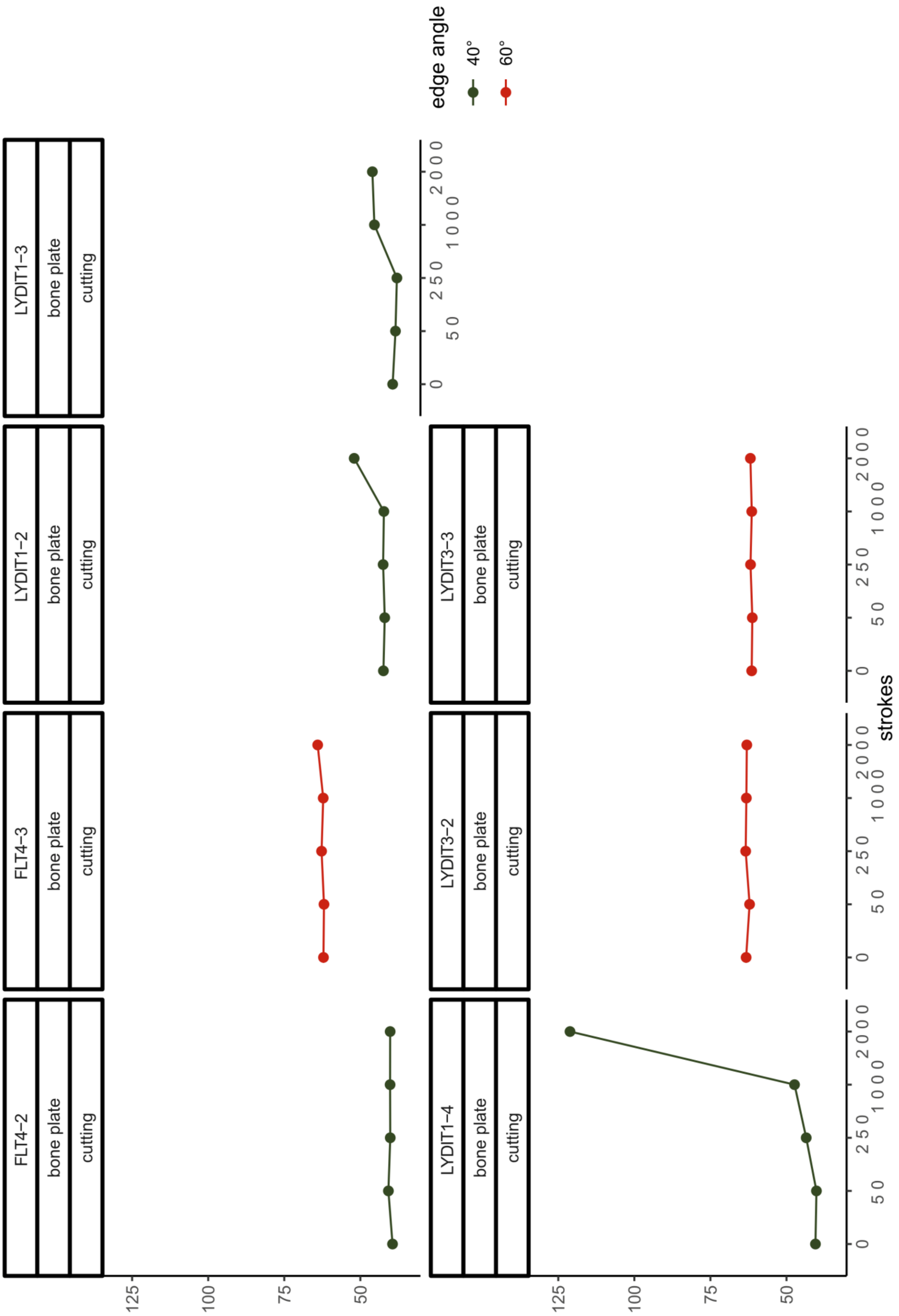

Fig. 152 Edge angle values calculated per sample used during the initial experiment (calculated with the '3-point' procedure; mean value of section 2 to 8 and distance 3 to 6). The data points per sample represent the values after the performance of each cycle (0, 50, 250, 1000 and 2000 cutting strokes).

Altogether, the preliminary observations made during the initial experiment show a reproducible trend: lydite breaks more easily than flint when the tool has a low edge angle (= 40°). With a higher edge angle of 60° this difference between flint and lydite can no longer be observed (Schunk et al., 2019). At the same time, lydite seems more efficient in the sense of the achieved cutting depth. The more fragile the raw material, the bigger the risk of damages, which can affect the durability. In the case of the more fragile lydite, increasing the edge angle leads to an improved durability. Efficiency and durability both play a role when evaluating tool performance.
Neither a qualitative nor a quantitative use-wear analysis was done on the samples from the initial experiment.

5.5.2 Data analysis - 'artificial VS. natural' experiment

The second experiment was the 'artificial VS. natural' experiment (**fig. 37**). The goal of the experiment was to evaluate, whether standardised, artificial contact materials lead to comparable results as the use of natural contact material does. Simultaneously, this experiment was meant to add more data on how the independent variables – here raw material and contact material – influences tool efficiency, durability and performance. Concerning the use-wear, this experiment was also meant to provide data in order to test and understand the mechanics behind the formation of use-wear traces. Moreover, the reflection of these processes in the quantitative data should be investigated.
The twelve lydite and the twelve flint samples were all unifacially cut with a 60° edge angle. The samples were tested in four cycles on a bone plate with a rubber skin layer, a fresh cow scapula, a soft tissue pad and a piece of natural pork skin. All 24 samples passed through the four cycles and completed the 2000 cutting strokes respectively.
The first analysed aspects were the sensor data from the SMARTTESTER®. As explained in the method chapter, the focus thereby was lying on the data from the depth sensor. The penetration depth for each sample was recorded throughout the entire experiment. The data was plotted per sample (**fig. 153**). The plots always show in one plot each single stroke from the first cycle (n = 50 strokes) and every 40th stroke from all the four cycles together in a second plot. These plots illustrated a continuous increase in depth with a rapid penetration during the first 250 strokes (dependant on the contact material). Unfortunately, some issues with the software of the SMARTTESTER® can be noticed similarly. Some of the plots show clear outliers with sudden changes in depth. These are part of the data, but could be identified as wrong recoding due to problems with the software. Moreover, the absolute penetration depth per sample was calculated (**fig. 154 - 155**). The plots of these calculations reveal some interesting aspects. First of all, the samples reached a greater cutting depth on the natural contact materials compared to the artificial contact materials. More surprisingly is that the lydite samples performed better than the flint ones. Except for the skin pad, where the results are similar between the samples from the two raw materials, lydite tends to achieve a higher cutting depth.

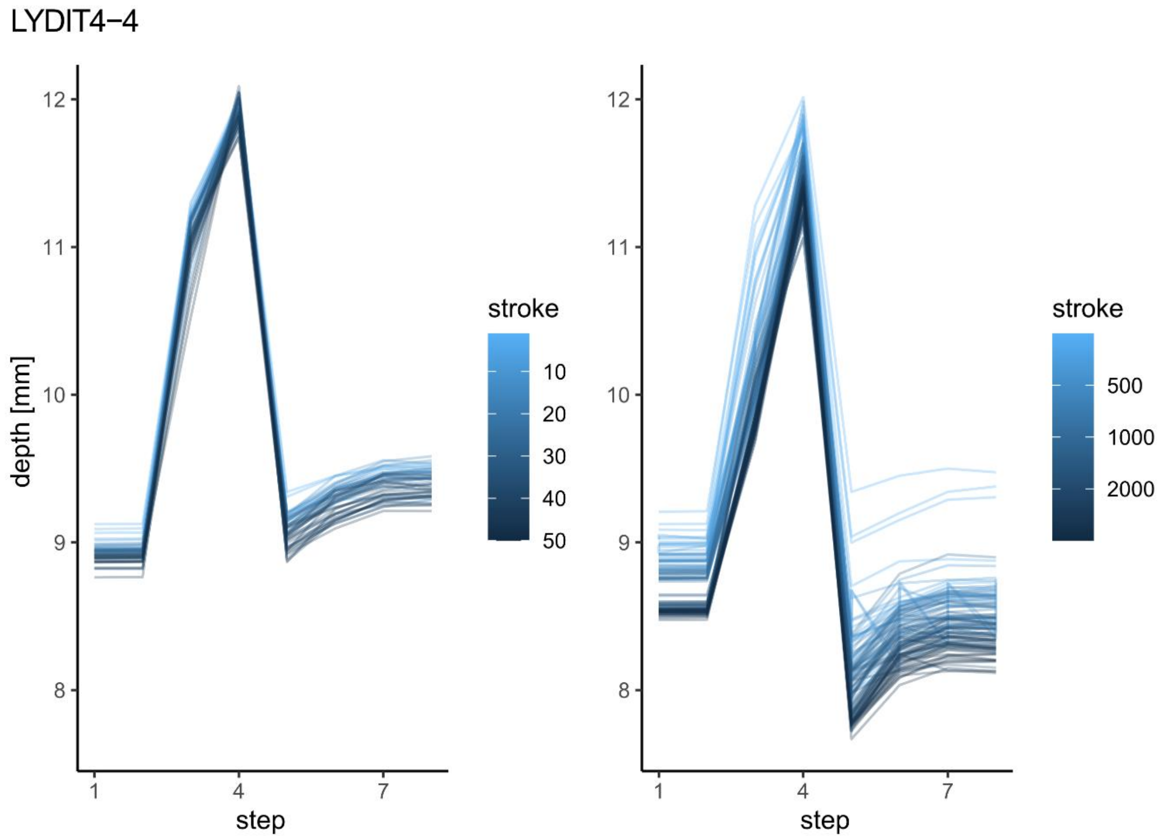

Fig. 153 Sensor recorded penetration depth achieved with a cutting movement performed with the SMARTTESTER® during the 'artificial VS. natural' experiment. Exemplarily presented here the recording of sample LYDIT4-4. The left graph shows each cutting stroke within the first cycle (0 to 50 strokes). The right graph shows each 40th cutting stroke within all cycles (0 to 2000 strokes). The darker the colour, the greater the penetration depth.

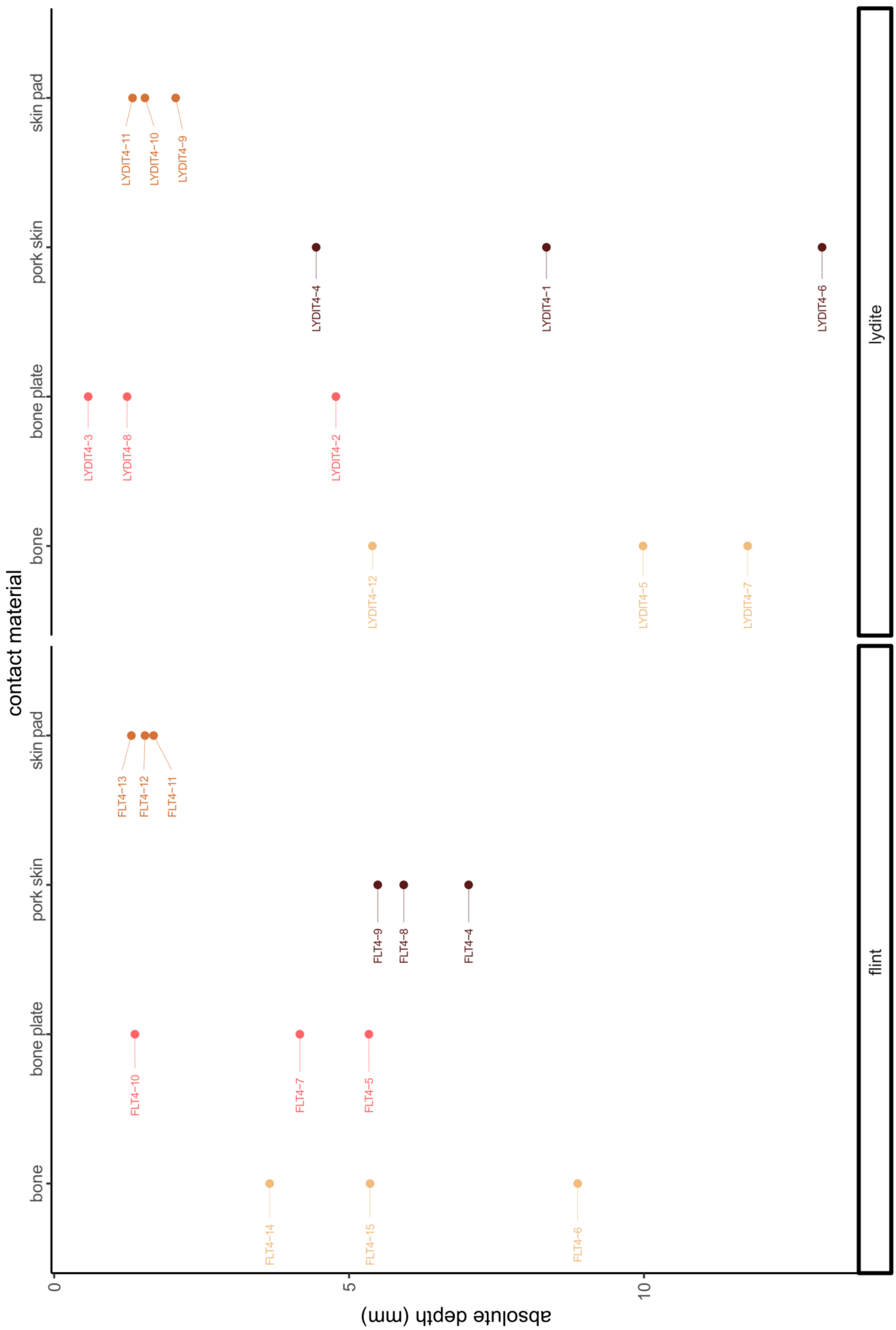

Fig. 154 Absolute cutting depth of all samples used during the 'artificial VS. natural' experiment. The samples are organised according to the standard sample raw material and the contact material.

Fig. 155 Absolute cutting depth of all samples used during the 'artificial VS. natural' experiment. The samples are organised according to the contact material.

Identical to the initial experiment, the edge angle values of all samples during the different stages were calculated (**fig. 156**). Before explaining the results, it has to be mentioned that a few data points are misleading. The scans from one sample, LYDIT4-9, are slightly problematic. The scans after 50 strokes and after 1000 strokes displayed some small holes on the edge, indicating that the edge was not perfectly scanned. These holes needed to be filled in order to calculate the edge angle values. Apparently, the filling was not accurate enough. These two data points are wrong and do not display the real edge angle values. That these data points are incorrect can be reconstructed by inspecting the raw data of the 3D models and the EDF pictures of the edge. For the mentioned two samples, no visible change occurred during the corresponding cycles. One other sample displays misleading results. The sample FLT4-7 got damaged right before it was used in the experiment. Due to this damage, the cutting edge of the standard sample was partly modified. One half of the edge was still complete and displayed the typical diamond band saw cut, the other half looked retouched (**fig. 157**). Since it takes many hours to produce such a standard sample, it was decided to use this sample as initially planned. The sample was documented again and treated as any other new sample. However, the edge angle of the retouched part of the standard sample was slightly higher than the targeted 60°. Therefore, the mean edge angle of sample FLT4-7 deviates with ~ 66° from the other standard samples. For the remaining edge angle calculations, no mistake could be identified. For the twelve samples (lydite and flint) used on the soft materials, natural pork skin and artificial soft tissue pad, no significant change could be documented. All edge angle changes are within the approximated 3° threshold of the expected impreciseness of the measurement method. The results differ when looking at the samples used to cut the hard contact material, fresh cow scapula. The samples used on the fresh cow scapula are characterised by alteration along the standard sample edge. The alteration occurs directly during the first cycle and proceeds continuously throughout each cycle. The edge angle values shift about 3° to 9°, whereas the edge alternation is slightly bigger for the lydite samples than for the flint samples. The results for the samples used on the second hard material, the artificial bone plate, are comparable to the results from the soft contact material. One exception should be mentioned. Sample LYDIT4-2 displays a small alternation of the edge of about 6° in total. Here, the modification is also characterised by a continuous process starting already during the first cycle. To summarize, the hard contact material favours alteration of the standard samples. This process was documented on the flint standard samples as well as on the lydite standard samples. However, this effect is stronger in lydite. The last aspect is emphasised by the results from sample LYDIT4-2.

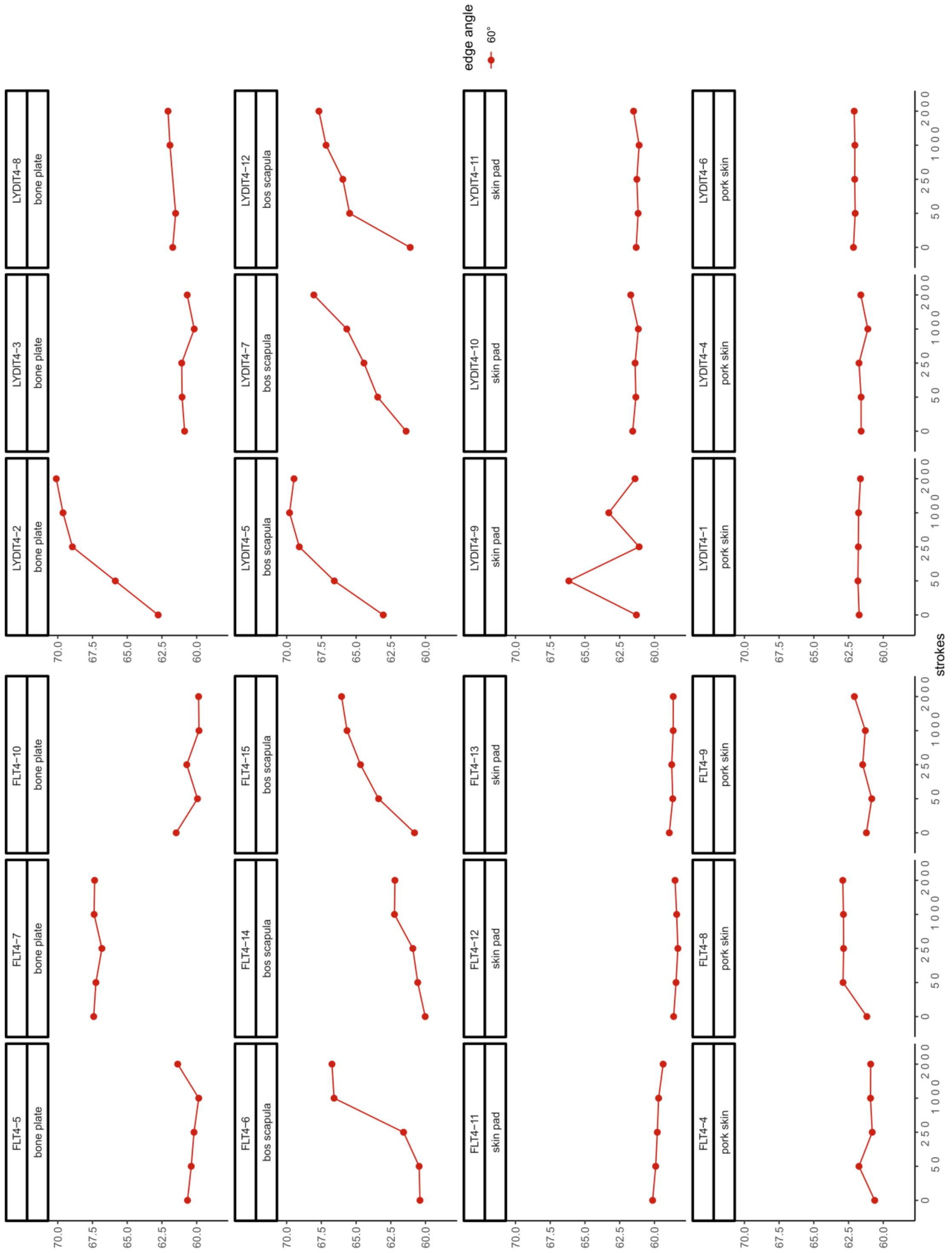

Fig. 156 Edge angle values calculated per sample used during the 'artificial VS. natural' experiment (calculated with the '3-point' procedure; mean value of section 2 to 8 and distance 3 to 6). The data points per sample represent the values after the performance of each cycle (0, 50, 250, 1000 and 2000 cutting strokes).

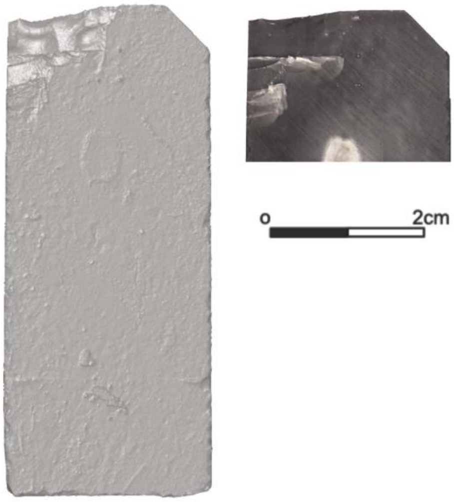

Fig. 157 Flint standard sample FLT4-7 as 3D scan (left) and EDF-stitching image of the edge (right) used during the 'artificial VS. natural' experiment. The sample is damages on the left side.

The qualitative and quantitative use-wear analysis was done for eight samples from the 'artificial VS. natural' experiment (see appendix IV.). These eight standard samples have been selected systematically so that four flint and four lydite samples were involved in the analysis. *Per* raw material, there was one sample respectively tested from each of the four contact materials. For the qualitative use-wear analysis, the 'dorsal' (A and B) and the 'ventral' surface (D and C) were analysed with the upright light microscope (ZEISS Axio Scope.A1 MAT). All use-wear traces are illustrated as figures in the supplementary material. The question behind the use-wear analysis was to see how, where and when use-wear develops on the standard samples. Another question was, whether or not the use-wear traces produced with the natural contact material differ from the ones produced with the artificial contact material or vice versa. To answer these questions, the selected eight samples (moulds) were microscopically analysed before and after each cycle. To start with the soft contact material again, first the results for the natural pork skin will be explained (**fig. 158 - 159**). On the flint sample (FLT4-4), there is no development of use-wear visible until 250 strokes. Use-wear is visible on the 'dorsal' (B) surface. The spot is further developed after 2000 strokes. The lydite sample (LYIT4-1) used on the natural pork skin starts to develop some use-wear traces after 250 strokes (D), but identifiable use-wear traces are only visible after 2000 strokes (A, B, D). However, the surface shows in the beginning clear traces of the diamond band saw cut and these traces turned weaker within the first cycles. The same can be noticed for the lydite sample (LYDIT4-9) used on the artificial soft tissue pad. Throughout the cycles, the initially visible traces from the diamond band saw abrade and disappear, the 'natural' surface seems to appear and during the last cycle, use-wear traces develop (B). The situation is different for the corresponding flint sample (FLT4-15). In this case, the traces from the manufacturing are evident, but the surface did not visibly change throughout the experiment. The flint sample (FLT4-5) used on the artificial bone plate only displays use-wear traces (A, B) after 2000 strokes. By contrast, use-wear traces (A, C) on the lydite sample (LYDIT4-2) are already visible after 50 strokes. Both samples (FLT4-15 and LYDIT4-9), which were used on the fresh cow scapula, show traces right after the first cycle (flint: B, D; lydite: A, B). Only the traces on the 'ventral' surface (D) of the lydite sample occur as distinct traces not until 1000 strokes.

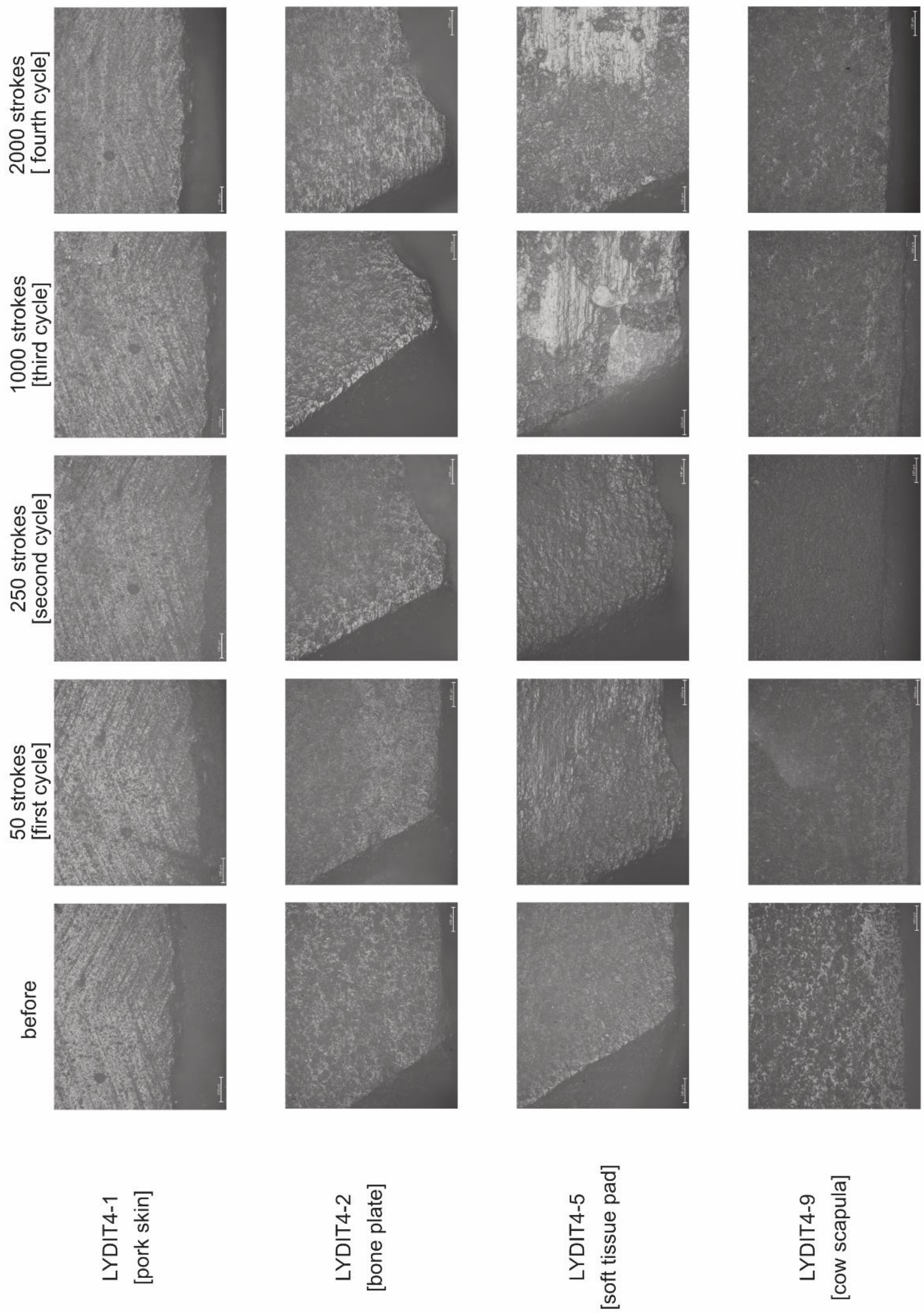

Fig. 158 Use-wear formation on the analysed lydite standard samples during the four cycles of the 'artificial VS. natural' experiment (all images are taken with a 10x optical objective).

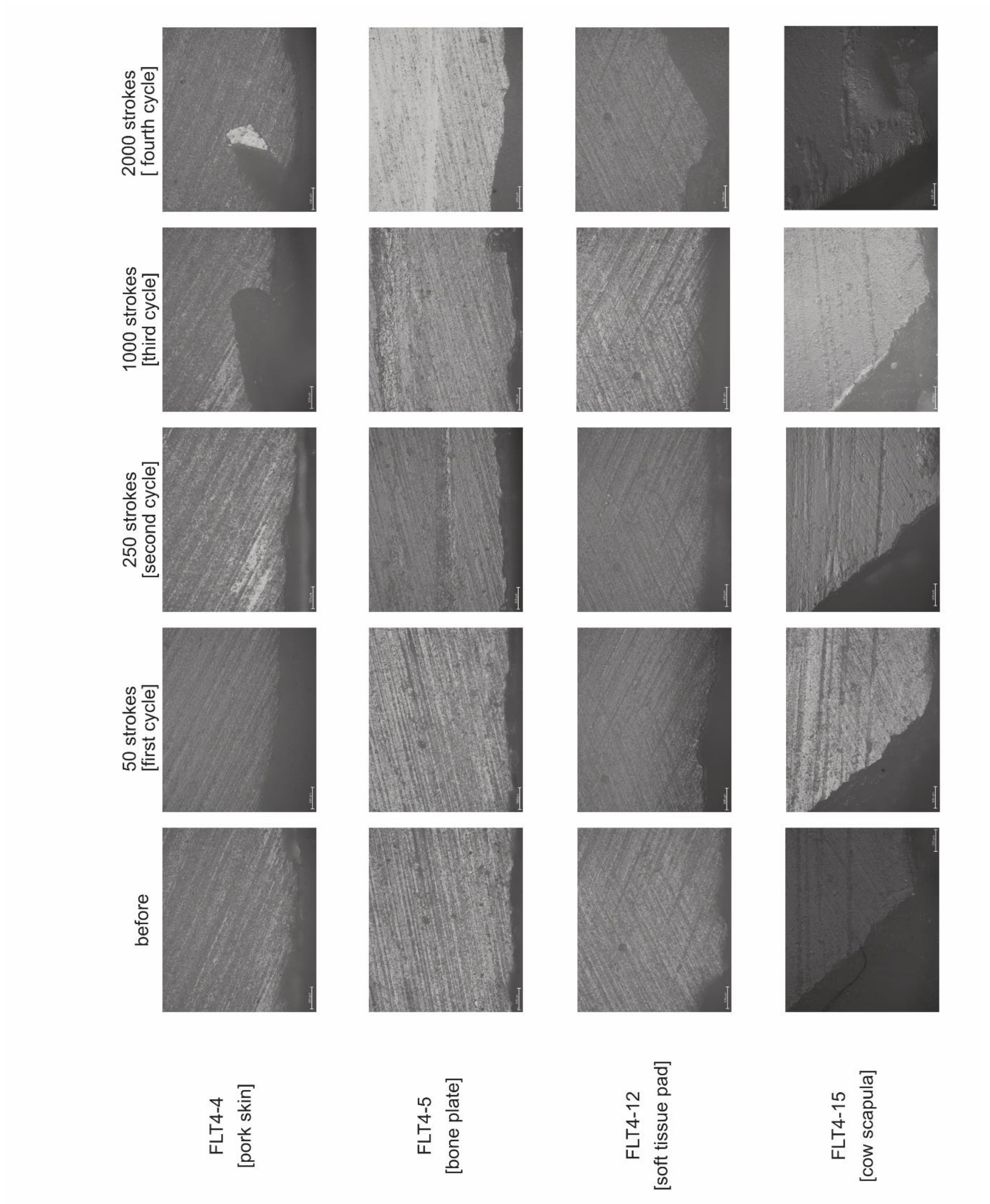

Fig. 159 Use-wear formation on the analysed flint standard samples during the four cycles of the 'artificial VS. natural' experiment (all images are taken with a 10x optical objective).

The qualitative analysis could prove that use-wear traces do develop on the standard samples, although they are missing the surface texture characteristic for the material. Moreover, these observations clearly show that the harder the contact material, the easier is it for use-wear traces to develop. At the same time, a modification of the standard sample surface occurs faster on lydite than on flint. The answer for the comparability between natural and artificial contact materials is less straightforward though. Visually inspected, the traces produced by both groups of contact material do appear similar. The developed polished areas do look typical for hard and soft contact materials. However, the process, when the traces develop, is not always comparable. The results for the lydite samples are identical on the natural as well as on the artificial contact materials. The lydite samples used on both soft contact materials display use-wear traces after 250 and 1000 strokes, the ones used on both hard contact materials after 50 strokes. The situation for the flint samples is different. While cutting, the natural soft contact material led to use-wear traces after 250 strokes, the artificial soft contact material did not produce use-wear traces at all. The sample used on the natural hard contact material developed traces after 50 strokes, while traces from the artificial hard contact material appeared not until 1000 strokes. Unfortunately, only one sample per raw material and contact material was analysed, so that the results are not statistically evaluable.

Additionally, a quantitative use-wear analysis was conducted. The same eight samples were used for the analysis, but only the moulds from before the experiment and after 2000 strokes were analysed. Thanks to the coordinate system (beads) (Calandra et al., 2019a) on each tool surface, it was possible to relocate to the identical spot on the before and after surface. Thus, variability due to positional inaccuracy could be excluded. Generally, one spot per sample was selected for the quantitative use-wear analysis. Two samples constitute an exception: on two flint samples (FLT4-14 and FLT4-15) two instead of one spot were measured. Scans were acquired on well-developed polished areas (after 2000 strokes). As done already for the quantitative use-wear analysis from the archaeological material, each use-wear trace was measured three times (a - c) on nearby, but not identical spots. In total, n = 30 measurements were taken on the samples from before the experiments and n = 30 on the samples from after 2000 strokes. Identical to the qualitative use-wear analysis performed on the archaeological samples, the data was acquired to the ISO 25178-2. Furthermore, the same n = 21 ISO 25178-2 parameters, n = 3 furrow parameters, n = 3 texture direction parameters, n = 1 texture isotropy parameter and the SSFA parameters *epLsar, NewEplsar, Asfc, Smfc, HAsfc9 and HAsfc81* were calculated on each surface (**tab. 11**).

A first attempt to review the data was done by plotting the data in a scatterplot per parameter (**fig. 160 - 161**). These scatterplots include information about the sample, the raw material and the contact material as well as the location (A-D). The data is illustrated in a way that the results from before and after 2000 strokes can be compared directly.

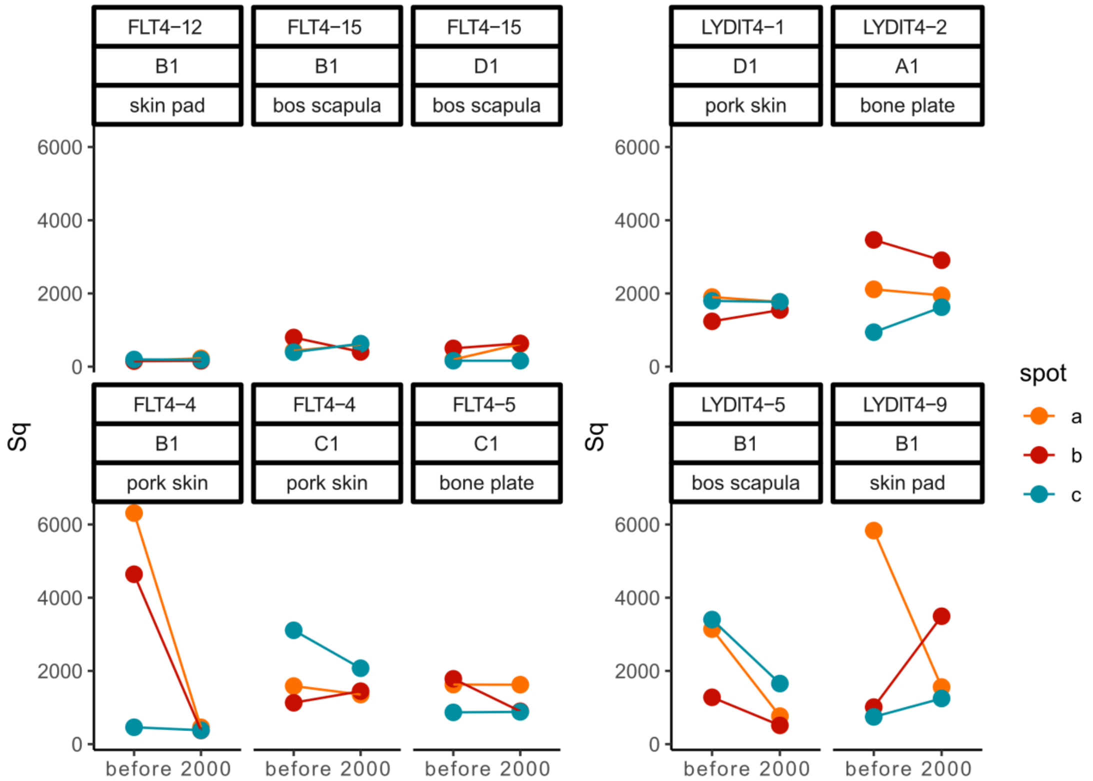

Fig. 160 *Sq* values before and after 2000 cutting strokes measured on identical spots on each standard sample used during the 'artificial VS. natural' experiment respectively. Spot a, b and c refers to the three measurements taken per use-wear trace.

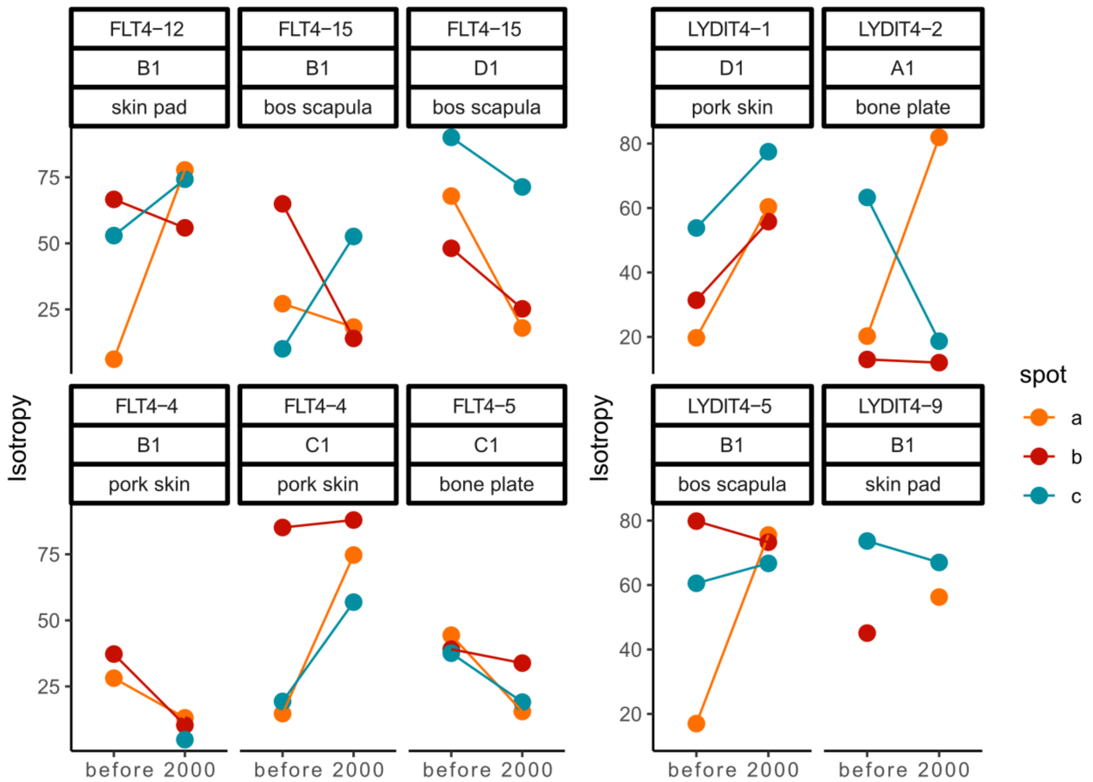

Fig. 161 *Isotropy* values before and after 2000 cutting strokes measured on identical spots on each standard sample used during the 'artificial VS. natural' experiment respectively. Spot a, b and c refers to the three measurements taken per use-wear trace.

Four data points, identified as outliers, need to be mentioned. Since the use-wear on the standard samples is extremely marginal due to the low penetration depth into the contact material, it was often difficult to acquire the data without scanning beyond the edge. Whenever this happens, such areas are interpreted as non-measured points. Filling these data points in order to calculate the parameters leads to divergent results. Unfortunately, that happened in four cases. The samples FLT4-4-B1-a, FLT4-4-B1-b, LYDIT4-9-B1-a (all before) and LYDIT4-9-B1-b (2000 strokes) need to be treated as outliers and excluded from interpretations. Most of the parameters, as for instance *Sq*, *Vmc, Sxp* or *Sdr* change from before to after 2000 strokes only insignificantly. For single samples, as for example the sample LYDIT4-5, the surface roughness seems to decrease after 2000 strokes. Clear changes are noticeable when looking at the *isotropy* or *epLsar* (equal to anisotropy) (**fig. 161**). With some exceptions within the flint samples (FLT4-4-B1, FLT4-5-C1, FLT4-15-D1), the *isotropy* values increase from before towards 2000 strokes. This means, the directionality of the surface is getting less, and the surface is getting more similar in all directions. It seems as if directionality of the surface, characterised by the diamond band saw cut, stands in contrast to the directionality of the use-wear traces. In another plot type, the three measurements per use-wear traces were taken together and the arithmetic mean values per use-wear trace were calculated (**fig. 162**). These plots only emphasize, what was pointed out before. Based on the calculated ISO parameters, there is no significant recognisable change between before and after the 2000 strokes. The only exception still, is sample LYDIT4-5 use on fresh bone. Nevertheless, it seems as if the initial surface texture roughness influences how significant the change from before to after the use is. Samples with an initially higher surface roughness seem to experience more change than samples with an initially lower surface roughness. However, a clear shift can be noticed concerning the texture isotropy parameter and the SSFA parameters.

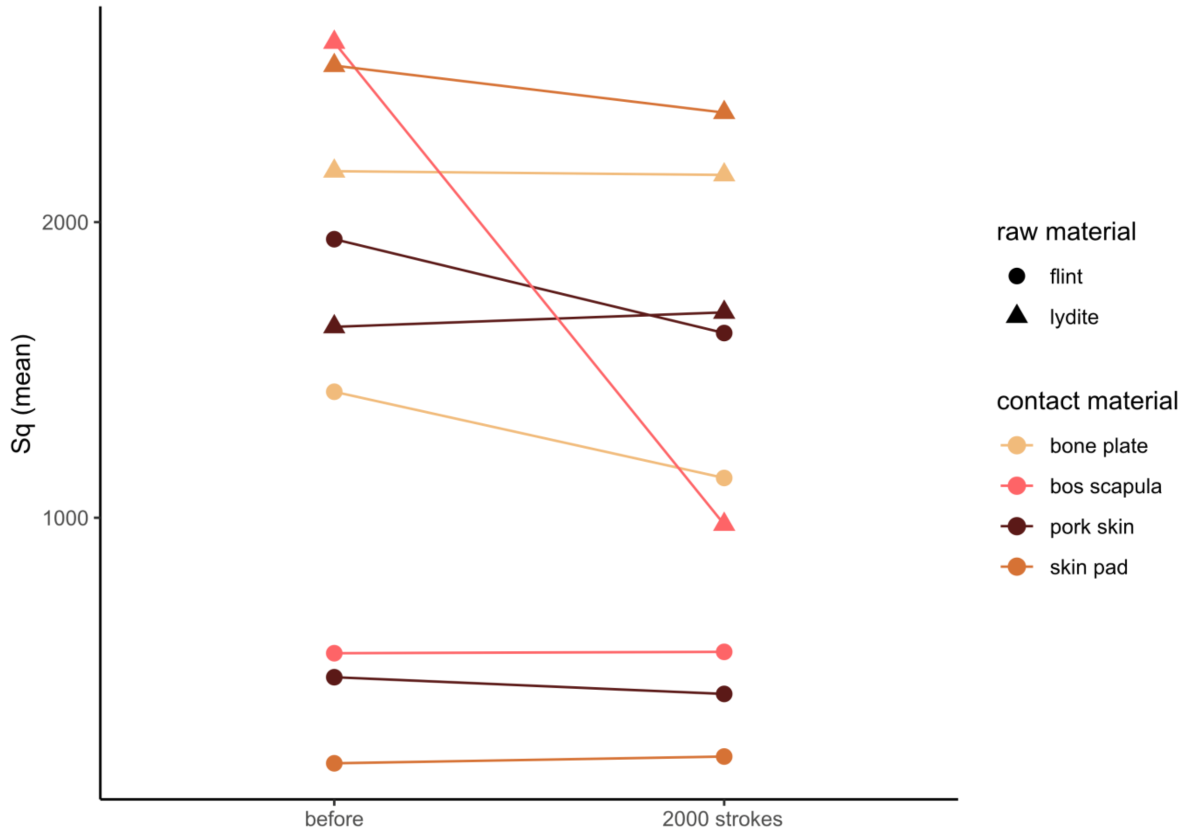

Fig. 162 *Sq* values before and after 2000 cutting strokes measured on identical spots on each standard sample used during the 'artificial VS. natural' experiment, respectively. *Sq* reflects the mean value of the three measured spots taken per use-wear trace. The colours indicate the contact material the tool was used on.

On seven selected parameters, a principal component analysis (PCA) was applied. The same parameters as for the last PCA (see chapter xx) were chosen in order to perform the PCA. These parameters are *Sq, Ssk, Vmc, Mean density of furrows, Isotropy, Asfc* and *HAsfc9*, spanning the different categories of field parameters. The first PCA reflects the variance between the samples used on the four contact materials (**fig. 163**). Principal component 1 (PC1) reflects 42.74% of the variance in *Sq, Vmc*, and *Asfc*. The variance in *Ssk, Mean density of furrows, Isotropy* and *HAsfc9* is represented by Principal Component 2 (PC2), which accounts for 18.69 %. The data cluster from the four contact materials overlap. Unfortunately, the cluster from the natural contact material and the corresponding artificial contact material differ distinctly in both cases.

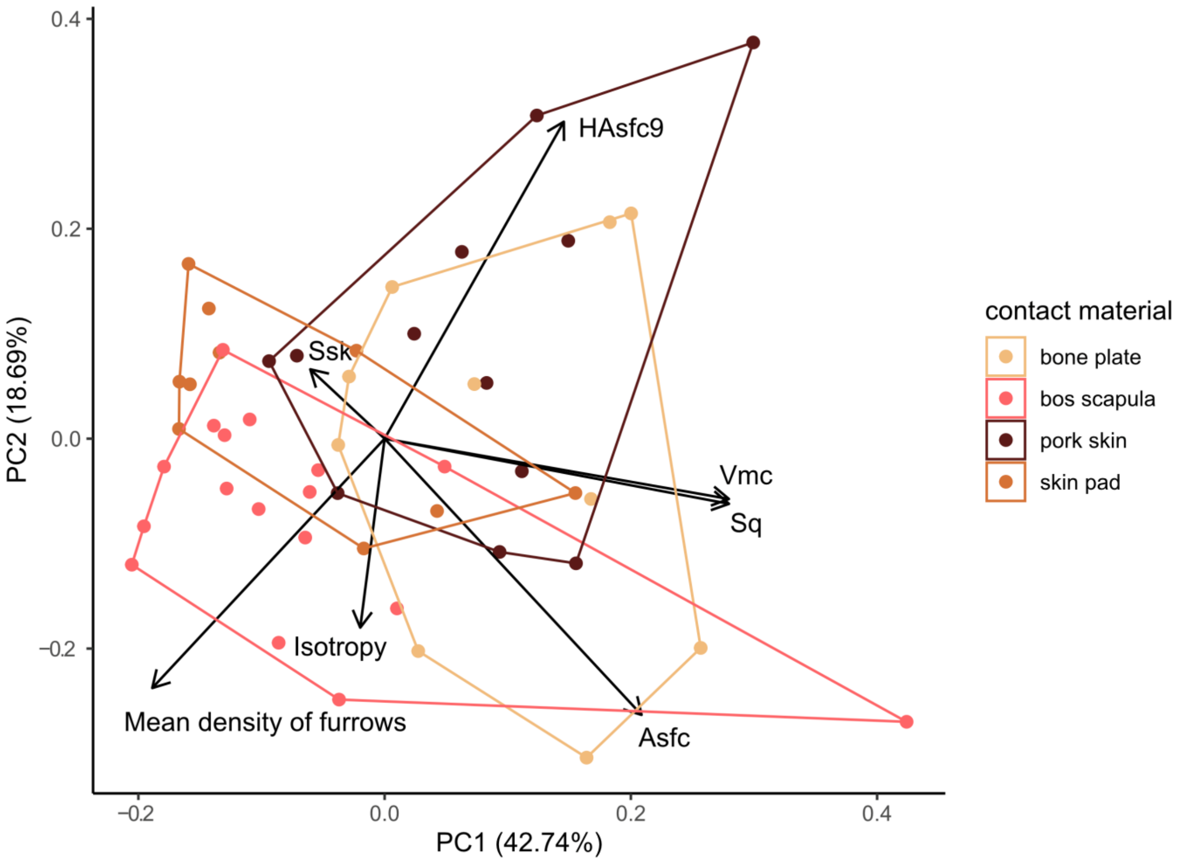

Fig. 163 Principal component analysis applied on the measured use-wear traces of the analysed standard samples from the 'artificial VS. natural' experiment after 2000 cutting strokes, reflecting variation regarding the contact material.

A second PCA visualises the variance in the two categories before and after 2000 strokes (**fig. 164**). The two cluster overlap mainly in the left part of the PC1 axis. At the same time, the data points from before scatter more over the plot. The cluster from after 2000 strokes is denser, pointing to more homogeneous data.

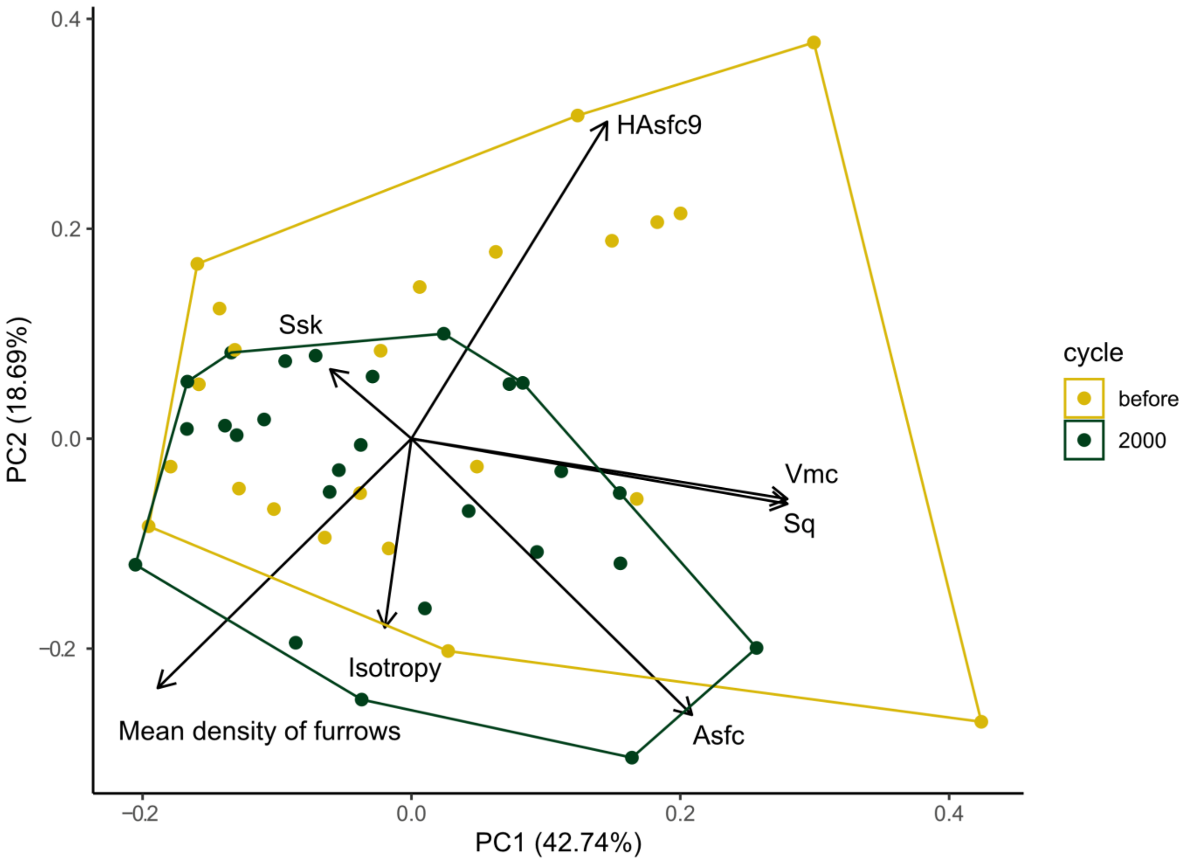

Fig. 164 Principal component analysis applied on the measured use-wear traces of the analysed standard samples from the 'artificial VS. natural' experiment, reflecting variation regarding before and after 2000 cutting strokes.

The results of the quantitative use-wear analysis illustrate the diversity within the measured, individual use-wear traces. While the homogeneity for the three measured spots (a, b and c) *per* use-wear trace is given, this does not count for the use-wear traces on the different samples. The acquired data emphasise that within the selected use-wear traces, a variance exists. This means, the use-wear traces on the flint samples and the use-wear traces on the lydite samples produced on identical contact material respectively, already differ. The same results count for the comparison between the natural and the artificial contact material. The analysis highlights the importance of the amount of data and the relevance of replicas. Here, the acquired data is not statistically evaluable since only one sample per raw material and contact material was part of the quantitative use-wear analysis. Otherwise, it would be interesting to see, whether the data acquired on the replicas used within the experiment would lead to different results within each analysed category.

5.5.3 Data analysis - tool function experiment

The final experiment was the tool function experiment (**fig. 38**). Raw material, edge angle and movement served as independent variables. Tool efficiency, durability and

performance were tested on artificial bone plates. In total 24 unifacially cut standard samples were used. The samples can be separated in the following groups: twelve flint and twelve lydite standard samples with six times 35° and 45° edge angel each. Three samples per category were used for cutting, three samples per category for carving.
In a first step analogous to the experiment before, the sensor data from the SMARTTESTER® will be presented. In the focus of this analysis stands again the data recorded with the depth sensor. The individual results per sample are accessible as plots showing the first 50 strokes and additionally each 40th stroke combined (**fig. 165**). The plots illustrate a continuous increase in penetration depth throughout the experiment with an especially rapid increase during the first strokes. In order to put the efficiency, here only measured as penetration depth, in relation to all 24 samples, the absolute depth achieved per sample was calculated. As reported for the previous experiment, sometimes software issues with the SMARTTESTER® appeared, leading to wrong recordings. These wrong recordings are identifiable in the plots. Within the recorded data, recorded data for single strokes reaches values beyond the possible moving radius of the mechanical device. Thus, some outliers are included in the data. The outliers are not only visible when checking the individual penetration depth per stroke and sample (**fig. 166**), but also in the plots showing the absolute penetration depth. This specific plot (**fig. 167**) includes next to the penetration depth also the information about the sample, the raw material, the edge angle and the movement. Three samples, FLT8-3, FLT8-4 and FLT8-10 differ from the other samples. These are the three identified outliers. In order to get a better resolution of the correctly displayed data, the outliers have been removed (**fig. 168**). The biggest penetration depth was reached with a lydite sample (LYDIT5-7). With the exception of this sample, the penetration depth reached during cutting is comparable between the 35° and the 45° samples. Concerning the carving, the 45° samples achieved a comparable higher penetration depth than the 35° samples. A general tendency is that the lydite samples penetrated deeper into the contact materials than the flint samples. While this observation is not so clear for carving, it is undoubtedly seen for cutting.

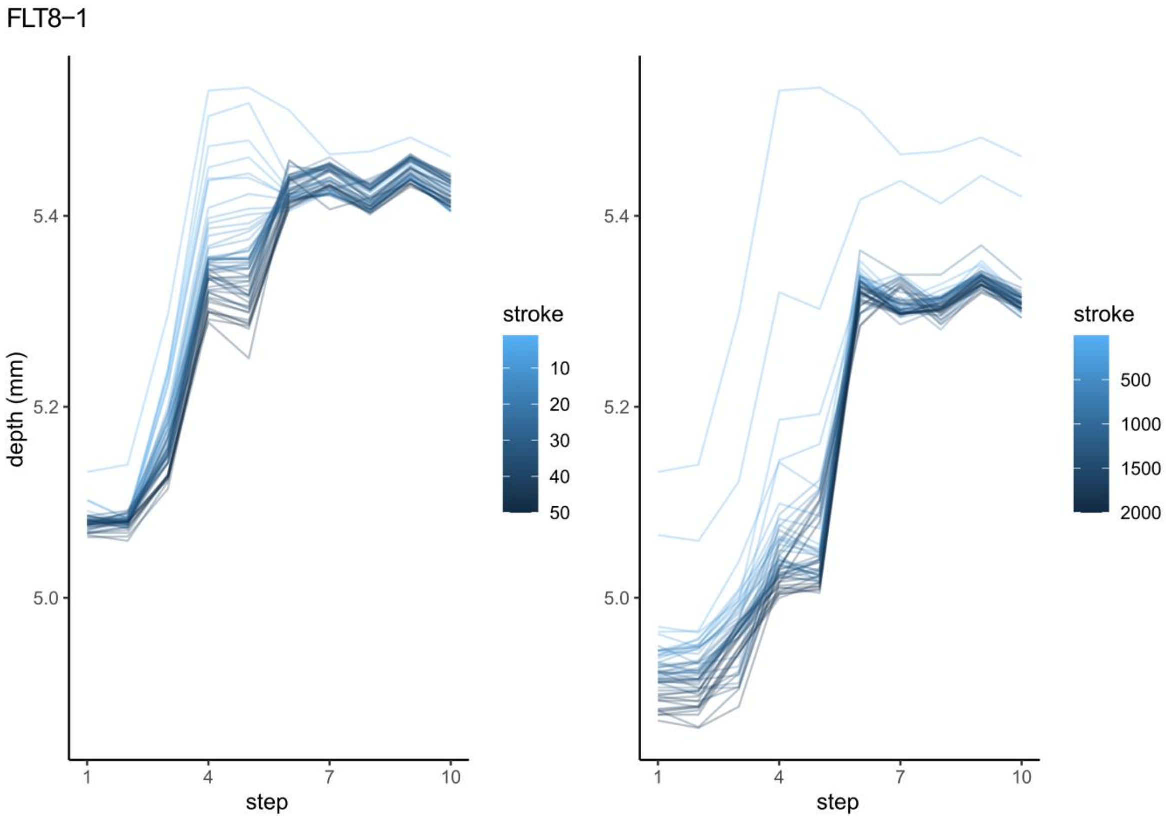

Fig. 165 Sensor recorded penetration depth achieved with a cutting movement performed with the SMARTTESTER® during the tool function experiment. Exemplarily presented here the recording of sample FLT8-1. The left graph shows each cutting stroke within the first cycle (0 to 50 strokes). The right graph shows each 40th cutting stoke within all cycles (0 to 2000 strokes). The darker the colour, the more increased is the penetration depth.

FLT8-10

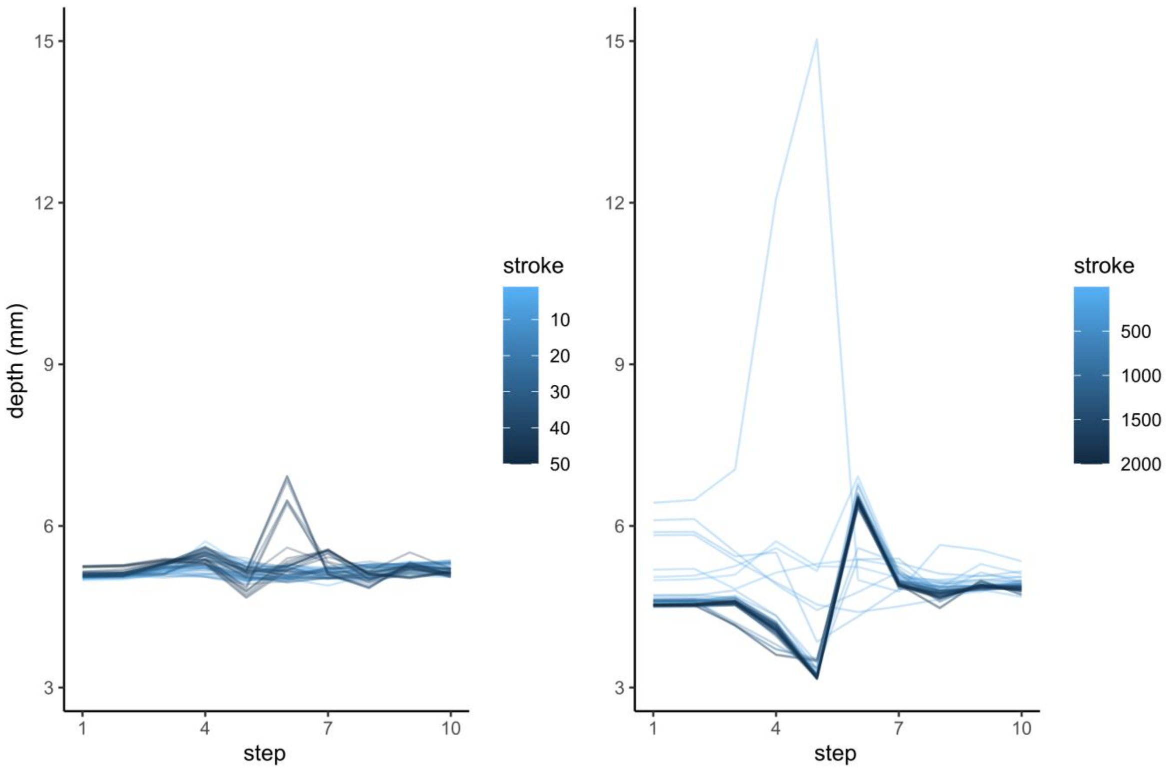

Fig. 166 Sensor recorded penetration depth achieved with a carving movement performed with the SMARTTESTER® during the tool function experiment. Exemplarily presented here the recording of sample FLT8-1. The left graph shows each cutting stroke within the first cycle (0 to 50 strokes). The right graph shows each 40th cutting stoke within all cycles (0 to 2000 strokes). The recording includes outliers as displayed with the light blue line reaching up to 15 mm depth. The darker the colour, the more increased is the penetration depth.

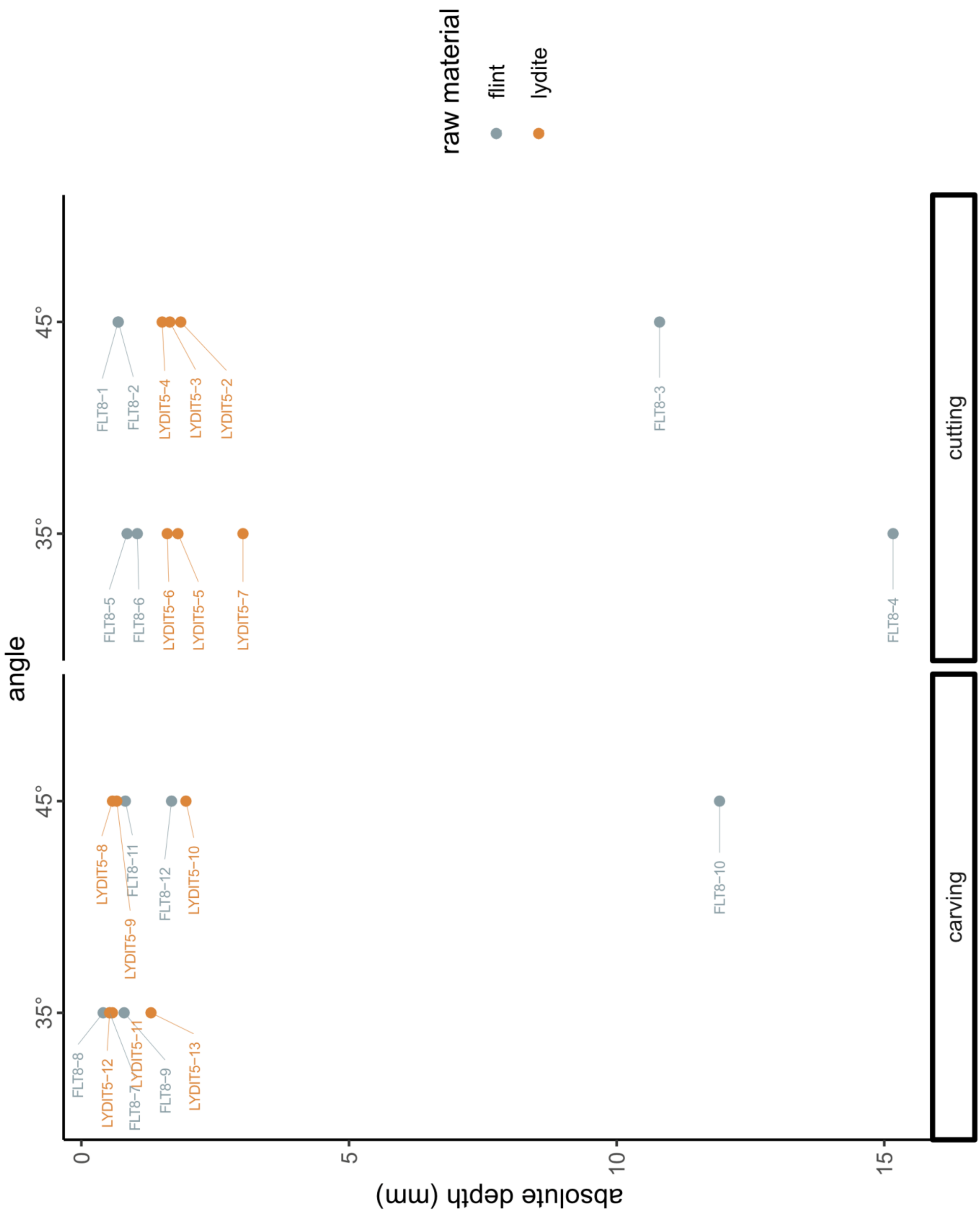

Fig. 167 Absolute cutting depth of all samples used during the tool function experiment. The samples are organised according to the performed task and the edge angle of the standard sample.

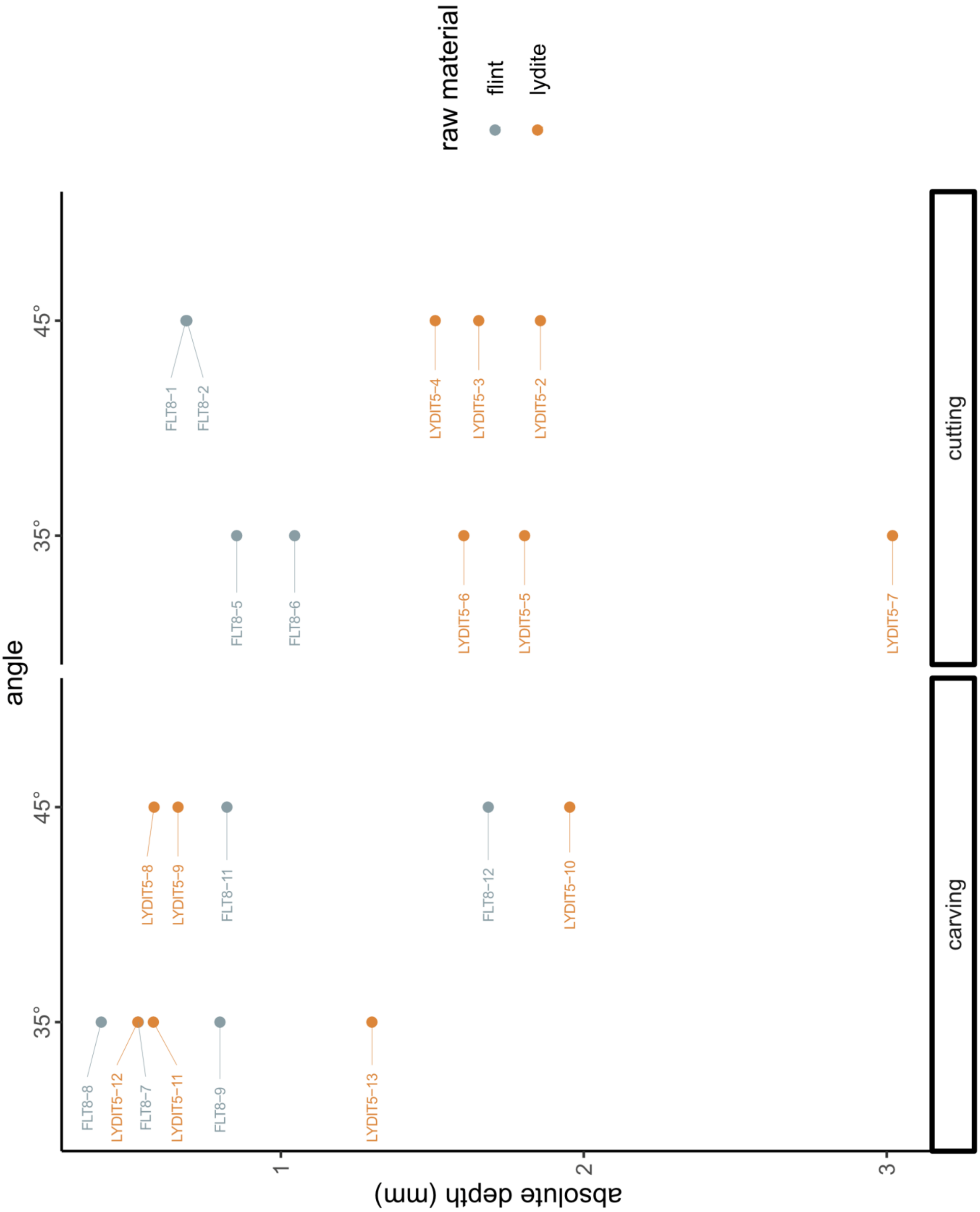

Fig. 168 Absolute cutting depth of all samples used during the tool function experiment. The samples are organised according to the performed task and the edge angle of the standard sample. Outliers removed.

In regard of tool efficiency, the edge angle measurements need to be mentioned. As for the other two experiments, the edge angles of the n = 24 samples were measured before and after each cycle (**fig. 169**). Before explaining the data, one outlier has to be reported. The first edge angle calculation (before) for sample FLT8-3 is not reflecting the accurate value. This sample was produced with 45° edge angel, but displays a 55° edge angle. An examination of the raw data revealed small holes in the 3D data along the edge. Apparently, also in this case, filling the holes changed the edge angel. However, this is the only data point, which needs to be excluded for interpretation.

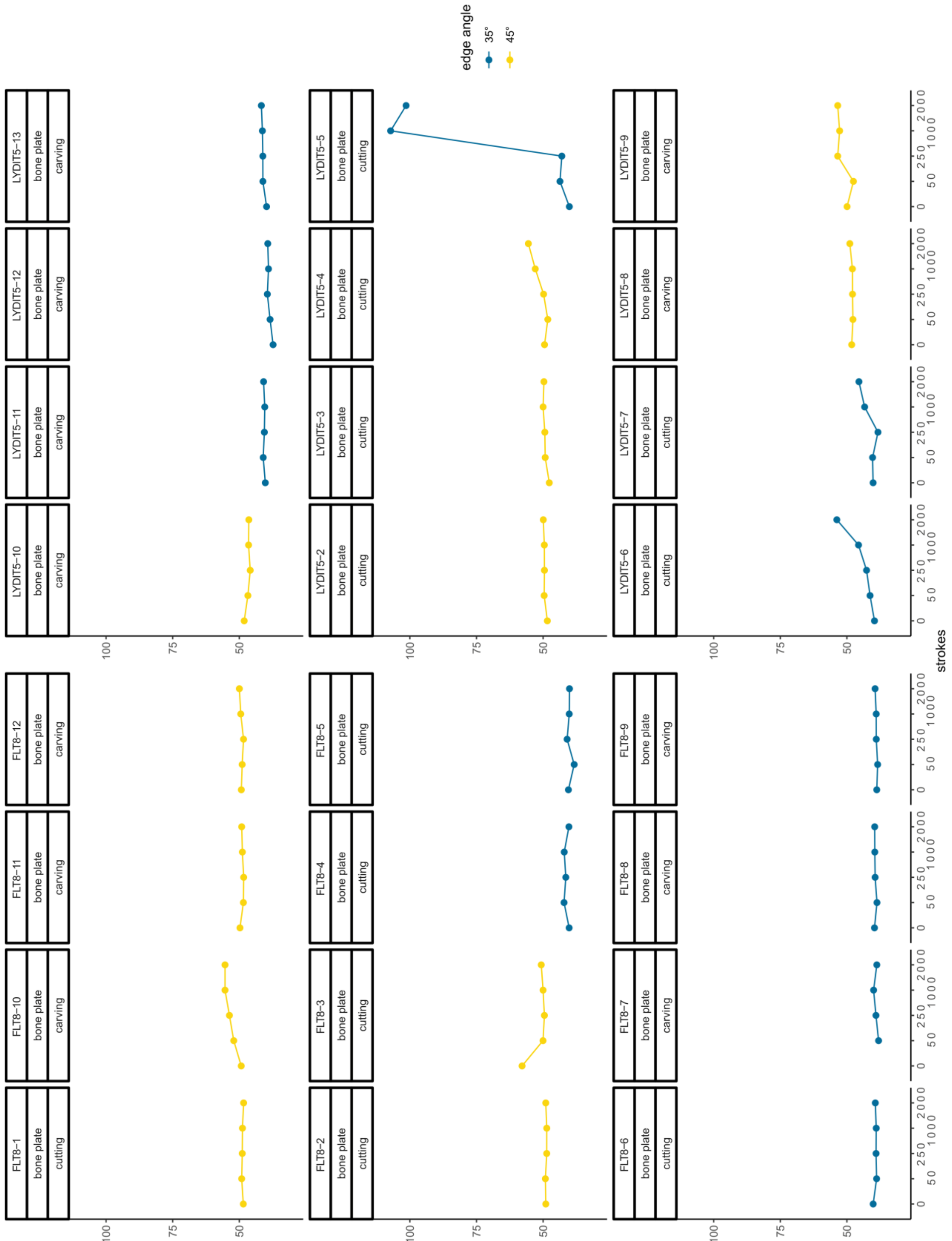

Fig. 169 Edge angle values calculated per sample used during the tool function experiment (calculated with the '3-point' procedure; mean value of section 2 to 8 and distance 3 to 6). The data points per sample represent the values after the performance of each cycle (0, 50, 250, 1000 and 2000 cutting strokes).

The results for cutting differ depending on the edge angle. While the shift in the edge angle is only minimal for the three flint and lydite standard samples with 45°, the results are different for the 35° samples. For one flint sample (FLT8-6), only minimal changes could be observed, but the two other samples (FLT8-4 and FLT8-5) display material loss and thus, a slight shift in edge angle values towards increased bluntness. For the three lydite samples with a 35° edge angle, a decrease in acuteness is clearly visible and illustrated by continuous material loss throughout the experiment. One sample changed from 35° to approximated 75° due to a fracture. Surprisingly the six samples with a 35° used for carving did not change significantly. The same counts for a majority of the 45° samples used for carving. Nevertheless, two samples, one flint and one lydite sample, experienced some alternation after 50 strokes, leading in both cases to a continuous but small increase in the edge angle.

In general, the 10° difference between the two sets of standard samples (35° and 45°) seems to make a difference in durability when used to perform cutting strokes. Although, none of the samples were altered or damaged in a way that it could not function anymore. All 24 samples completed the 2000 strokes. However, the 35° samples exhibit more damage in the sense of small fractures and material loss. This observation cannot be transferred to the results from the carving movement. Irrespective of the raw material, more alteration could be documented for the 45° samples.

The edge angle measurements can be correlated with the volume loss of the standard samples. The volume of each sample was calculated based on the 3D models. Thus, the measurements can only be as precise as the quality of the 3D model allows. On average, lydite samples experience a volume loss of 0.21% (~ 0.37 mm^3). Flint samples display a slightly higher volume loss of 0.36 % (~ 0.52 mm^3). These values could be verified with the weight measurements. Although the lydite samples fracture more and thus also experience more frequent and significant damage, on average, the material loss is only minor. However, the lydite samples appear more fragile and tiny particles break away, which is reflected in the edge angle measurements (**fig. 170**). By contrast, the flint samples more often display material loss comparable to retouch and not fractures. The retouch-like material loss might go further on the surface and could explain the bigger loss in volume and weight. Moreover, this type of material loss might not change the edge angle in a way that the breaking particles do on the lydite.

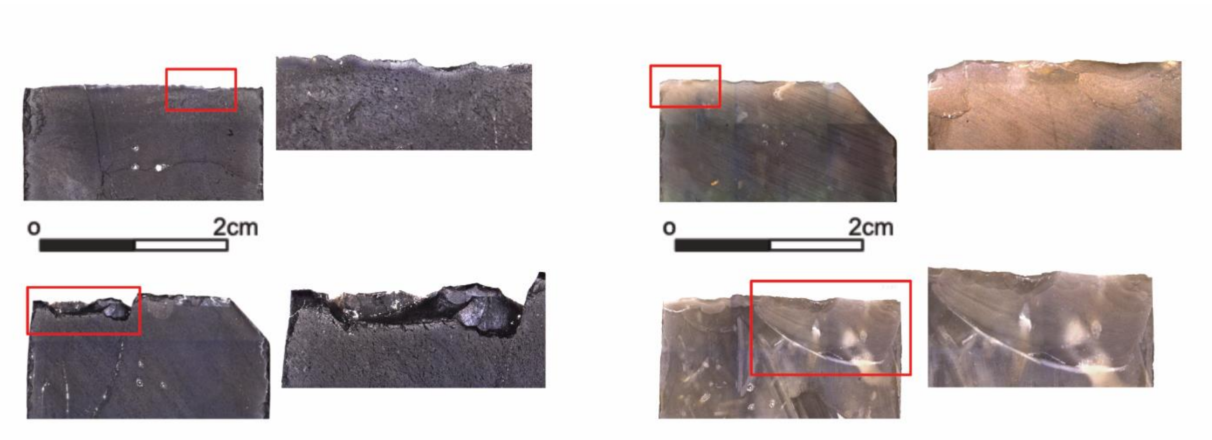

Fig. 170 Tool alteration on standard samples made of lydite (left) and flint (right) after 2000 strokes used during the tool function experiment.

Another aspect is the quality of the cuts or scratches produced on the bone plates (**fig. 171**). Quality can be defined by the regularity, the uniformity and the width of the cuts or scratches. In this sense, quality is one relevant aspect in order to evaluate tool performance. As already mentioned for the initial experiment, the cuts produced with flint samples optically differ slightly from the ones produced with the lydite samples. This observation is only based on a visual assessment. The flint cuts appear as thin lines, whereas the lydite cuts seem thicker and less precise. In particular the cuts produced with the 35° lydite samples seem broader. For the majority of the traces left on the bone plates during carving, no significant difference between the traces caused by the flint samples and the ones caused by the lydite samples is noticeable. One exception is the trace left by the flint sample FLT8-10. This sample achieved a comparable high penetration depth. During the first cycle, the sample was not perfectly fixed in the sample holder and was able to move a little. Thus, the contact between the sample and the bone plate did not happen exactly parallel to each other. During the second cycle, this problem was solved, and the samples could not move anymore in the sample holder. As a result of the first cycle, the surface of the bone plate (the trace) was a bit uneven causing more resistance and friction which in turn caused more alteration on the tool.

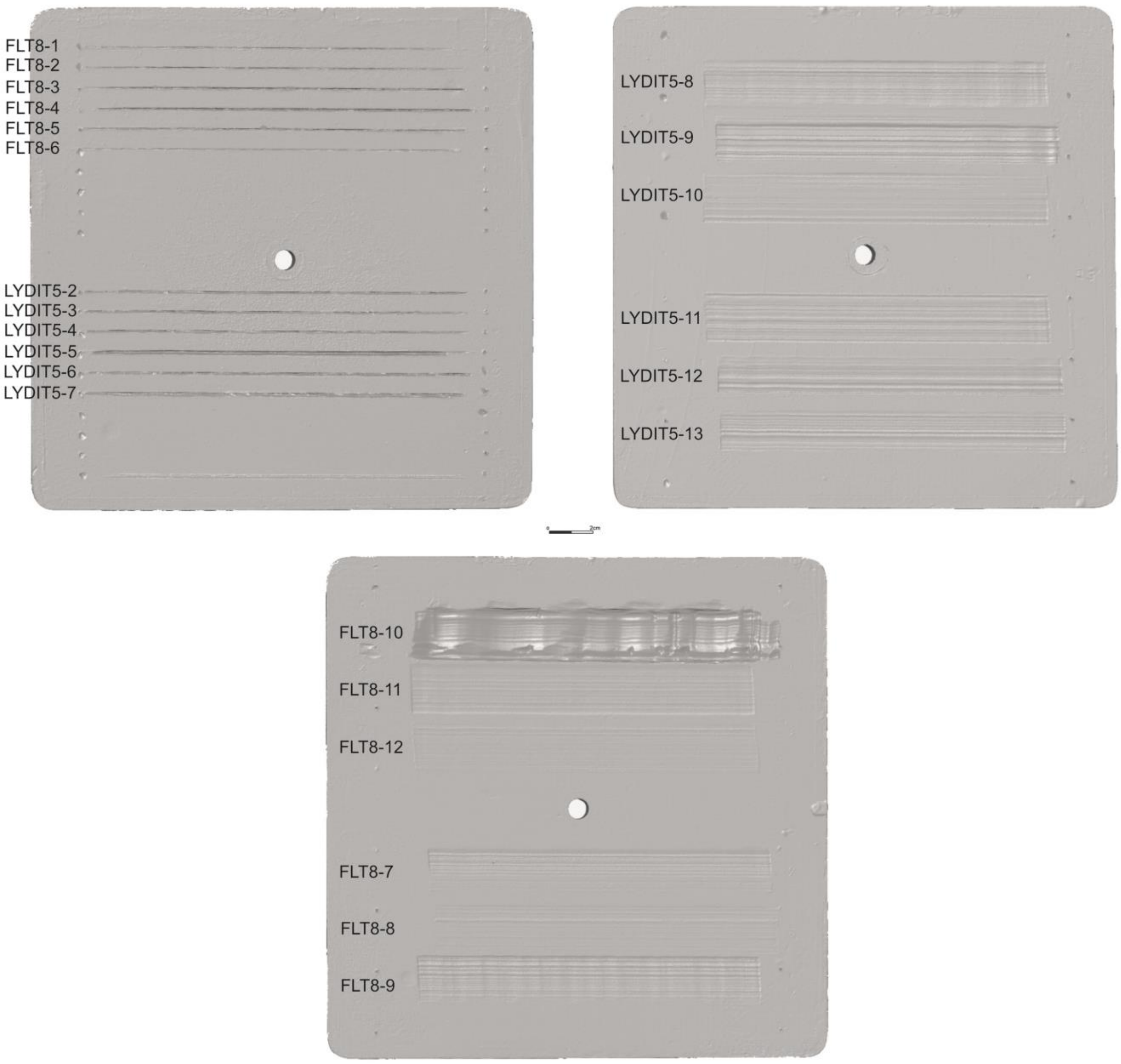

Fig. 171 3D scans of the artificial bone plates used during the tool experiment after 2000 strokes. The upper left scan shows the plate used for cutting, the upper right scan the plate used for carving with lydite samples. The lower scan illustrates the scan of the bone plate used for carving with flint samples.

A qualitative and quantitative use-wear analysis was conducted for eight samples from the tool function experiment (see appendix IV.). These eight samples always include one sample *per* raw material, edge angle and movement. For the qualitative use-wear analysis, only the samples from before and after 2000 strokes were analysed. All images of the use-wear analysis can be found as figures in the supplementary material. All four samples used for cutting developed use-wear throughout the four cycles of the experiment (**fig. 172**). The use-wear traces are visible on the 'dorsal' as well as the 'ventral' surface of the standard samples. One exception is the flint sample FLT8-2, which did only developed use-wear on the 'ventral' surface (D). The samples used for the carving movement also developed use-wear within the 2000 strokes. However, the use-wear traces are often marginal. The reason for that can likely be seen in the low penetration depth into the contact material. Thus, there was less possibility of friction between the samples and the contact material. While the flint sample FLT8-9 displays use-wear traces on both surfaces, the other three samples developed use-wear traces only either on the dorsal or ventral surface.

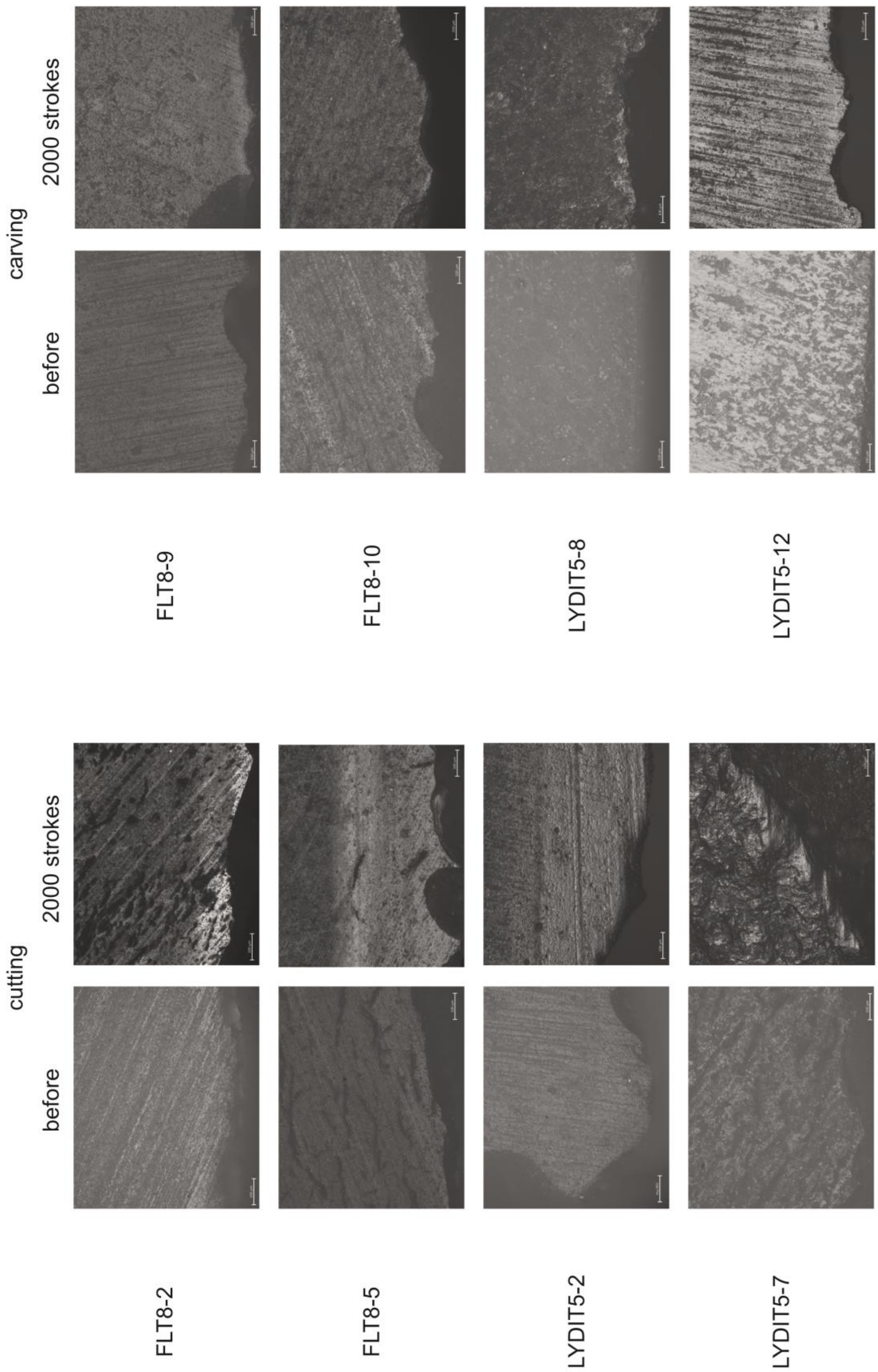

Fig. 172 Use-wear formation on the analysed flint and lydite standard samples before and after (2000 strokes) performing the tool function experiment. The left side shows the samples used for cutting, the right side the samples used for carving (all images are taken with a 10x optical objective).

The same eight samples were selected for the quantitative use-wear analysis, whereas the data was only acquired on the samples after 2000 strokes. Well-developed use-wear traces were selected for the analysis. The eight traces were measured three times each, as done similarly for the other performed qualitative use-wear analyses. Again, the data was calculated based on the identical n = 34 parameters (see **tab. 10**). Scatterplots from each parameter combined with information about the sample, the raw material, the task and the edge angle display the results (**fig. 173**). Prominent within these scatterplots are two data points. Both of the data points belong to the categories flint and carving. One of the samples has a 35° edge angle (FLT8-9-B1-01-a), the other one a 45° edge angle (FLT8-10-C1-01-b). These tow samples clearly differ from the corresponding tow measurements per use-wear trace. A review of the raw data made an identification of these two data points as possible outliers. In one case, the acquired data included some data from next to the use-wear trace, in the other case the scan went beyond the edge. In both cases, the results are misleading and should be thus excluded as outliers. Although the data analysis leads to no significant results, differences between the categories are visible. The data acquired on the flint samples used for carving shows a variance between the 35° edge angle results and the 45° edge angle results. Moreover, the results from the sample with the 35° edge angle tend to be more homogeneous. The lydite samples also display differences between the 35° and 45° edge angels, whereas the results are homogeneous in both cases. A significant variance between the two groups of raw material, flint and lydite, are not noticeable.

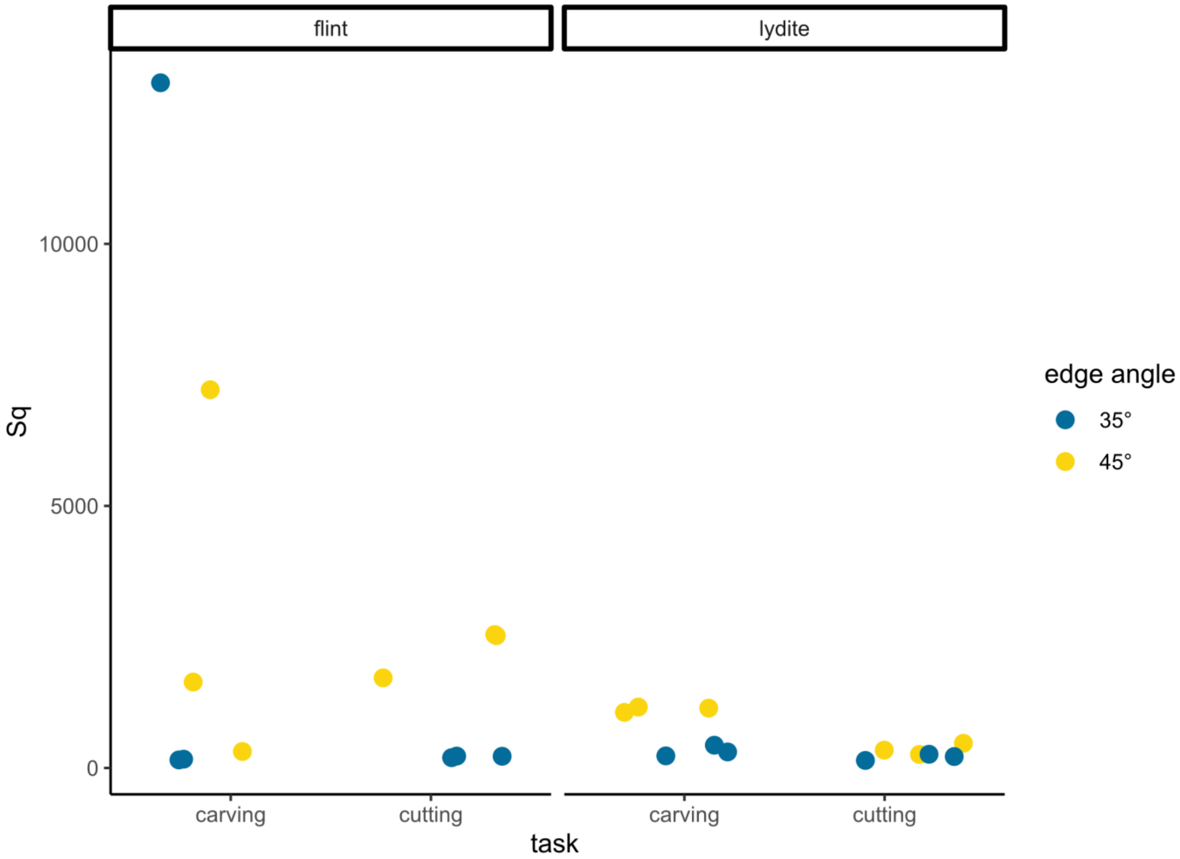

Fig. 173 *Sq* values measured on the flint and lydite samples after 2000 strokes used during the tool function experiment. Three data points are shown per sample, reflecting the three measurements taken per use-wear trace (spot a, b and c). The data is categorised according to the performed task. The colour indicates the edge angle of the standard samples.

The data was explored further with a principal component analysis. The PCA was applied on the identical seven components used for the previously described PCAs, the parameters *Sq, Ssk, Vmc, Mean density of furrows, Isotropy, Asfc* and *HAsfc9*. The variance in *Sq, Vmc* and *Mean density of furrows* is explained by Principal component 1 (PC1), reflecting 53.06 % of the variance. Principal component 2 (PC2) accounts for 19.47% of the variance with *Ssk, Isotropy, Asfc* and *HAsfc9*. The first PCA reflects this variance combined with the movement, cutting and carving (**fig. 174**). The data scatters mainly on the right part of the PC1 axis and clearly overlaps.

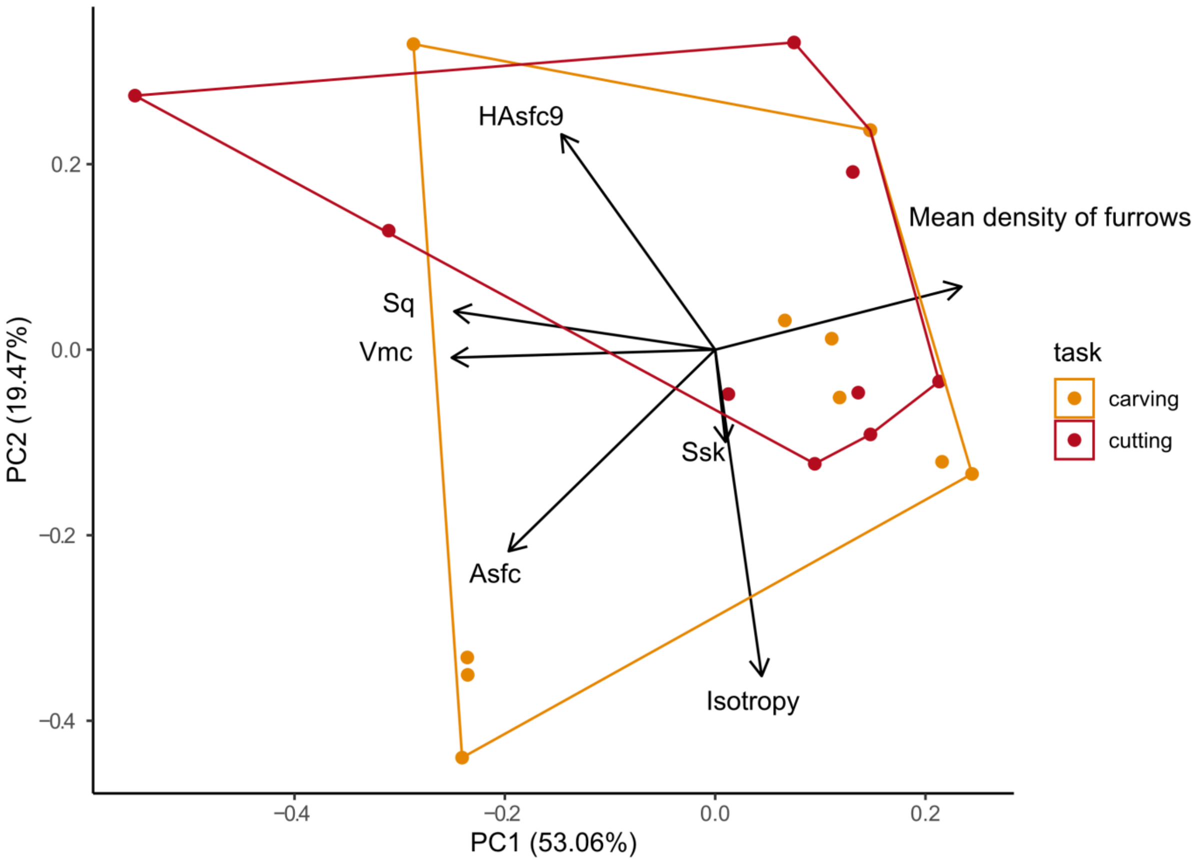

Fig. 174 Principal component analysis applied on the measured use-wear traces of the analysed standard samples from the tool function experiment, reflecting variation regarding the performed task.

A second PCA visualises the variance of the raw material of the standard samples based on the same seven components (**fig. 175**). Although the data overlaps again in the right part of the PC1 axis, the data scatters in different directions.

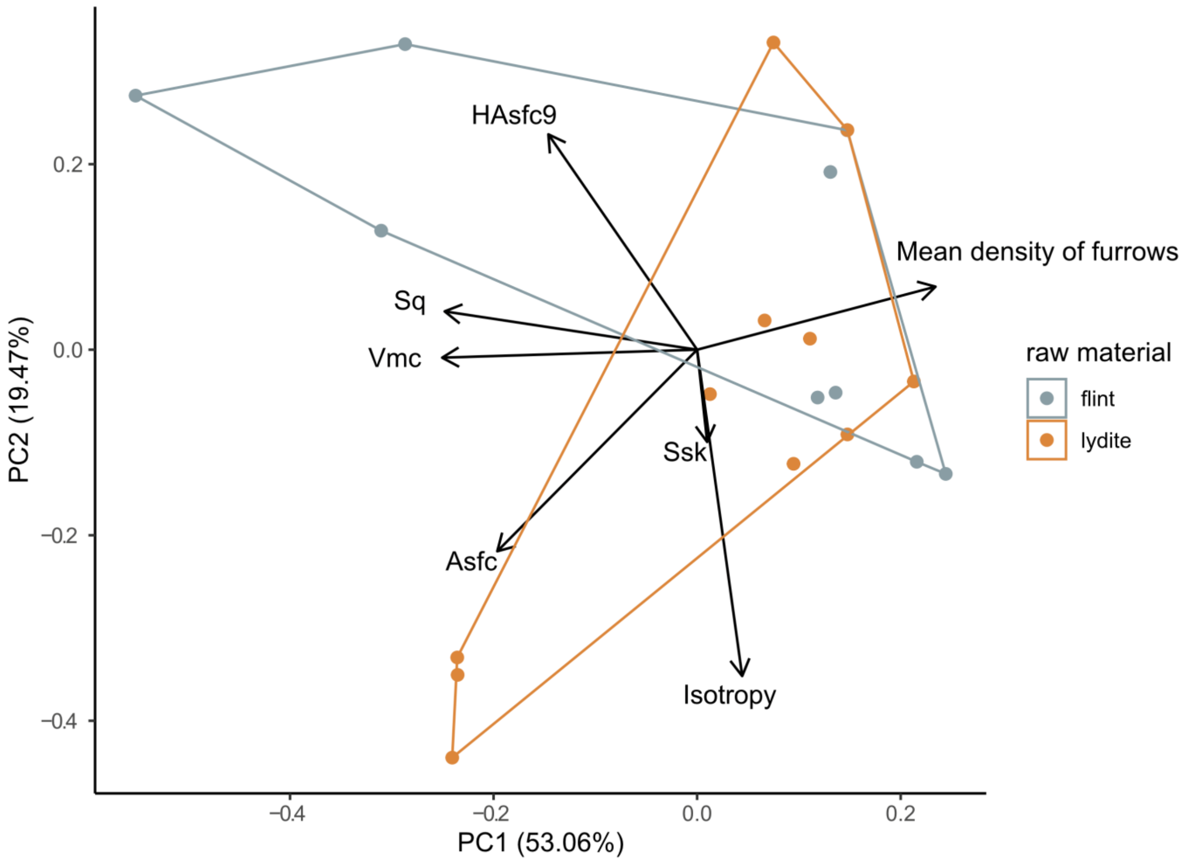

Fig. 175 Principal component analysis applied on the measured use-wear traces of the analysed standard samples from the tool function experiment, reflecting variation regarding the raw material of the standard samples.

The only PCA that results in distinct clusters is the third applied PCA (**fig. 176**). This PCA reflects the variance combined with the edge angles, 35° and 45°. The results are consistent with the results mentioned from the scatterplots mentioned before. The cluster from the 35° edge angle is narrow, while the cluster from the 45° is scattered more, likely due to the less homogeneous data.

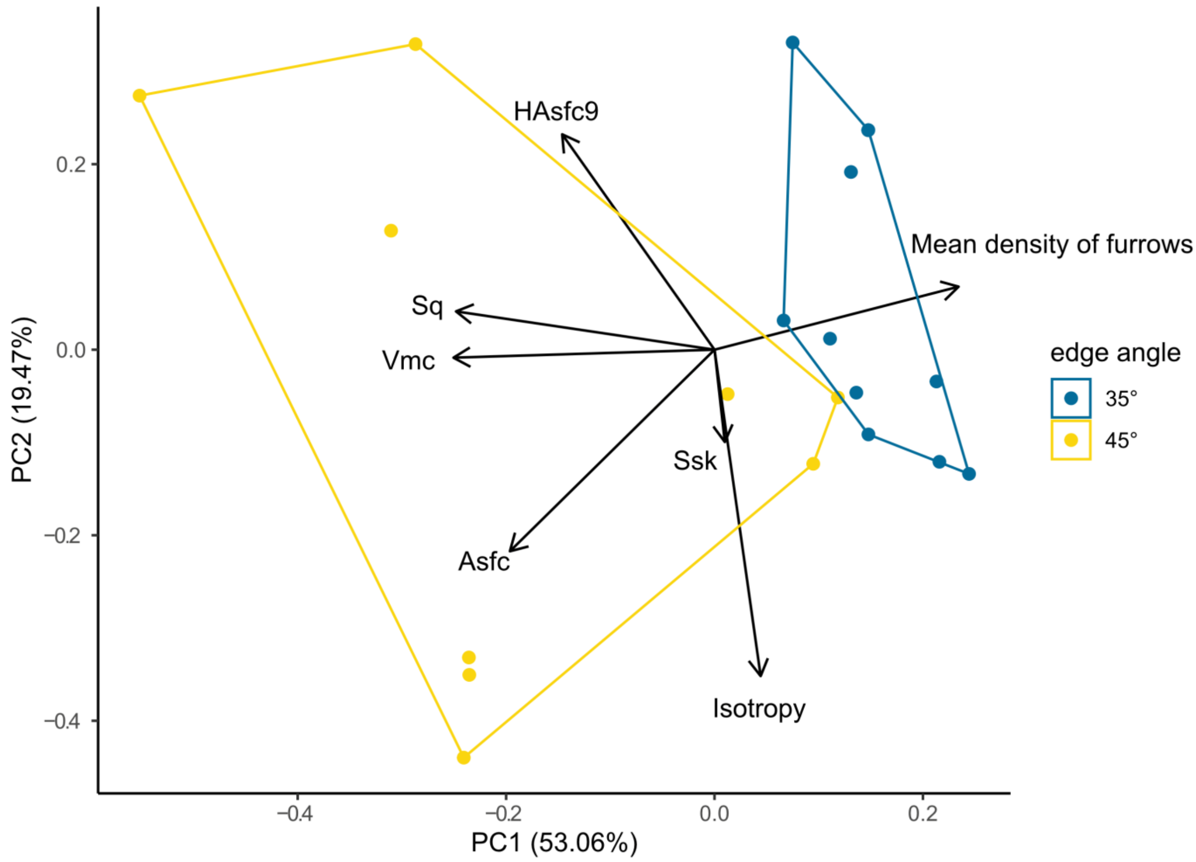

Fig. 176 Principal component analysis applied on the measured use-wear traces of the analysed standard samples from the tool function experiment, reflecting variation regarding the edge angle of the standard samples.

The data from the quantitative use-wear analysis acquired on the samples from the tool function experiment leads to unexpected results. Neither the raw material of the standard samples nor the performed movement seems to affect the measured features of the use-wear traces. However, the edge angles of the standard samples seem to have an effect.

5.5.4 Combined data of the experiments

It was possible to combine the data from the three experiments in several ways. First, the alteration of the tool and thus the change of the edge angle will be addressed. Throughout the three experiments, a reproducible trend could be noticed: The lower the edge angle, the more alteration occurs on the tool's edge. This trend gets strengthened through two additional impacts, the raw material of the standard samples and the characteristics of the contact material. Concerning the raw material, flint seems to be more durable than lydite, which is likely due to the raw material properties of the tool. The hardness of the contact material seems also to be of influence. However, the hardness of the contact material might not be the only relevant aspect concerning the material properties. The artificial bone plates do have a comparable shore hardness to

the fresh cow scapula used during the 'artificial VS. natural' experiment. Still, the cow scapula had a stronger effect on the tool alteration than the artificial bone plate. The mentioned trend could be observed for cutting movements, not for carving. The standard samples with the lower 35° edge angle used for carving display only minimal alteration compared to the samples with the 45° edge angles.
The results from the qualitative use-wear analysis of the 'artificial VS. natural' experiment and the tool function experiment can be compared. The comparison is possible for all samples used for cutting on artificial bone plates. All samples belonging to this category developed use-wear traces within the 2000 strokes. Interestingly, visible use-wear traces on flint samples only formed after 2000 strokes. By contrast, lydite samples displayed use-wear traces already after 50 strokes.

Moreover, some results from the quantitative use-wear analysis of the 'artificial VS. natural' and the tool function experiment have been combined. While all the data from the tool function experiment could be used for a comparison, only the data acquired on the 60° samples used for cutting on bone plates from the 'artificial VS. natural' experiment was included. To do so, data was combined in one plot per parameter (**fig. 177**). The results from the samples with the 35° edge angle are, compared to the 45° and 60° samples, more homogenous. This observation was already mentioned beforehand, but in combination with 60° samples, it becomes more obvious. The data obtained on the samples with the 60° edge angle clearly differs from the other data points.

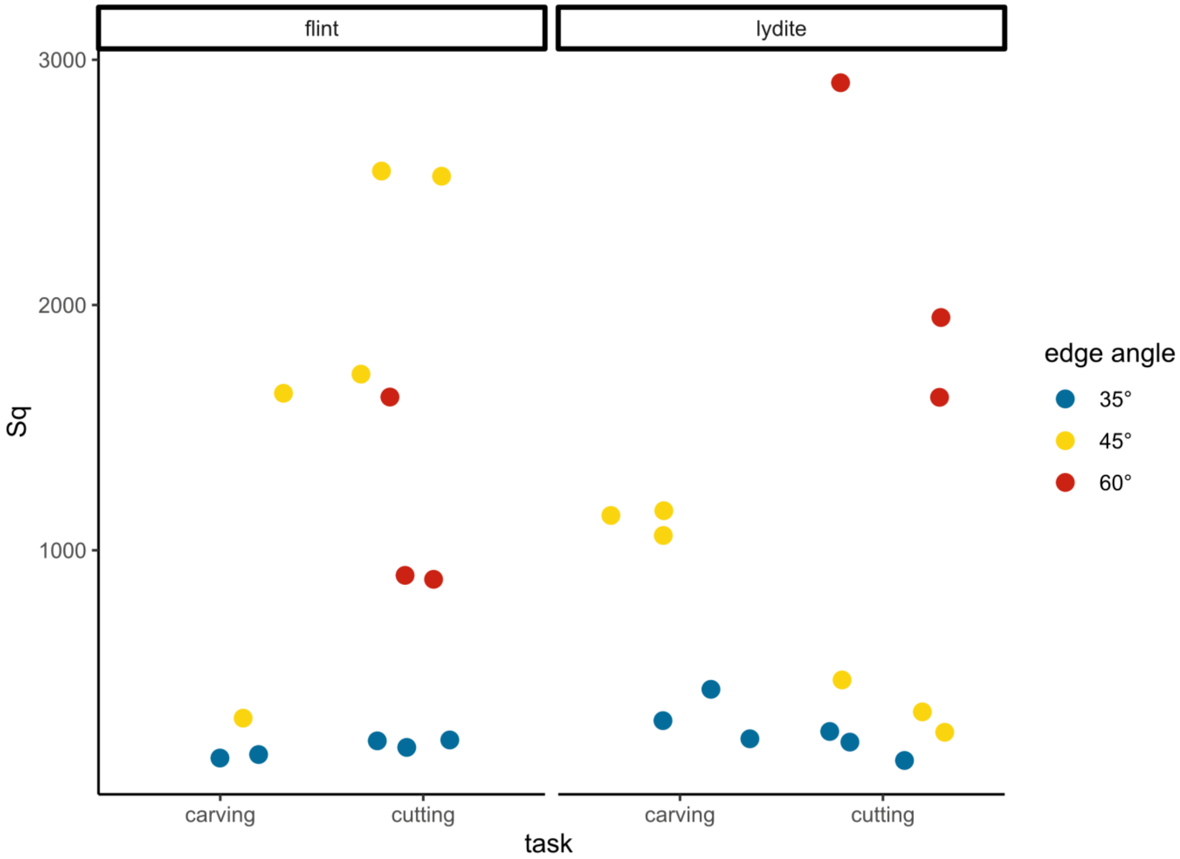

Fig. 177 *Sq* values measured on the flint and lydite samples after 2000 strokes used during the tool function experiment and the 'artificial VS. natural' experiment. Three data points are shown per sample, reflecting the three measurements taken per use-wear trace (spot a, b and c). The data is categorised according to the performed task. The colour indicates the edge angle of the standard samples. The 35° and 45° samples have been used during the tool function experiment, the 60° samples during the 'artificial VS. natural' experiment.

To summarise, the standard samples made of lydite turned out to be more fragile and more easily affected by alteration (e.g. due to hardness, schistosity). Furthermore, the raw material promotes the formation and development of use-wear traces. At the same time, the lydite samples are more efficient in cutting when judged by the penetration depth solely. However, efficiency defines the ratio between cost and benefits. Benefits, in this case, can be measured based on the achieved penetration depth. Costs are the loss of material and volume. In this sense, lydite exhibits a greater loss when judged by single artefacts. In one case (initial experiment, LYDIT1-4), the loss was so severe, that it affected the durability. In the course of the experiment, the sample fractured so much, that the functionality could not be retained. Thus, the sample was not able to achieve the goal (2000 strokes). However, the lydite sample described above is an exception. Although the other lydite samples used for cutting or carving experienced material loss, the loss was not enough to lose the functionality. Measured on the change in volume and weight (tool function experiment), the loss of raw material is slightly higher on flint samples. Nevertheless, likely due to the raw material properties, the flint samples alter in a different way than the lydite samples. While material loss on flint samples appears more as retouch-like, material loss on lydite samples displays fractures and breakages. This observed difference is also expressed in the shift of the edge angle values.

6. 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.

6.1 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 and 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. 178**) 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 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* (**fig. 54 – 55**). 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 and Uomini, 2019) additional thinning (back and distal posterior part, convex upper surface) and lateral sharpening led to the desired shape.

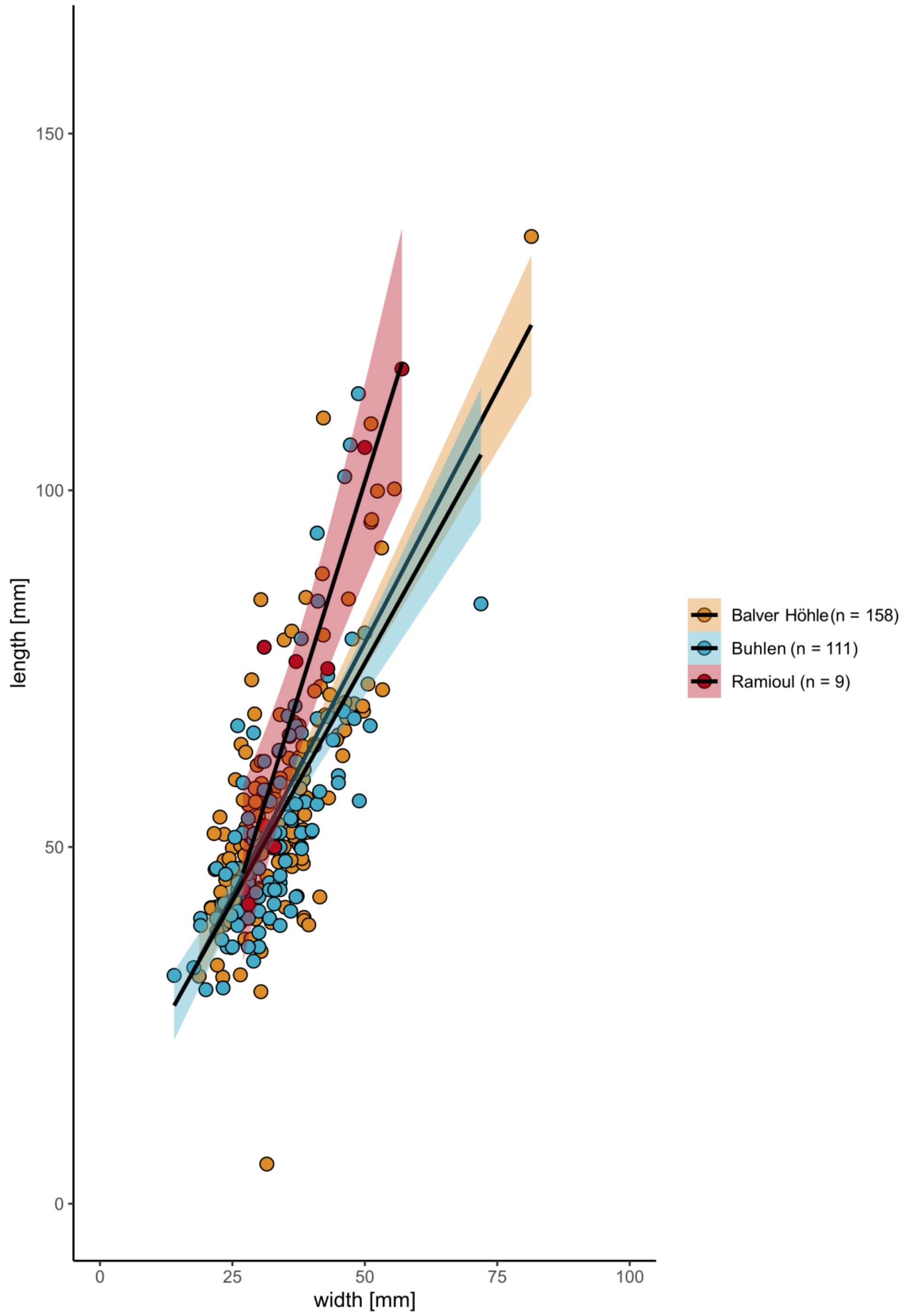

Fig.178 Length-width ratio of all complete *Keilmesser* from Buhlen, Balver Höhle and Ramioul. The regression line *per* site shows the overall trend of the data set.

Moreover, also the dimensions of the *Prądnik scrapers* are comparable to the ones from *Keilmesser* (**fig. 179**). 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*.

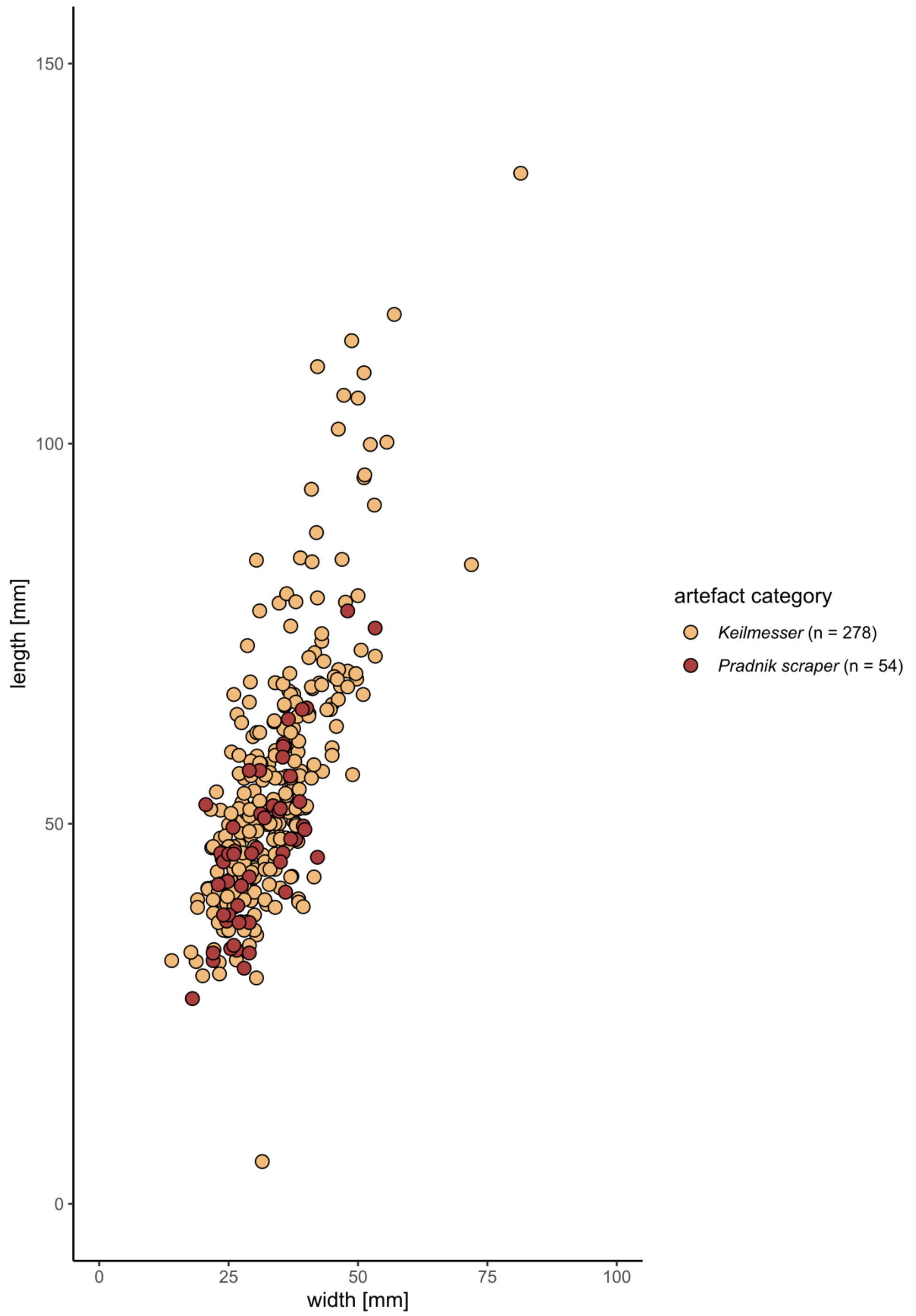

Fig. 179 Length-width ratio of all complete *Keilmesser* and *Prądnik scraper* from Buhlen (n = 111, n = 24), Balver Höhle (n = 158, n = 27) and Ramioul (n = 9, n = 3).

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. 101**). In this way, the previously expressed assumption (see also Jöris, 2012; Jöris and Uomini 2019; Migal and Urbanowski, 2006; Urbanowski, 2003; 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 and Urbanowski, 2006; Iovita, 2010; Jöris and 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, 1969b). 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; Kozlowski, 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 and 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; see also Shils, 1971; Handler and Linnekin, 1984).

6.2 Tool design: technological choices and edge design

<u>The *Keilmesser* concept</u>

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; Jöris and Uomini, 2019, Frick and Heckert, 2019; Delpiano and 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 and 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 and Herkert, 2019; Delpiano and 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 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 and Herkert, 2019; Jöris and 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.

<u>*Keilmesser* edge design</u>

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. 180**) an edge angle of 47.8°

could be calculated ('best-fit' procedure; mean value of section 2 to 4 and distance 3 to 6) 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 5 to 9 and distance 3 to 6). 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. 180**), 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 and Grosman, 2015; Prévost, Centi and 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 and 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 and 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.

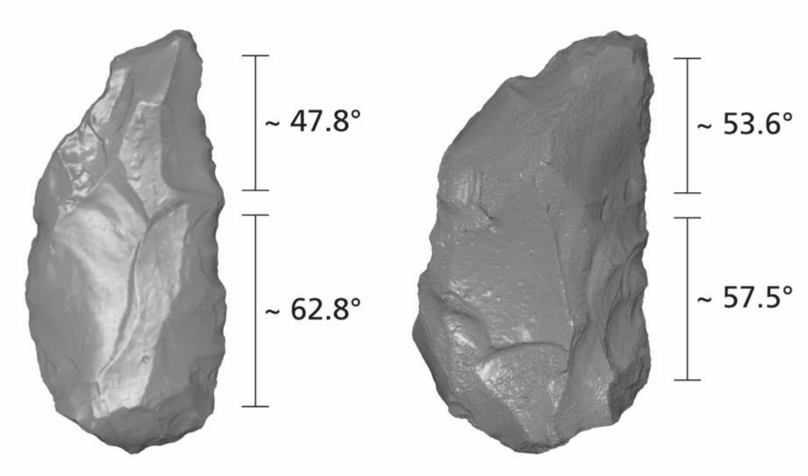

Fig. 180 3D scan of a *Keilmesser* modified by the application of the *Prądnik method* (left; Balve, ID MU-202) and of a *Keilmesser* without this modification (right; Balve, ID MU-197), illustrating the average edge angle in the distal and proximal part of the tool (calculated with the 'best-fit' procedure; mean value of section 2 to 4 and distance 3 to 6).

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 and Herkert, 2019; Jöris and Uomini, 2019). Sometimes, the perimeter sections are also used to infer functional units (Iovita, 2010; Weiss et al., 2018; Frick and 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. 181**). The traces are 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.

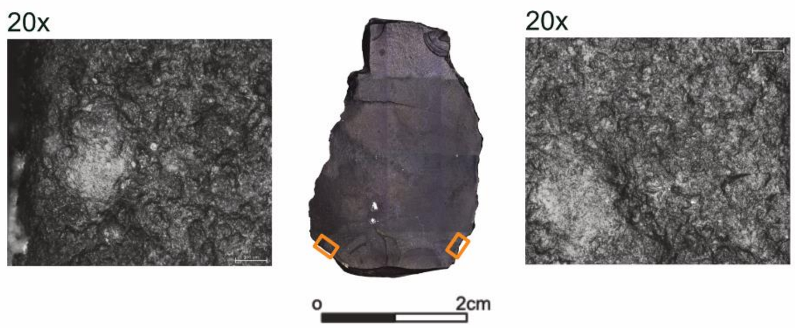

Fig. 181 EDF stitching image of the ventral surface of a *Prądnik scraper* (Buhlen, ID BU-099). The images on the left and right show use-wear traces (images are taken with a 20x optical objective).

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 and Uomini, 2019; Weiss et al. 2018; Frick and 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 and 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 and 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 and 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. 128**). 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. 182**). 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 2 to 4 and distance 3 to 6). 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 angel 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 and 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 slightly sharper edge as suggested for *Keilmesser* as well (Jöris, 2001, 2006; Frick et al., 2017; Frick and Herkert, 2019; Jöris and Uomini, 2019).

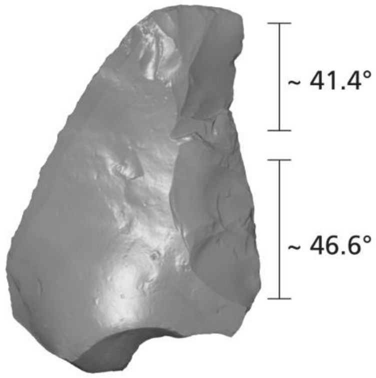

Fig. 182 3D scan of a *Prądnik scraper* (Ramioul, ID R-010) illustrating the average edge angle in the distal and proximal part of the tool (calculated with the 'best-fit' procedure; mean value of section 2 to 4 and distance 3 to 6)

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.

6.3 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 and Ruck, 2019). As argued, handedness is closely related to brain lateralisation and cognitive evolution (Corballis et al., 2012; Ruck et al., 2015; Cai and van der Haegen, 2015; Uomini and Ruck, 2018). Human behaviour related aspects such as the development of language and social learning are linked with handedness (Corballis et al., 2003; Steele and Uomini, 2008a, b; Uomini, 2009; Poza-Rey, Lozano and Arsuaga, 2017; Uomini and 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. Bermúdezde Castro et al., 1988; Trinkhaus, 1994; Frayer et al., 2010, 2012, 2016; Volpato et al., 2012; Fiore et al. 2015; Condemi et al., 2016; Lozano et al., 2017), sometimes based on lithic studies (Semenov, 1964; Cornford, 1986; Uomini, 2008a, 2009; Ruck et al., 2015; Jöris and Uomini, 2019; Prévost, Centi and 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 and 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 and 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 and 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.

6.4 Resharpening and recycling behaviour

Resharpening address by a functional analysis

An envisaged long use-life involving the option of recurrent resharpening has been documented as an inherent part of the *Keilmesser* concept (Jöris, 1994; 2001; Richter, 1997; 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, 2016). 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. 183**), 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. 184**) 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. 185**). This scar appears as relatively 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-129 (**fig. 186**). 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. 187**). 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. 188**). 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.

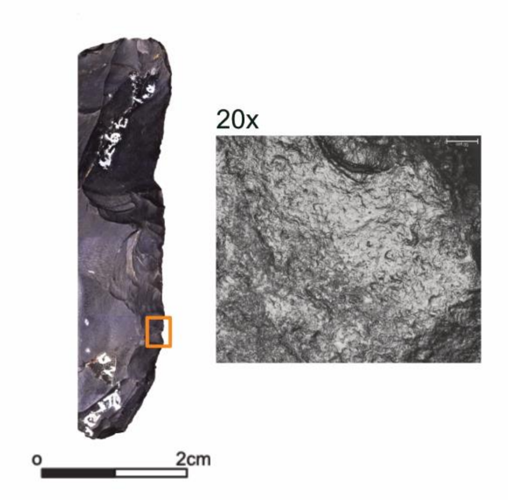

Fig. 183 EDF stitching image of the dorsal surface of a *Keilmesser* (Buhlen, ID BU-057). The image on the right shows the documented use-wear (image is taken with a 20x optical objective).

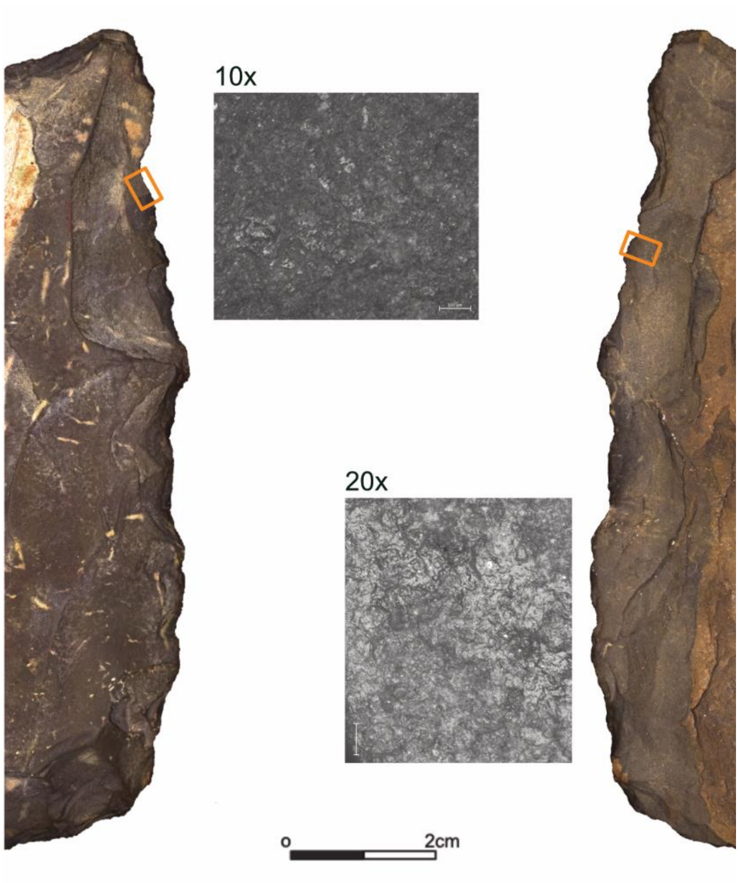

Fig. 184 EDF stitching image of the dorsal (left) and ventral (right) surfaces of a *Keilmesser* (Balve, ID MU-202). The images in the middle show the documented use-wear (images are taken with a10x and 20x optical objective).

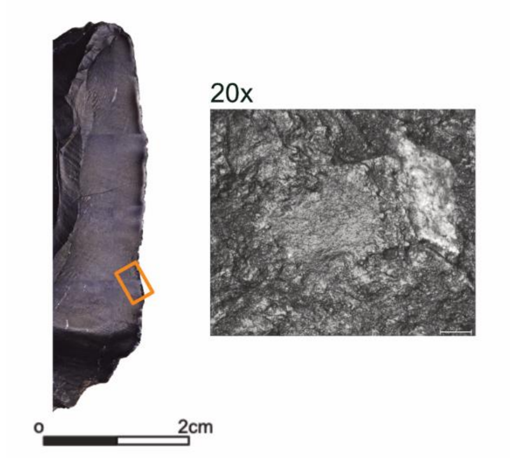

Fig. 185 EDF stitching image of the dorsal surface of a *Keilmesser* (Buhlen, ID BU-051). The image on the right shows the documented use-wear (image is taken with a 20x optical objective).

Fig. 186 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 20x optical objective).

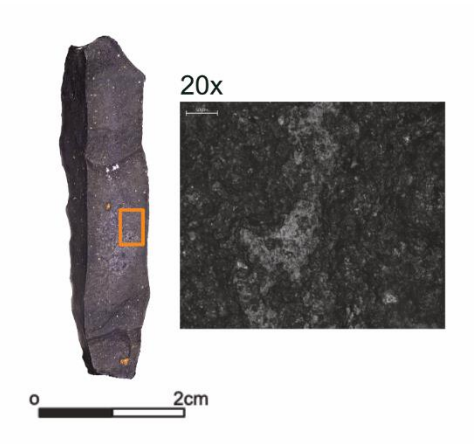

Fig. 187 EDF stitching image of the ventral surface of a primary *Prądnik spall* (Buhlen, ID MU-104). The image on the right shows the documented use-wear (image is taken with a 20x optical objective).

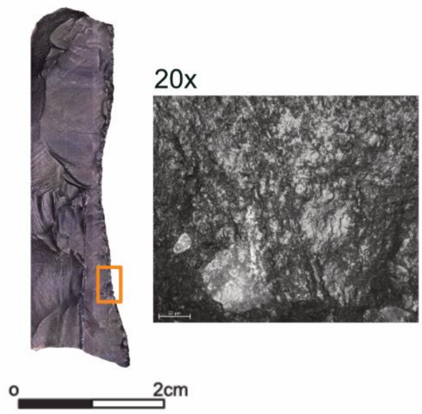

Fig. 188 EDF stitching image of a secondary *Prądnik spall* (Buhlen, ID BU-136). The image on the right shows the documented use-wear (image is taken with a 20x optical objective).

6.5 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 effect 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 and 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 et al., 2003), the contact material and the force needed to perform a task (Schuldt et al., 2013, Schuldt et al., 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 et al., 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 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 and 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. 189**). 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.

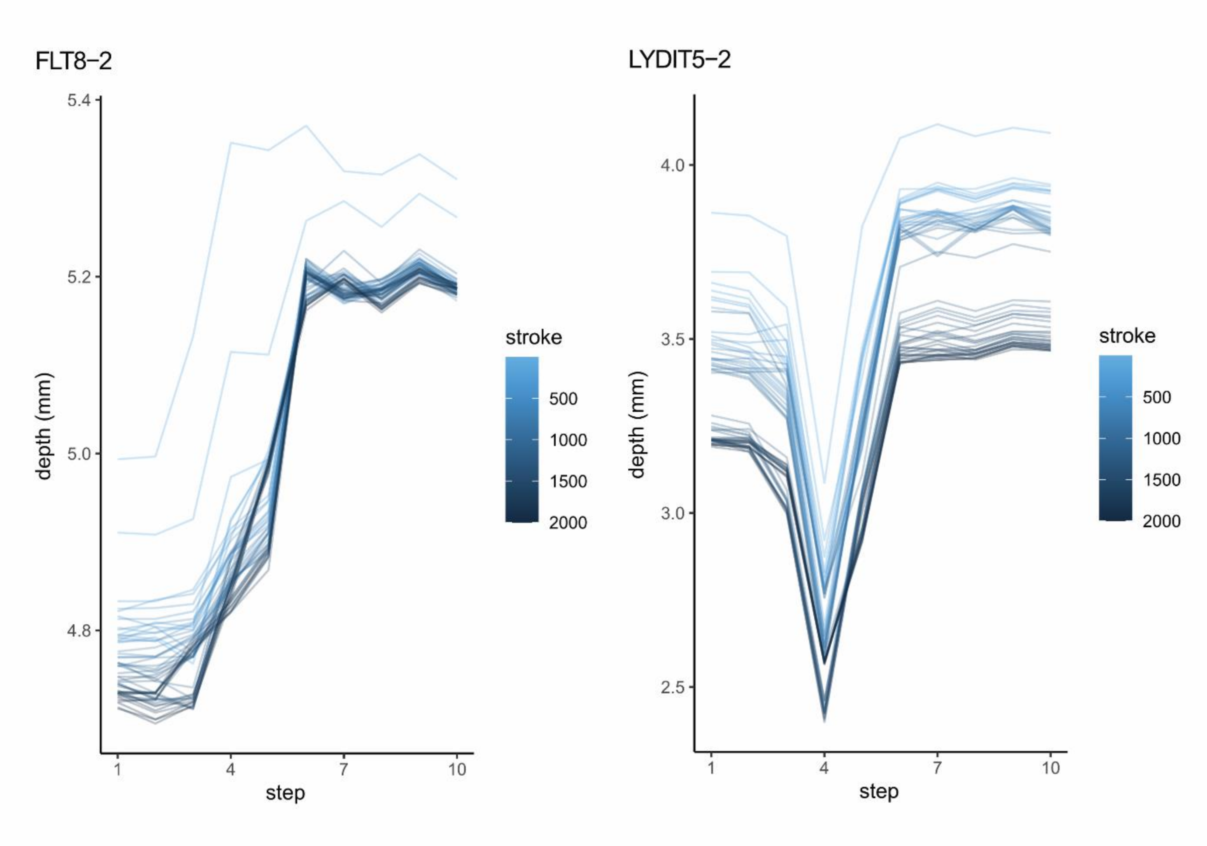

Fig. 189 Sensor recorded penetration depth achieved with a cutting movement with the SMARTTESTER® during the tool function experiment. On the left is the recording of the sample FLT8-2 and on the right the recording of the sample LYDIT5-2. The graphs show each 40th cutting stroke within all cycles (0 to 2000 strokes). The darker the colour, the more increased the penetration depth.

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.

6.6 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, 2006, 2012, 2014; Urbanowski, 2003; Rots, 2009; Golovanova et al., 2017; Frick and 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. 123**, **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 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. 190**). 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.

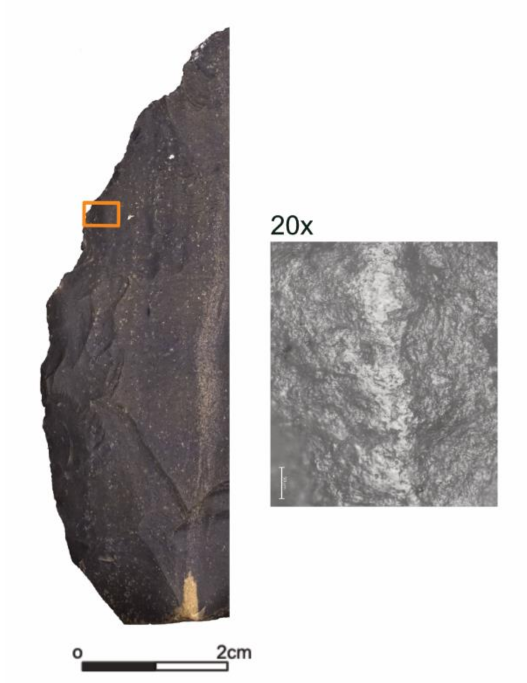

Fig. 190 EDF stitching image of a *Keilmesser* (Balve, ID MU-199). The image on the right shows the documented use-wear (image is taken with 20x optical objective).

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. 191**). 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. 192**). Intense polish (type V. / VI.) was documented in the distal 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 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 and 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. 193**). 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 2 to 9 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. 194**). 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 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, 2012, 2014; Rots, 2009; Golovanova et al., 2017; Frick and 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.

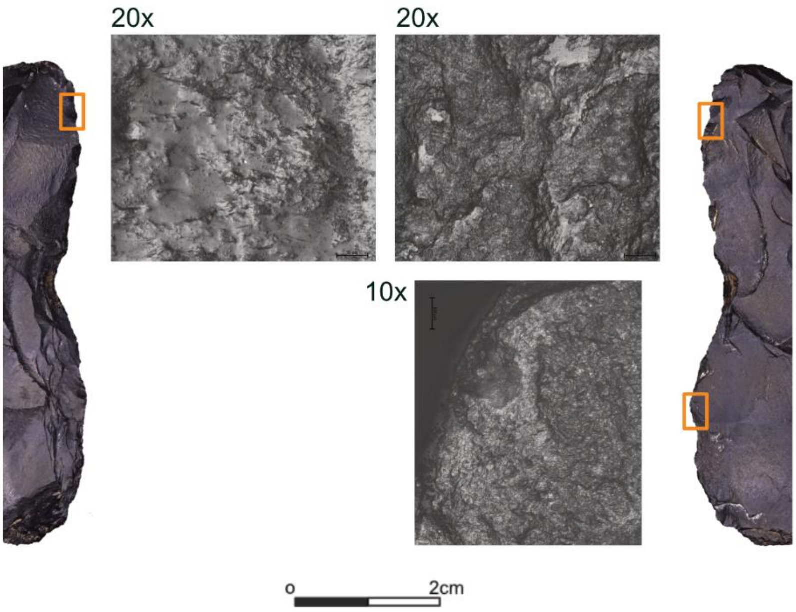

Fig. 191 EDF stitching image of a *Keilmesser* (Balve, ID MU-111). The images in the middle show the documented use-wear (images are taken with 20x optical objective).

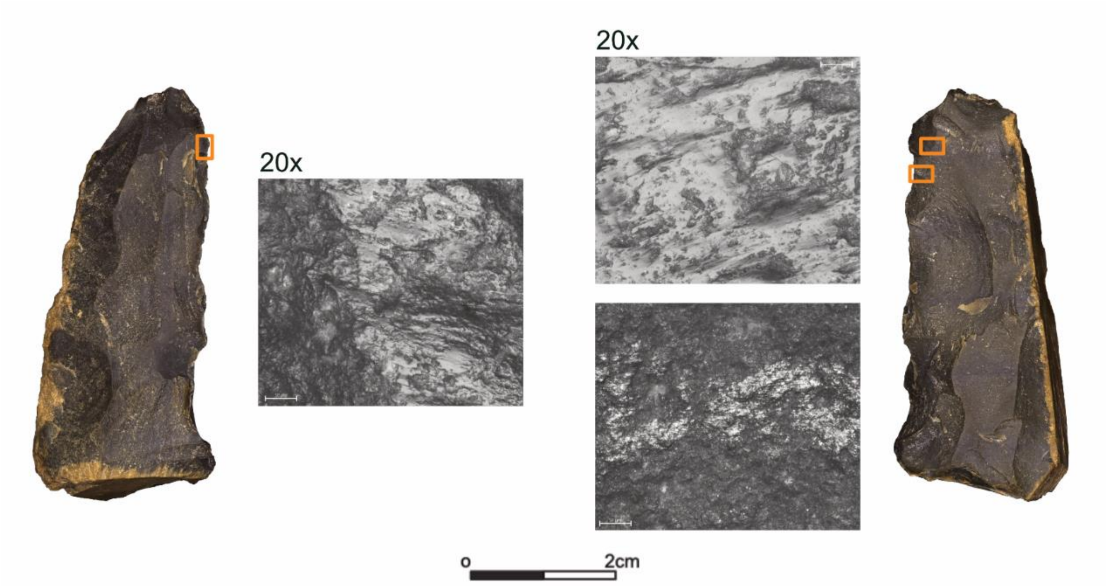

Fig. 192 EDF stitching image of a *Keilmesser* (Balve, ID MU-246). The images in the middle show the documented use-wear (images are taken with a 20x optical objective).

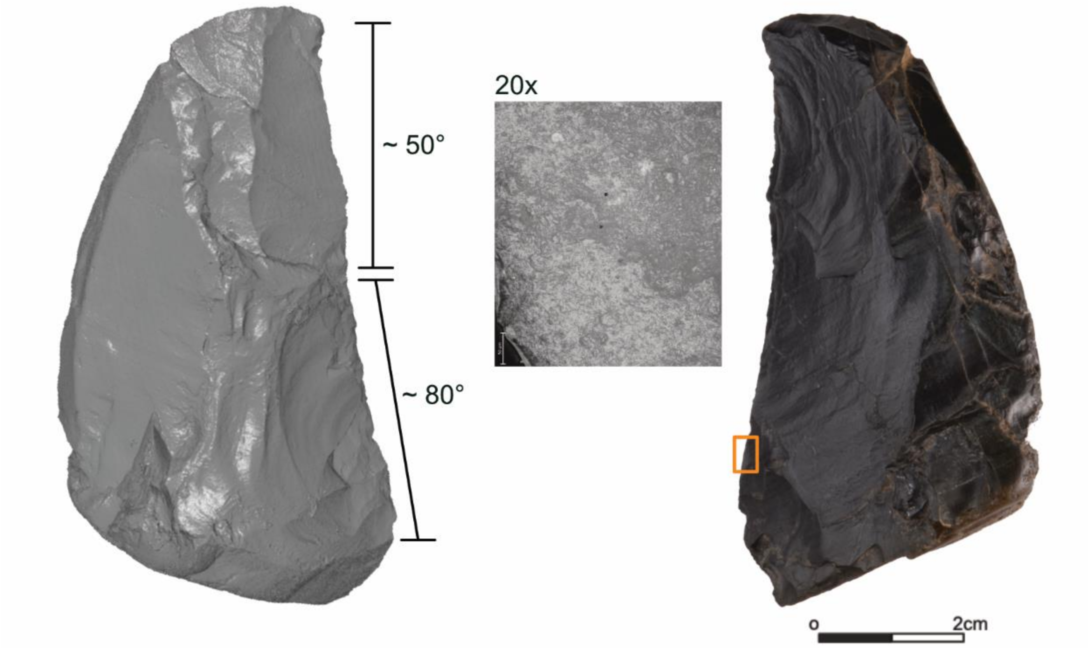

Fig. 193 3D scan (left) and EDF stitching image (right) of a *Keilmesser* (Buhlen, ID BU-158). The image in the middle shows the documented use-wear (image is taken with a 20x optical objective). The 3D scan indicates the average edge angle in the distal and proximal part of the tool (calculated with the 'best-fit' procedure, mean value of section 2 to 9 at the 3 mm to 6 mm distance to the intersection).

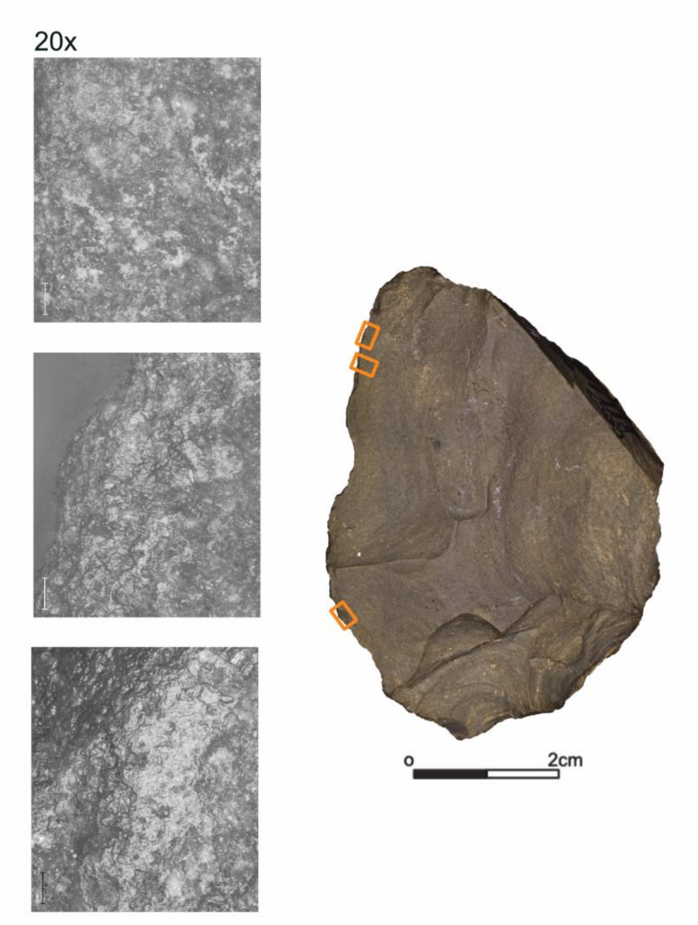

Fig. 194 EDF stitching image of the ventral surface of a *Keilmesser* (Balve, ID MU-214). The images on the left show the documented use-wear (images are taken with 20x optical objective).

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. 125**).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.

<u>Tool performance and variables affecting it</u>

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 (chapter 6.5). 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 and 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. 176**).

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*) (Pedergnana et al., 2020b; Martisius et al., 2020), 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. 162**). Standard samples with an original rougher surfaces resulted in a modified surfaces roughness with the prevailing trend of decreasing values. In other words, a rough surface gets smoother during 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. 195**). 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 1.49 µm and for the other spot, type V., is 1.33 µm. This data supports the interpretation 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. 196**). 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 are lower after the usage. Interestingly, these values are more comparable to the ones from the artefact categories interpreted as more intense (e.g. type IV., V., VI.). 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.

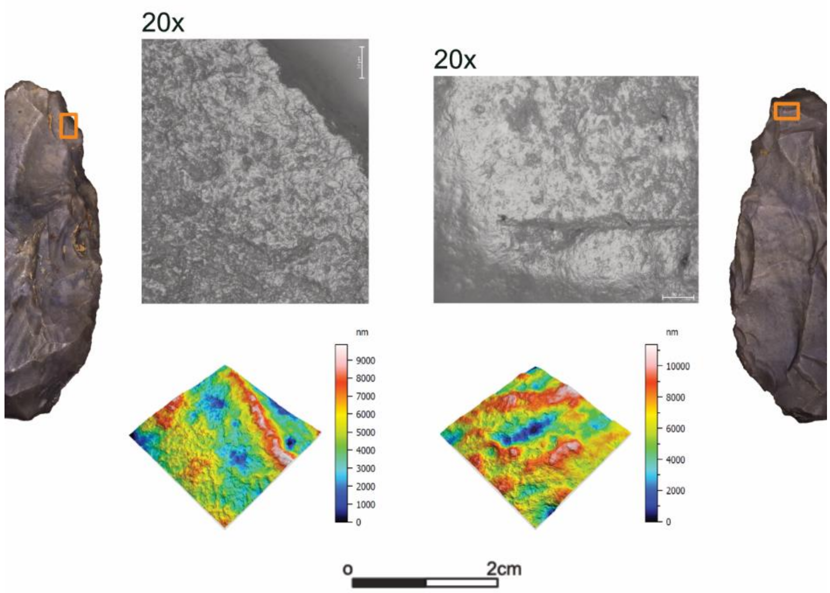

Fig. 195 EDF stitching images of the dorsal (left) and ventral right surfaces of a *Keilmesser* (Balve, ID MU-224). The images in the middle show the documented use-wear (images are taken with 20x optical objective) and the corresponding micro-surface texture. The colour of the surfaces corresponds to the height on the z-axis.

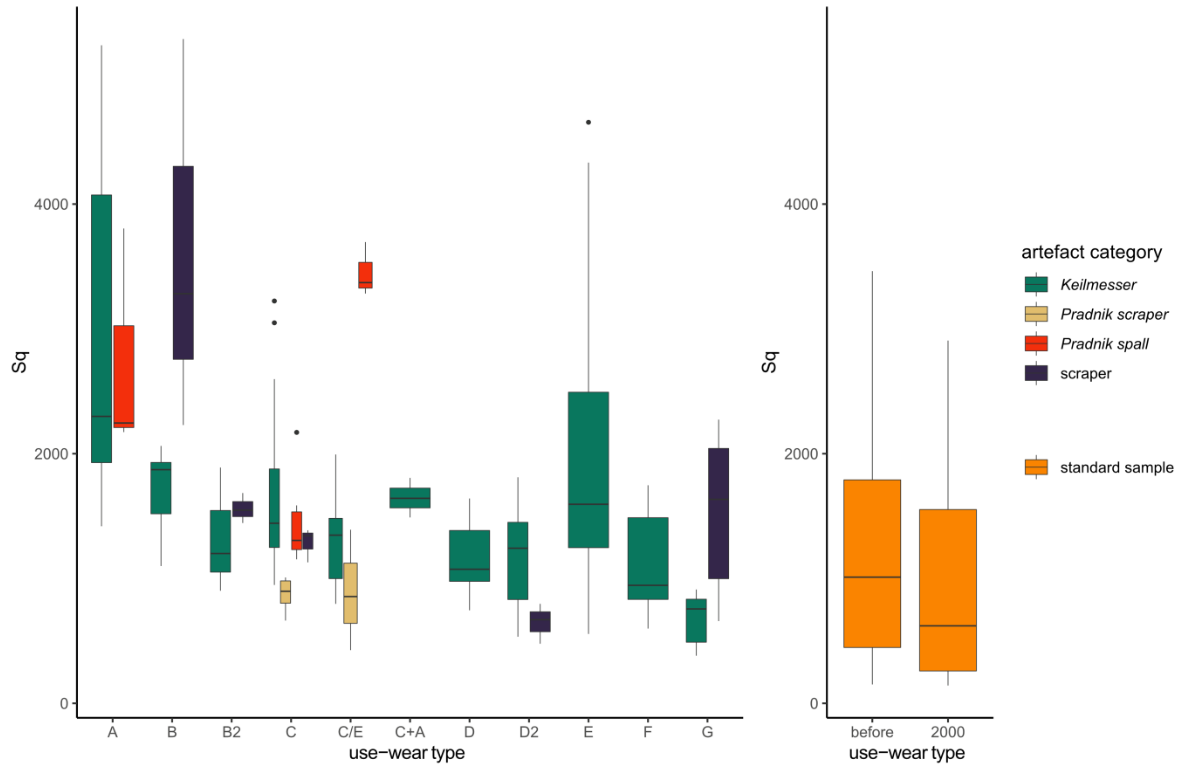

Fig. 196 Distribution of *Sq* values for the measured use-wear traces (n = 50) on the archaeological artefacts (left), combined with the measured use-wear traces (n = 28) from the 'artificial VS. natural' and tool function experiment (right). The data is categorised according to the interpreted use-wear types and coloured based on the artefacts type.

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 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. With one exception (FLT4-12 used on skin pad), all analysed standard samples ('artificial VS. natural' and tool function experiment) developed with 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.

7. Conclusion

The research presented and discussed in this dissertation aimed to gain a more precise picture about asymmetric tools from the Late Middle Palaeolithic by testing common interpretations concerning their tool design and function. As a case study, *Keilmesser* and *Prądnik scrapers* as well as their resharpening debris, *Prądnik spalls,* from three sites - Buhlen, Balver Höhle and Ramioul - have been studied. Based on a multidisciplinary approach, including a functional analysis combined with controlled experiments, new data could be collected. To summarise the main findings, the addressed aspects concerning tool design are given in combination with the obtained results. The following conclusions can be drawn based on the data gained through the application of interrelated methods and techniques.

To start with, the first aspect concerns the results achieved through the raw material characterisation, which indicates the importance of raw material analyses in functional studies. The significance of the raw material regarding tool performance and wear formation could be clearly observed based on the results of the conducted experiments and quantitative use-wear analysis. During the sequential experiments, the observation could be made that lydite standard samples performed better than flint standard samples. Performance is thereby measured based on tool efficiency and durability. Although the lydite samples experienced more material loss and changes in the edge angles during usage, this did not affect the tool function. With one exception, all samples performed 2000 strokes without any maintenance processes. The flint standard samples displayed less material loss, but material loss is visually more similar to retouch than edge damage. The efficiency was evaluated via the contact material displacement and recording the penetration depth when constant force was applied. Lydite could be documented as less hard, but with a higher surface roughness compared to flint. Moreover, lydite contains schistosity planes and natural cracks, leading altogether to a more fragile impression. These raw material properties likely explain the better performance of the lydite samples in the course of the experiments. The material loss documented on the flint samples can be described as microfracturing, which is likely leading to the promotion of continuous 'refresh' during tool use. In contrast, the minimal material loss observed on the flint samples seemed to have caused a blunting of the tool's edge in early stages. In order to achieve the same penetration depth with a flint sample compared to a lydite sample, additional force would need to be applied.

During the quantitative use-wear analysis, a second aspect related to the raw material of the samples became evident: the raw material properties of lydite promote the formation of use-wear traces more than the properties of flint do. As previously mentioned, the surface roughness of the machine-cut lydite samples is higher than the one from the flint samples. In the course of the sequential experiments, it could be documented, that from a qualitative point of view, the surface begins to change earlier than the surface from the flint samples. The results from the quantitative use-wear analysis performed for the 'artificial VS. natural' experiment support this observation. It could be demonstrated that samples with initially higher *Sq* values (surface texture roughness), experienced more abrasion during the use, which is visible on the samples' surface as use-wear. To generalise, some raw materials seem to be, due to their properties, more prone to surface abrasion and thus, develop use-wear more easily. At the same time, *Sq* as a parameter for the surface texture roughness, can be pointed out as an indicator for tool use duration or intensity as it reflects surface abrasion processes. Correlated with the initial surface roughness of the artefact, the measured parameters for the use-wear traces can be put into relation. The observation from the experiments and the quantitative use-wear analysis taken together, emphasise the need of raw material characterisation in functional studies in order to create a framework for reliable and meaningful interpretations (Lerner, 2012). Moreover, the results raise a question, which requires further investigation; to which degree do the properties of the raw materials influence for instance the active edge design and tool resharpening?

Regarding the tool design, information could be gained through a techno-typological analysis, the quantification of the edge angles and the use-wear analysis. The overall tool design is often seen as standardised, following an underlying concept for tool production and curation (Veil et al., 1994; Jöris, 1994, 2001, 2012; Richter, 1997; Pastoors, 2001; Migal and Urbaowski, 2006). The results of the techno-typological analysis of the studied artefacts confirm this perspective. The individual tools from each archaeological assemblage share many features regarding the selected blanks, dimensions (e.g. relative standardised back thickness) and edge retouch (in particular regarding the perimeter attributes). This is not only the case for the artefacts *per* site, but applies also to the inter-site comparison.

The perimeter sections are seen as functional units (Jöris, 2001; Iovita, 2010; Frick et al. 2017; Weiss et al., 2018; Weiss, 2019). The base and the back serve as a prehensile area. The distal posterior part is the most variable perimeter section, serving in many specimens as a striking platform for thinning the distal end of the tool, which further allowed edge angle maintenance of the active edge. These aspects could not be disproven based on the techno-typological results. On the contrary, the results of the perimeter section analysis support the idea of *Keilmesser* as being shape variable while changes occur isometrically in relation to the perimeter sections. Additionally, the qualitative use-wear analysis verified that the active edge is the area, concentrating the highest number of traces, and therefore, is interpreted as the used part of the tool. The amount of documented use-wear traces along the back and the base is significantly lower, which could be due to function as a prehensile area. Clear traces indicating a hafting of the tools could not be found, supporting the idea of *Keilmesser* as handheld tools (Jöris, 2001; Jöris and Uomini, 2019).

Additionally, *Keilmesser* are described as tools with a distinct laterality (Jöris and Uomini, 2019; Frick and Herkert, 2019). Laterality is seen as a proxy for handedness. This means, *Keilmesser* are either made by and/ or for individuals with a certain hand preference. The lateralisation of the studied artefacts was recorded, leading to an overall majority of right-lateral artefacts in Buhlen, Balve and Ramioul. Although evidence or indications for handedness in the Palaeolithic exist, these are often individual cases, not leading to any percentage figures. Nevertheless, several research studies indicate a bias towards the right-handedness (Ruck et al., 2015; Uomini and Ruck, 2019), as still valid for our modern population worldwide. Hence, the data obtained from the three archaeological assemblages builds on existing evidence concerning the predominance of right-handedness starting in early hominin populations. The laterality of the studied artefacts was addressed within the project, in order to see if the tool laterality can be confirmed by the use-wear analysis. Unfortunately, the data obtained with the qualitative and quantitative use-wear analysis did not provide significant evidence that could add more information to this topic.

Part of the overall tool design is the design of the active edge. In order to analyse the design, edge angle values along the entire tool active edge have been calculated. In the distal part of the tool, edge angles are more acute and increase in value towards the proximal part of the tool. The change amounts to a shift of 10° on average. The data for the proximal tool area is often near or above 60°, which is seen as a threshold for cutting tasks (Veil et al., 1994). This observation applies for *Keilmesser* with and without the modification by the application of the *Prądnik method*. However, *Keilmesser* characterised by a scar of the *Prądnik spall* removal at the distal part tend to have slightly more acute edges in this specific tool area. The difference is only small though and ranges between a few and maximum ten degrees. All *Keilmesser* display the same trend of diverging edge angle values in the distal and proximal tool parts. Thus, the data is in line with the morphological interpretation and supports the idea of *Keilmesser* as tools with bipartite edge morphology, whereas the focus lies on the distal tool edge. Thereby, the application of the *Prądnik method* likely fulfilled the purpose of resharpening the edge by creating more acute angles.

The aforementioned observation could also be addressed based on the results of the use-wear analysis performed on the *Prądnik spalls*. The results indicate the use of the tools, before the *Prądnik spalls* were removed. At least, some of the analysed primary *Prądnik spalls* show use-wear traces along the former active edge of the *Keilmesser* or *Prądnik scrapers.* This contradicts the idea, that the spalls were removed before the tool was subjected to use. The numerous secondary *Prądnik spalls* attest repeated (re-) sharpening sequences. Here again, the use-wear analysis could confirm traces along the former active edge of the *Keilmesser* or *Prądnik scrapers* on some pieces.

The idea of primary *Prądnik spalls* as a result of the tool finishing to create a bipartite active edge has led to the common interpretation of *Keilmesser* as multifunctional tools (Jöris, 2001, 2006; Jöris and Uomini, 2019; Frick and Herkert, 2019; Frick, 2020). Next to the edge angle calculation, the conducted use-wear analysis could provide further information regarding the type (e.g. polish, striations), the intensity and the location of use-wear. The results indicate a more versatile use compared to the other studied artefact categories, *Prądnik scrapers* and scrapers. Versatile means thereby that some artefacts show identical use-wear traces along the entire tool edge, some display traces either only in the distal or in the proximal part of the tool and others again illustrate diverging use-wear traces in both sections of the active edge. In general, data suggests that *Keilmesser* were either used for more than one single activity or that at least the handling (in the sense of how to hold the tool and how to perform a task) was not static, resulting in different locations and intensities of use-wear along the active edge. However, this does not exclude the possibility of some *Keilmesser* only being used for a single task solely. The conducted *second generation* experiments could confirm the suitability of certain edge angle values (extrapolated from the archaeological assemblages) for the performance of cutting as well as carving movements.

Keilmesser are not always the only asymmetric tools in Late Middle Palaeolithic assemblages. Some, as the three studied assemblages, also yield similar tools, here called *Prądnik scrapers.* One interpretation of *Prądnik scrapers* refers to them as simple, spontaneous and therefore less carefully produced versions of *Keilmesser* (Jöris, 2001, 2004; Jöris and Uomini, 2019; see also Weiss et al., 2018); another interpretation argues that *Prądnik scrapers* could have been produced by less experienced knappers, who imitate or copy more experienced knappers (Jöris and Uomini, 2019). *Prądnik scrapers* do resemble *Keilmesser* in many ways. While the underlying tool concept as explained for *Keilmesser*, can also be in parts retrieved in *Prądnik scrapers*, other aspects differ. Both have the asymmetric shape in common, which is derived from the morphological components. In addition, *Prądnik scrapers* are modified by the application of the *Prądnik method*. Contrary to *Keilmesser*, the vast majority of *Prądnik scrapers* are produced from flakes and only unifacially or semi-bifacially retouched along the active edge. Moreover, (re-)sharpening processes, which go beyond the application of a primary *Prądnick spall* removal, and reworking are rarely documented for *Prądnik scrapers*. In summation, these results support the idea of *Prądnik scraper* as an '*ad hoc*' version of *Keilmesser*. However, the use-wear analysis does not support the idea of *Prądnik scrapers* mimicking, concerning their function. Based on these results, *Prądnik scrapers* do not display a versatile use in the sense of diverging use-wear types such as polish and striations, or the combination of those in different locations. However, the use-wear traces reflect a long-term or intense usage of the *Prądnik scrapers*. Additionally, the calculated edge angle values indicate a considerably more acute active edge with fewer differences in the values along the entire edge. Thus, due to their tool design, the data taken together supports the idea of *Prądnik scrapers* as a simplistic version of *Keilmesser*. At the same time, the results also suggest that *Prądnik scrapers* show less versatility in their handling and function than *Keilmesser*. Based on these findings, an alternative interpretation, which sees *Prądnik scrapers* as morphologically simplistic versions of *Keilmesser* with only a single function, will be proposed.

Additionally, new information about *Prądnik spalls* could be gained through the conducted qualitative use-wear analysis. Next to use-wear traces along the former active edge of the *Keilmesser* or *Prądnik scrapers*, several use-wear traces could be documented in other locations on the dorsal as well as the ventral surface. The results of this analysis indicate that *Prądnik spalls* likely have been used as a tool after being removed from *Keilmesser* or *Prądnik scraper*. The edge angle calculation for the *Prądnik spalls* resulted in low values around 20° to 25° on average. Perhaps, these acute edge angles made them more suitable for certain tasks than other tools.

To summarise, asymmetric tools from the Late Middle Palaeolithic seem to be designed as standardised tools following a specific concept, which creates the typical morphology and allows for maintaining this morphology throughout the life-history of each individual tool. This observation is strengthened by the fact that these alleged standards are not only visible within the temporal resolution of one archaeological assemblage, but also across sites. Thus, these aspects taken together with the documented tool laterality, which, when seen as proxy for human handedness can be linked with social learning, knowledge transmission and the existence of certain rules and regulations, point towards the emerge of regional traditions. The *Keilmesser* tool concept would thereby be passed on as a skill from generation to generation.

In *Keilmesser*, the active edge design offers the possibility to perform different tasks. Based on the edge angle calculations and the results of the use-wear analysis, it seems as if these traits assign a unique role to *Keilmesser* within the studied artefact categories, but maybe also in *Keilmesser* assemblages in general.

As mentioned earlier, *Keilmesser* are well studied from a techno-typological point of view. However, use-wear on *Keilmesser* has rarely been addressed (Rots, 2009); and, as a consequence, experiments focusing on tool use and function have not yet been conducted. This is precisely why a multidisciplinary approach promised the greatest chance of achieving new insights. As demonstrated, the results from the techno-typological approach only, could confirm the existing interpretations about *Keilmesser*. Interestingly, the data also showed that the three studied assemblages – Buhlen, Balve and Ramioul – share many similarities. However, the raw material analysis, the use-wear analysis and the conducted *second generation experiments* could enhance the data relating to this research topic. The calculation of the edge angle values made it possible to first quantify edge geometry and second, to verify assumptions about this design. From this point of view, the experiments fulfilled a similar goal. By conducting the experiments, the interpretations of the *Keilmesser* functionality could be tested. It could be demonstrated that the various tested edge angles (35°, 40°, 45° and 60°) can be used to perform unidirectional cutting as well as carving movements. At the same time, these sequential experiments made it possible to gain information about the mechanics behind tool abrasion and the formation of use-wear. To current knowledge, this project is the first one to illustrate this, applying qualitative and quantitative use-wear analysis to a lithic assemblage of this size. In particular the combination of both use-wear disciplines is new for lithic studies. Together, these two analyses led to new data concerning the use of *Keilmesser*, *Prądnik scrapers* and *Prądnik spalls*, especially to their use intensity.

While the application of the mentioned methods and techniques could provide a more distinct picture about asymmetric tools from the Late Middle Palaeolithic, they also have their limitations. The first limitation relates to the experiments. *Second generation experiments*, such as the conducted ones, focus on basic fundamental mechanics by testing the effect of individual variables. This means at the same time, the obtained results are only valid within the exact same experimental framework. The results cannot directly be transferred to the archaeological record. Certainly, the results can be extrapolated, but still, they need to be tested again within another experimental setup. Thus, a *second generation experiment* in itself is limited. In order to overcome this limitation, a subsequent *third generation experiment* should be conducted (Marreiros et al., 2020), incorporating the human variability and testing the models detected during the previous generation of experiments. The second limitation could be experienced regarding the quantitative use-wear analysis. Quantitative use-wear analysis is a relatively new approach in archaeology. This means, reference collections or interpretations of the data are rarely existing. Most quantitative use-wear studies have been applied on experimental samples (Stemp and Stemp, 2001, 2003; Lerner et al., 2007; Evans and Donahue, 2008; Evans and Macdonald, 2011; Stemp and Chung, 2011, Giusca et al., 2012; Ibáñez et al., 2018; Galland et al., 2019; Stemp, Macdonald and Gleason, 2019; Álvarez-Fernández, 2020; Pedergnana et al., 2020b), some on archaeological bone samples (d'Errico and Backwell 2009; Martisius et al., 2018; Bradfield 2020; Martisius et al., 2020). Quantitative use-wear studies on lithic artefacts are not published yet and especially a raw material such as silicified schist has not been the focus of such studies yet. Unfortunately, that makes the interpretation of the data insecure and complicated, in particular when trying to infer on the contact material. Although, following international standards (ISO 25178-2) for data analysis offers a secure way, it does not explain the data itself. The relevance of the individual parameters for lithic studies is not conclusively known yet.

Based on these conclusions, the following recommendations for future research can be made. Firstly, the importance of raw material characterisation should again be stressed. The raw material properties play an important role concerning various aspects such as tool production, curation and performance as well as material abrasion, and therefore, the formation of use-wear traces. In order to obtain reliable results throughout quantitative use-wear analyses, besides the use-wear traces, the original surface should also be measured. The identification of properties such as the surface texture roughness will provide information necessary to understand how the use-wear formed. Since the development of use-wear is the result of surface abrasion (Schmidt et al., 2020), these processes are highly dependent on the raw material of the used sample. Without analysing these properties, the mechanics behind the use-wear formation cannot be incorporated in the overall interpretation. As demonstrated, within the experimental frame, the raw material properties likely play a more important role than the contact material. Further research is needed to determine the effects of the contact material in the process of use-wear formation. However, since the mechanics, which affect the sample during use, are not entirely understood, functional interpretations of diagnostic use-wear traces should be made with caution. Without this important background information, a judgment regarding the performed task or the contact material can only result in speculation. These observations lead to a second aspect. Use-wear studies would benefit from the incorporation of tribology. An interdisciplinary research approach including tribology would help to understand principles such as friction and lubrication and the cause-effect relation of wear formation. To better understand the implications of these observations, future studies could address these tribological principles, in order to build a framework to transfer theoretical and experimental results to the archaeological record.

Lithic artefacts provide key insights into early hominin behaviour. The study of stone tools such as Late Middle Palaeolithic artefacts helps to contextualise technological adaptability, innovations and dynamics in Neanderthal behavioural choices. By analysing the three *Keilmesser* assemblages from Buhlen, Balver Höhle and la Grotte de Ramioul new data concerning tool design, usage and functionality could be gathered. *Keilmesser* represent thereby such a complex and sophisticated artefact category, offering the potential to address numerous fundamental aspects. These aspects cover nearly the entire range of features that are possible to study on lithics. This includes raw material selection, tool production, maintenance and reworking, tool handling, functionality and use. In *Keilmesser*, all these features are combined in one specific tool design. Moreover, this tool design illustrates a technology, which has been kept and transmitted over long periods of time, giving clear indications on Neanderthal behaviour. Together, this makes it likely, that this tool design fulfilled a specific purpose. The data could be achieved through the employment of different methods and scales of analysis. For the first time, *Keilmesser* have been studied by combining techno-typological analyses with controlled experiments as well as qualitative and quantitative use-wear analysis. Consequently, the research presented herein provides a more holistic view on *Keilmesser.* Thus, this study adds a significant piece to the puzzle of our understanding of the evolutionary trajectory of past human behaviour.

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Appendix I.

Results of the techno-typological lithic analysis for the studied assemblages from Buhlen, Balver Höhle and Ramioul.

Buhlen

ID	loan	excavation year	artefact labelling	stratigraphy	level	artefact drawing	raw material	artefact state
BU-002	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 138 IIIb1 57	YES	III b	NO	silicified schist	complete
BU-003	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 165 IIIc2	YES	IIIc	YES by unknown	silicified schist	complete
BU-004	Depot Hessisches Landesmuseum Kassel	1960s	Bu66 117 IIIb	YES	III b	YES by unknown	silicified schist	complete
BU-005	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 67/165 II	YES	II	NO	silicified schist	complete
BU-006	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 166 II	YES	II	NO	silicified schist	complete
BU-007	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 163 II	YES	II	NO	silicified schist	complete
BU-008	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 139 IIIb2 14	YES	III b	YES by unknown	silicified schist	complete
BU-009	Depot Hessisches Landesmuseum Kassel	1960s	Bu69 / 203 IIb80	YES	II b	NO	silicified schist	complete
BU-010	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 120 IIIb x	YES	III b	NO	silicified schist	complete
BU-011	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 169 III b76	YES	III b	YES by Jörisöris	silicified schist	complete
BU-012	Depot Hessisches Landesmuseum Kassel	1960s	Bu66 / 110 VI b	YES	VI b	YES by unknown	silicified schist	complete
BU-013	Depot Hessisches Landesmuseum Kassel	1960s	Bu 67 120 IIIb	YES	III b	NO	silicified schist	complete
BU-014	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 169 IIIb2 34	YES	III b	YES by Jöris	silicified schist	complete

ID	blank	*Keilmesser* shape	cortex	cortex percentage	cortex location	morpho-logy back	retouch active edge	retouch type edge
BU-002	core	Bockstein	YES	25-50	back	cortex unworked	YES	bifacial
BU-003	core	Buhlen	YES	<25	base	cortex partly retouched	YES	bifacial
BU-004	core	Pradnik	YES	<25	back	cortex unworked	YES	bifacial
BU-005	core	Balve	YES	50-75	ventral and dorsal	cortex unworked	YES	bifacial
BU-006	core	Pradnik	YES	25-50	back	cortex unworked	YES	bifacial
BU-007	core	Buhlen	YES	25-50	base	cortex unworked	YES	bifacial
BU-008	core	Pradnik	YES	25-50	back	cortex unworked	YES	bifacial
BU-009	core	Balve	YES	<25	back	cortex partly retouched	YES	semi-bifacial
BU-010	core	Pradnik	YES	25-50	medial dorsal	cortex unworked	YES	bifacial
BU-011	core	Buhlen	NO	N/A	N/A	cortex unworked	YES	bifacial
BU-012	N/A	Balve	NO	N/A	N/A	cortex unworked	YES	bifacial
BU-013	core	Bockstein	NO	N/A	N/A	partly retouched	YES	semi-bifacial
BU-014	core	Buhlen	YES	25-50	back	cortex unworked	YES	bifacial

ID	tip morphology	application Pradnik method	frequency application Pradnik method	tool lateral-isation	length [mm]	width [mm]	thick-ness [mm]	weight [kg]
BU-002	rounded	NO	N/A	dex.	48.0	35.0	14.0	0.0259
BU-003	rounded	YES	one	dex.	58.0	31.0	18.0	0.0337
BU-004	rounded	YES	one	dex.	56.3	38.8	16.0	0.0391
BU-005	pointed	NO	N/A	dex.	69.0	46.0	14.0	0.0561
BU-006	rounded	YES	one	dex.	53.7	36.2	17.0	0.0367
BU-007	rounded	NO	N/A	dex.	51.6	30.0	18.0	0.0258
BU-008	rounded	YES	multiple	dex.	66.0	29.0	19.0	0.0387
BU-009	pointed	YES	multiple	dex.	65.0	44.0	31.0	0.0733
BU-010	pointed	YES	multiple	dex.	67.0	26.0	13.0	0.0224
BU-011	pointed	YES	multiple	dex.	56.0	35.0	12.0	0.0204
BU-012	rounded	YES	one	dex.	44.0	26.0	11.0	0.0127
BU-013	pointed	NO	N/A	dex.	40.0	32.0	14.0	0.0167
BU-014	rounded	YES	one	dex.	74.0	43.0	23.0	0.0648

ID	peri-meter basis + back [cm]	peri-meter distal posterior part [cm]	peri-meter active edge [cm]	thick-ness back [mm]	taphonomic visual inspection	tool edges preser-vation	use-wear analysis	3D-scan	schist-osety
BU-002	8.4	0.0	5.6	14.0	sharp edges and preserved surface	edges preserved	NO	YES	N/A
BU-003	8.2	1.6	4.7	11.0	sharp edges and preserved surface	edges preserved	YES	YES	NO
BU-004	7.5	2.1	6.5	14.0	sharp edges and preserved surface	edges preserved	YES	YES	NO
BU-005	8.4	2.2	8.2	12.0	sharp edges and preserved surface	edges preserved	NO	YES	YES
BU-006	8.2	1.0	4.4	17.3	sharp edges and preserved surface	edges preserved	YES	YES	YES
BU-007	7.6	1.5	4.2	8.0	sharp edges and preserved surface	edges preserved	NO	YES	NO
BU-008	7.7	3.9	5.7	17.0	sharp edges and preserved surface	edges preserved	YES	YES	YES
BU-009	9.4	2.5	7.0	16.0	sharp edges and preserved surface	edges preserved	YES	YES	N/A
BU-010	8.1	2.4	5.1	9.0	sharp edges and preserved surface	edges preserved	YES	YES	YES
BU-011	8.8	1.0	4.7	8.0	sharp edges and preserved surface	edges preserved	NO	YES	NO
BU-012	5.5	0.6	5.0	11.1	sharp edges and preserved surface	edges preserved	YES	YES	NO
BU-013	7.2	0.0	3.9	6.0	sharp edges and preserved surface	edges preserved	NO	NO	NO
BU-014	9.9	0.8	8.5	26.0	sharp edges and preserved surface	edges preserved	NO	YES	NO

ID	loan	excavation year	artefact labelling	stratigraphy	level	artefact drawing	raw material	artefact state
BU-015	Depot Hessisches Landesmuseum Kassel	1960s	Bu69 - 177 IIIc	YES	III c	NO	silicified schist	complete
BU-016	Depot Hessisches Landesmuseum Kassel	N/A	BuhlenZ(mittl.Fp.?)	N/A	N/A	NO	silicified schist	complete
BU-017	Depot Hessisches Landesmuseum Kassel	1960s	Bu69 / 191: IIIb	YES	III b	YES by unknown	silicified schist	complete
BU-018	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 143 IIIb2/35	YES	III b	YES by Jöris	silicified schist	complete
BU-019	Depot Hessisches Landesmuseum Kassel	1960s	Bu66 / 112 D1? III	YES	III	NO	silicified schist	complete
BU-020	Depot Hessisches Landesmuseum Kassel	1960s	Bu66 113 IIIb x	YES	III b	YES by Jöris	silicified schist	complete
BU-021	Depot Hessisches Landesmuseum Kassel	1960s	Bu66 119 III x	YES	III	NO	silicified schist	complete
BU-022	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 153 IIIb1 17	YES	III b	NO	silicified schist	complete
BU-023	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 163 II	YES	II	NO	silicified schist	complete
BU-024	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 182 II	YES	II	YES by unknown	silicified schist	complete
BU-025	Depot Hessisches Landesmuseum Kassel	1960s	Bu69 / 190 :: IIIb	YES	III b	NO	silicified schist	complete
BU-026	Depot Hessisches Landesmuseum Kassel	1960s	Bu66 / 111 D1 23 III	YES	III	needed	silicified schist	complete
BU-027	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 / 120 IIIb	YES	III b	YES by Jöris	silicified schist	complete

ID	blank	*Keilmesser* shape	cortex	cortex percentage	cortex location	morpho-logy back	retouch active edge	retouch type edge
BU-015	N/A	N/A	NO	N/A	N/A	retouched	YES	bifacial
BU-016	core	Balve	NO	N/A	N/A	partly retouched	YES	bifacial
BU-017	core	Pradnik	NO	N/A	N/A	retouched	YES	bifacial
BU-018	core	Balve	NO	N/A	N/A	cortex partly retouched	YES	bifacial
BU-019	core	Balve	NO	N/A		cortex partly retouched	YES	bifacial
BU-020	core	Pradnik	YES	25-50	back	cortex unworked	YES	bifacial
BU-021	core	Klausennische	YES	25-50	back	cortex unworked	YES	bifacial
BU-022	N/A	Balve	YES	<25	Back	cortex unworked	YES	bifacial
BU-023	core	Buhlen	YES	<25	medial ventral	cortex partly retouched	YES	bifacial
BU-024	core	Pradnik	YES	<25	base	retouched	YES	bifacial
BU-025	core	Pradnik	NO	N/A	N/A	cortex unworked	YES	bifacial
BU-026	N/A	Pradnik	YES	<25	back	cortex unworked	YES	semi-bifacial
BU-027	core	Pradnik	NO	N/A	N/A	cortex unworked	YES	bifacial

ID	tip morphology	application Pradnik method	frequency application Pradnik method	tool lateral-isation	length [mm]	width [mm]	thick-ness [mm]	weight [kg]
BU-015	rounded	YES	multiple	dex.	54.0	36.0	13.0	0.0253
BU-016	rounded	YES	one	dex.	52.0	38.0	18.0	0.0413
BU-017	rounded	YES	one	dex.	52.0	30.0	22.0	0.034
BU-018	pointed	YES	one	dex.	45.0	32.0	10.0	0.0194
BU-019	rounded	YES	one	dex.	40.0	26.0	15.0	0.016
BU-020	rounded	NO	N/A	dex.	44.0	28.0	17.0	0.0257
BU-021	rounded	N/A	N/A	dex.	60.0	45.0	24.0	0.0554
BU-022	rounded	NO	N/A	dex.	45.0	34.0	10.0	0.0219
BU-023	rounded	YES	one	dex.	41.0	29.0	18.0	0.0179
BU-024	rounded	YES	one	dex.	56.0	37.0	16.0	0.037
BU-025	rounded	NO	N/A	dex.	41.0	30.0	17.0	0.0211
BU-026	rounded	YES	one	dex.	32.0	14.0	7.0	0.0045
BU-027	rounded	YES	multiple	dex.	40.0	19.0	12.0	0.0121

ID	perimeter basis + back [cm]	perimeter distal posterior part [cm]	perimeter active edge [cm]	thickness back [mm]	taphonomic visual inspection	tool edges preservation	use-wear analysis	3D-scan	schistosety
BU-015	6.8	1.0	7.0	4.0	sharp edges and preserved surface	edges preserved	NO	NO	NO
BU-016	6.9	3.0	5.7	8.0	sharp edges and preserved surface	edges preserved	YES	YES	NO
BU-017	7.7	1.5	5.4	14.0	sharp edges and preserved surface	edges preserved	YES	YES	NO
BU-018	6.3	2.8	4.0	9.0	sharp edges and preserved surface	edges preserved	NO	YES	YES
BU-019	4.7	2.9	3.7	6.0	sharp edges and preserved surface	edges preserved	YES	YES	NO
BU-020	6.2	2.8	4.5	14.0	sharp edges and preserved surface	edges preserved	NO	YES	NO
BU-021	9.6	1.0	6.2	23.0	sharp edges and preserved surface	edges preserved	YES	YES	NO
BU-022	6.9	2.5	4.0	7.0	sharp edges and preserved surface	edges preserved	NO	NO	NO
BU-023	6.6	0.9	3.8	8.0	sharp edges and preserved surface	edges preserved	YES	YES	NO
BU-024	6.7	3.1	5.5	13.0	sharp edges and preserved surface	edges preserved	YES	YES	NO
BU-025	7.2	1.9	4.0	16.0	sharp edges and preserved surface	edges preserved	NO	NO	NO
BU-026	4.2	2.0	2.1	6.0	sharp edges and preserved surface	edges preserved	YES	YES	NO
BU-027	5.3	2.0	3.6	11.0	sharp edges and preserved surface	edges preserved	NO	NO	NO

ID	loan	exca-vation year	artefact labelling	strati-graphy	level	artefact drawing	raw material	artefact state
BU-028	Depot Hessisches Landesmuseum Kassel	1960s	Bu69 / 197 II 40-50	YES	II	NO	silicified schist	complete
BU-029	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 / 2 145 IIIb1	YES	III b	NO	silicified schist	complete
BU-030	Depot Hessisches Landesmuseum Kassel	1960s	BU66 119 IIIb	YES	III b	NO	silicified schist	complete
BU-031	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 146 I	YES	I	NO	silicified schist	complete
BU-032	Depot Hessisches Landesmuseum Kassel	1960s	Bu66 111 B3	N/A	N/A	NO	silicified schist	complete
BU-033	Depot Hessisches Landesmuseum Kassel	1960s	BU67 120 IIIb	YES	III b	NO	other	complete
BU-034	Depot Hessisches Landesmuseum Kassel	1960s	Bu66 119 IIIb	YES	III b	NO	silicified schist	complete
BU-035	Depot Hessisches Landesmuseum Kassel	1960s	Bu66 116 IIIb	YES	III b	NO	silicified schist	complete
BU-036	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 171 IIIa	YES	III a	NO	silicified schist	complete
BU-037	Depot Hessisches Landesmuseum Kassel	1960s	Bu66 119 IIIa	YES	III a	NO	silicified schist	complete
BU-038	Depot Hessisches Landesmuseum Kassel	1960s	Bu66 117 IIIb	YES	III b	NO	silicified schist	complete
BU-039	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 168 IIIb2 25	YES	III b	NO	silicified schist	complete
BU-040	Depot Hessisches Landesmuseum Kassel	1978	Bu66 118 IIIb	YES	III b	NO	silicified schist	complete

ID	blank	*Keilmesser* shape	cortex	cortex percentage	cortex location	morpho-logy back	retouch active edge	retouch type edge
BU-028	core	Buhlen	YES	<25	back	cortex partly retouched	YES	bifacial
BU-029	N/A	Klausennische	NO	N/A	N/A	cortex unworked	YES	bifacial
BU-030	core	Lichtenberg	YES	<25	base	cortex partly retouched	YES	semi-bifacial
BU-031	core	Buhlen	YES	25-50	proximal dorsal	cortex unworked	YES	semi-bifacial
BU-032	core	Lichtenberg	NO	N/A	N/A	retouched	YES	bifacial
BU-033	core	Bockstein	YES	<25	proximal dorsal	cortex unworked	YES	bifacial
BU-034	core	Klausennische	YES	<25	proximal ventral	cortex unworked	YES	bifacial
BU-035	core	Pradnik	YES	<25	back	cortex partly retouched	YES	semi-bifacial
BU-036	N/A	Balve	YES	<25	back	cortex unworked	YES	unifacial
BU-037	core	Buhlen	NO	N/A	N/A	cortex unworked	YES	bifacial
BU-038	core	Klausennische	YES	25-50	back	cortex unworked	YES	bifacial
BU-039	N/A	Balve	YES	<25	base	cortex partly retouched	YES	bifacial
BU-040	core	Klausennische	YES	25-50	medial dorsal	cortex partly retouched	YES	bifacial

ID	tip morphology	application Pradnik method	frequency application Pradnik method	tool lateral-isation	length [mm]	width [mm]	thick-ness [mm]	weight [kg]
BU-028	rounded	YES	one	dex.	59.0	45.0	23.0	0.0485
BU-029	pointed	YES	one	dex.	40.0	28.0	13.0	0.0144
BU-030	rounded	YES	one	dex.	50.0	38.0	20.0	0.0385
BU-031	rounded	YES	one	dex.	36.0	24.0	14.0	0.011
BU-032	rounded	YES	one	dex.	67.0	37.0	15.0	0.0426
BU-033	rounded	YES	multiple	dex.	49.0	29.0	13.0	0.0212
BU-034	rounded	YES	one	dex.	40.0	32.0	21.0	0.0224
BU-035	rounded	YES	multiple	dex.	39.0	19.0	13.0	0.0115
BU-036	rounded	YES	multiple	dex.	47.0	22.0	11.0	0.015
BU-037	rounded	YES	multiple	dex.	44.0	34.0	21.0	0.0321
BU-038	rounded	YES	one	dex.	59.0	27.0	20.0	0.0415
BU-039	pointed	YES	one	dex.	41.0	26.0	12.0	0.0119
BU-040	rounded	YES	one	dex.	51.0	32.0	14.0	0.0268

ID	perimeter basis + back [cm]	perimeter distal posterior part [cm]	perimeter active edge [cm]	thickness back [mm]	taphonomic visual inspection	tool edges preservation	use-wear analysis	3D-scan	schistosety
BU-028	10.5	2.4	4.7	19.0	sharp edges and preserved surface	edges preserved	YES	YES	NO
BU-029	6.3	1.5	4.0	12.0	sharp edges and preserved surface	edges preserved	NO	YES	NO
BU-030	7.7	2.0	5.3	9.0	sharp edges and preserved surface	edges preserved	NO	NO	NO
BU-031	6.0	1.3	3.5	9.0	sharp edges and preserved surface	edges preserved	YES	YES	NO
BU-032	9.4	2.7	6.6	9.0	sharp edges and preserved surface	edges preserved	YES	YES	YES
BU-033	7.3	1.0	5.6	15.0	sharp edges and preserved surface	edges preserved	YES	YES	NO
BU-034	4.4	3.3	4.1	17.0	sharp edges and preserved surface	edges preserved	NO	NO	NO
BU-035	4.5	1.4	4.8	12.0	sharp edges and preserved surface	edges preserved	NO	NO	NO
BU-036	5.4	1.7	4.6	9.0	sharp edges and preserved surface	edges preserved	YES	YES	NO
BU-037	7.2	1.5	3.7	20.0	sharp edges and preserved surface	edges preserved	NO	NO	NO
BU-038	6.6	2.1	7.0	19.0	sharp edges and preserved surface	edges preserved	NO	NO	NO
BU-039	5.4	1.9	4.6	8.0	sharp edges and preserved surface	edges preserved	YES	YES	NO
BU-040	5.2	3.7	5.0	12.0	sharp edges and preserved surface	edges preserved	YES	YES	NO

ID	loan	excavation year	artefact labelling	stratigraphy	level	artefact drawing	raw material	artefact state
BU-041	Depot Hessisches Landesmuseum Kassel	1960s	Bu66 119 IIIb	YES	III b	NO	silicified schist	complete
BU-042	Depot Hessisches Landesmuseum Kassel	1960s	Bu 66 110 IIIb	YES	III b	NO	silicified schist	complete
BU-043	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 121 IIIb	YES	III b	NO	silicified schist	complete
BU-044	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 144 IIIb 24	YES	III b	NO	silicified schist	complete
BU-045	Depot Hessisches Landesmuseum Kassel	1960s	Bu ? 120 IIIb	YES	III b	YES by Jöris	silicified schist	complete
BU-046	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 143 IIIb2 /63	YES	III b	NO	silicified schist	complete
BU-047	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 175 / I	YES	I	NO	silicified schist	complete
BU-048	Depot Hessisches Landesmuseum Kassel	1960s	Bu66 115-117 I	YES	I	NO	silicified schist	complete
BU-049	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 151 I	YES	I	NO	silicified schist	complete
BU-050	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 143 IIIb2 /42	YES	III b	NO	silicified schist	complete
BU-051	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 120 IIIb	YES	III b	NO	silicified schist	complete
BU-052	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 120 IIIb x	YES	III b	NO	silicified schist	complete
BU-053	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 / 176 II	YES	II	NO	silicified schist	complete

ID	blank	*Keilmesser* shape	cortex	cortex percentage	cortex location	morpho-logy back	retouch active edge	retouch type edge
BU-041	N/A	Pradnik	NO	N/A	N/A	cortex unworked	YES	bifacial
BU-042	N/A	Balve	NO	N/A	N/A	partly retouched	YES	bifacial
BU-043	core	Buhlen	YES	25-50	base	cortex unworked	YES	bifacial
BU-044	core	N/A	YES	25-50	back	cortex unworked	YES	semi-bifacial
BU-045	core	Balve	NO	N/A	N/A	partly retouched	YES	bifacial
BU-046	core	Buhlen	NO	N/A	N/A	partly retouched	YES	bifacial
BU-047	core	Lichtenberg	YES	25-50	base	retouched	YES	bifacial
BU-048	core	Klausennische	NO	N/A	N/A	cortex unworked	YES	semi-bifacial
BU-049	N/A	N/A	YES	25-50	back	cortex unworked	YES	bifacial
BU-050	core	Balve	YES	<25	back	cortex partly retouched	YES	semi-bifacial
BU-051	flake	Pradnik	NO	N/A	N/A	partly retouched	YES	bifacial
BU-052	core	Klausennische	YES	25-50	base	retouched	YES	semi-bifacial
BU-053	N/A	Pradnik	NO			retouched	YES	bifacial

ID	tip morphology	application Pradnik method	frequency application Pradnik method	tool lateral-isation	length [mm]	width [mm]	thick-ness [mm]	weight [kg]
BU-041	rounded	YES	one	dex.	47.0	25.0	15.0	0.0166
BU-042	rounded	YES	one	dex.	38.0	30.0	15.0	0.0162
BU-043	pointed	YES	one	dex.	43.0	37.0	19.0	0.0299
BU-044	rounded	NO	N/A	dex.	34.0	29.0	16.0	0.0126
BU-045	rounded	YES	one	dex.	39.0	26.0	13.0	0.0137
BU-046	rounded	YES	multiple	dex.	59.0	34.0	14.0	0.0325
BU-047	rounded	YES	one	dex.	67.0	51.0	9.0	0.044
BU-048	rounded	NO	N/A	dex.	94.0	41.0	17.0	0.0668
BU-049	rounded	YES	one	dex.	54.0	28.0	17.0	0.0226
BU-050	rounded	YES	one	dex.	56.0	41.0	22.0	0.0477
BU-051	rounded	YES	one	dex.	52.0	27.0	10.0	0.0155
BU-052	rounded	YES	one	dex.	47.0	26.0	12.0	0.0174
BU-053	rounded	YES	one	dex.	52.0	34.0	12.0	0.0234

ID	peri-meter basis + back [cm]	peri-meter distal posterior part [cm]	peri-meter active edge [cm]	thick-ness back [mm]	taphonomic visual inspection	tool edges preser-vation	use-wear analysis	3D-scan	schist-osety
BU-041	5.3	2.3	5.0	6.0	sharp edges and preserved surface	edges preserved	NO	NO	NO
BU-042	6.0	1.1	4.2	12.0	sharp edges and preserved surface	edges preserved	NO	NO	NO
BU-043	5.4	4.0	4.3	6.0	sharp edges and preserved surface	edges preserved	NO	NO	NO
BU-044	6.2	1.1	3.0	12.0	sharp edges and preserved surface	edges preserved	NO	NO	NO
BU-045	4.3	3.1	3.7	12.0	sharp edges and preserved surface	edges preserved	YES	YES	NO
BU-046	9.6	2.1	4.4	13.0	sharp edges and preserved surface	edges preserved	YES	YES	NO
BU-047	8.7	4.0	7.6	5.0	sharp edges and preserved surface	edges preserved	NO	YES	NO
BU-048	8.4	4.5	10.2	15.0	sharp edges and preserved surface	edges preserved	YES	YES	NO
BU-049	7.2	1.5	5.0	18.0	sharp edges and preserved surface	edges preserved	NO	NO	NO
BU-050	6.9	3.0	5.7	12.0	sharp edges and preserved surface	edges preserved	NO	NO	NO
BU-051	4.3	3.2	6.0	6.0	sharp edges and preserved surface	edges preserved	YES	YES	NO
BU-052	5.1	3.0	4.7	8.0	sharp edges and preserved surface	edges preserved	YES	YES	NO
BU-053	6.7	2.8	4.6	5.0	sharp edges and preserved surface	edges preserved	NO	NO	NO

ID	loan	excavation year	artefact labelling	stratigraphy	level	artefact drawing	raw material	artefact state
BU-054	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 175 IIId	YES	III d	NO	silicified schist	complete
BU-055	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 138 III b1 44	YES	III b	YES by Jöris	silicified schist	complete
BU-056	Depot Hessisches Landesmuseum Kassel	1960s	Bu66 116 IIIc	YES	III c	NO	silicified schist	complete
BU-057	Depot Hessisches Landesmuseum Kassel	1960s	BU67 138 IIIb2 /79	YES	III b	YES by Jöris	silicified schist	complete
BU-058	Depot Hessisches Landesmuseum Kassel	1960s	Bu66 117 IIIb x	YES	III b	YES by Bosinski	silicified schist	complete
BU-059	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 / 169 IIIb2 39x	YES	III b	NO	silicified schist	complete
BU-060	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 139 IIIb2 /18x	YES	III b	YES by Bosinski	silicified schist	complete
BU-061	Depot Hessisches Landesmuseum Kassel	1960s	Bu66 119 IIIb x	YES	III b	YES by unknown	silicified schist	complete
BU-062	Depot Hessisches Landesmuseum Kassel	1960s	Bu66 113 IIIc x	YES	III c	YES by Jöris	silicified schist	complete
BU-063	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 113 IIIb2 / 5	YES	III b	YES by Jöris	silicified schist	complete
BU-064	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 169 IIIb2 45	YES	III b	NO	silicified schist	complete
BU-065	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 172 IIIc	YES	III c	YES by unknown	silicified schist	complete
BU-066	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 169 IIIc	YES	III c	NO	silicified schist	complete

ID	blank	*Keilmesser* shape	cortex	cortex percentage	cortex location	morpho-logy back	retouch active edge	retouch type edge
BU-054	core	Klausennische	YES	25-50	base	cortex unworked	YES	bifacial
BU-055	core	N/A	NO	N/A	N/A	cortex unworked	YES	semi-bifacial
BU-056	core	Pradnik	YES	<25	back	cortex partly retouched	YES	bifacial
BU-057	core	Buhlen	YES	<25	back	cortex partly retouched	YES	bifacial
BU-058	N/A	Pradnik	YES	<25	base	retouched	YES	bifacial
BU-059	core	Klausennische	YES	25-50	back	cortex unworked	YES	semi-bifacial
BU-060	N/A	Buhlen	NO	N/A	N/A	cortex partly retouched	YES	bifacial
BU-061	flake	Pradnik	NO	N/A	N/A	partly retouched	YES	bifacial
BU-062	core	N/A	YES	25-50	back	cortex unworked	YES	bifacial
BU-063	core	Klausennische	YES	<25	back	cortex unworked	YES	bifacial
BU-064	core	Buhlen	YES	50-75	total	cortex unworked	YES	bifacial
BU-065	core	Lichtenberg	YES	25-50	base	cortex partly retouched	YES	bifacial
BU-066	flake	Balve	YES	<25	medial dorsal	partly retouched	YES	semi-bifacial

ID	tip morphology	application Pradnik method	frequency application Pradnik method	tool lateral-isation	length [mm]	width [mm]	thick-ness [mm]	weight [kg]
BU-054	rounded	NO	N/A	dex.	36.0	30.0	15.0	0.0207
BU-055	rounded	YES	one	dex.	36.0	25.0	17.0	0.0134
BU-056	pointed	YES	one	dex.	43.0	30.0	16.0	0.0255
BU-057	rounded	YES	one	dex.	49.0	29.0	11.0	0.016
BU-058	rounded	YES	one	dex.	44.0	32.0	13.0	0.0242
BU-059	rounded	YES	one	dex.	52.0	33.0	23.0	0.0349
BU-060	rounded	YES	one	dex.	56.0	34.0	17.0	0.0262
BU-061	rounded	YES	one	dex.	50.0	34.0	16.0	0.0267
BU-062	pointed	YES	one	dex.	46.0	34.0	25.0	0.0334
BU-063	pointed	YES	one	dex.	41.0	23.0	13.0	0.0122
BU-064	rounded	YES	one	dex.	41.0	36.0	18.0	0.0274
BU-065	pointed	YES	one	dex.	39.0	34.0	17.0	0.0223
BU-066	pointed	YES	one	dex.	37.0	23.0	13.0	0.0101

ID	peri-meter basis + back [cm]	peri-meter distal posterior part [cm]	peri-meter active edge [cm]	thick-ness back [mm]	taphonomic visual inspection	tool edges preser-vation	use-wear analysis	3D-scan	schist-osety
BU-054	4.6	3.7	3.2	11.0	sharp edges and preserved surface	edges preserved	YES	YES	NO
BU-055	3.9	3.2	3.1	6.0	sharp edges and preserved surface	edges preserved	NO	NO	NO
BU-056	6.0	2.1	4.5	15.0	sharp edges and preserved surface	edges preserved	YES	YES	NO
BU-057	6.0	2.0	4.9	9.0	sharp edges and preserved surface	edges preserved	YES	YES	NO
BU-058	5.5	2.7	4.7	8.0	sharp edges and preserved surface	edges preserved	YES	YES	NO
BU-059	5.2	4.0	5.0	10.0	sharp edges and preserved surface	edges preserved	NO	NO	NO
BU-060	7.5	2.1	5.6	16.0	sharp edges and preserved surface	edges preserved	YES	YES	NO
BU-061	6.7	4.4	4.3	8.0	sharp edges and preserved surface	edges preserved	NO	NO	NO
BU-062	7.1	1.9	3.3	24.0	sharp edges and preserved surface	edges preserved	YES	YES	NO
BU-063	5.7	1.9	4.3	10.0	sharp edges and preserved surface	edges preserved	YES	YES	NO
BU-064	7.4	1.1	3.5	19.0	sharp edges and preserved surface	edges preserved	NO	NO	NO
BU-065	5.0	3.0	4.2	6.0	sharp edges and preserved surface	edges preserved	NO	NO	NO
BU-066	4.7	2.2	2.5	10.0	sharp edges and preserved surface	edges preserved	YES	YES	NO

ID	loan	excavation year	artefact labelling	stratigraphy	level	artefact drawing	raw material	artefact state
BU-067	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 175 IIIb a/3 x	YES	III b	YES by unknown	silicified schist	complete
BU-068	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 169 IIIb2 27	YES	III b	NO	silicified schist	complete
BU-069	Depot Hessisches Landesmuseum Kassel	1960s	Bu66 119 IIIb x	YES	III b	NO	silicified schist	complete
BU-070	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 169 IIIb2 28	YES	III b	YES by Jöris	silicified schist	complete
BU-071	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 176 I c	YES	I	NO	silicified schist	complete
BU-072	Depot Hessisches Landesmuseum Kassel	1960s	Bu62 190:: II2 40-50	YES	II	YES by Jöris	silicified schist	complete
BU-073	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 161 II	YES	II	NO	silicified schist	complete
BU-073	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 / 178 II	YES	II	NO	silicified schist	complete
BU-074	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 163 II	YES	II	NO	silicified schist	complete
BU-075	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 168 III a	YES	III a	NO	silicified schist	complete
BU-076	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 x 143 III b/20	YES	III b	YES by unknown	silicified schist	complete
BU-077	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 120 IIIb x	YES	III b	NO	silicified schist	complete
BU-078	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 138 III /75	YES	III	YES by unknown	silicified schist	complete

ID	blank	*Keilmesser* shape	cortex	cortex percentage	cortex location	morpho-logy back	retouch active edge	retouch type edge
BU-067	core	Pradnik	YES	<25	proximal dorsal	retouched	YES	bifacial
BU-068	flake	Buhlen	NO	N/A	N/A	cortex partly retouched	YES	bifacial
BU-069	flake	Pradnik	YES	<25	medial dorsal	partly retouched	YES	bifacial
BU-070	core	Klausennische	NO	N/A	N/A	partly retouched	YES	bifacial
BU-071	N/A	Klausennische	YES	25-50	medial dorsal	partly retouched	YES	semi-bifacial
BU-072	core	Klausennische	YES	<25	back	cortex unworked	YES	bifacial
BU-073	core	Bockstein	YES	<25	back	cortex unworked	YES	unifacial
BU-073	core	N/A	NO	N/A	N/A	cortex unworked	YES	bifacial
BU-074	flake	Buhlen	YES	25-50	back	cortex unworked	YES	semi-bifacial
BU-075	core	Klausennische	YES	<25	back	cortex partly retouched	YES	bifacial
BU-076	core	Klausennische	NO	N/A	N/A	partly retouched	YES	bifacial
BU-077	core	Pradnik	YES	<25	back	cortex unworked	YES	bifacial
BU-078	core	Balve	YES	<25	base	partly retouched	YES	bifacial

ID	tip morphology	application Pradnik method	frequency application Pradnik method	tool lateral-isation	length [mm]	width [mm]	thick-ness [mm]	weight [kg]
BU-067	rounded	YES	one	dex.	36.0	28.0	14.0	0.0159
BU-068	N/A	YES	one	dex.	42.0	23.0	11.0	0.0119
BU-069	pointed	YES	one	dex.	45.0	26.0	9.0	0.0103
BU-070	rounded	YES	one	dex.	45.0	28.0	13.0	0.0203
BU-071	pointed	YES	one	dex.	40.0	22.0	13.0	0.0105
BU-072	pointed	YES	one	dex.	43.0	28.0	15.0	0.0117
BU-073	rounded	NO	N/A	dex.	68.0	48.0	21.0	0.049
BU-073	rounded	YES	one	dex.	51.0	29.0	14.0	0.0215
BU-074	pointed	YES	one	dex.	30.0	20.0	9.0	0.057
BU-075	rounded	NO	N/A	sin.	62.0	37.0	26.0	0.0571
BU-076	pointed	NO	N/A	sin.	66.0	38.0	17.0	0.0452
BU-077	rounded	YES	one	sin.	44.0	33.0	16.0	0.0208
BU-078	rounded	YES	one	sin.	47.0	30.0	14.0	0.0227

ID	peri-meter basis + back [cm]	peri-meter distal posterior part [cm]	peri-meter active edge [cm]	thick-ness back [mm]	taphonomic visual inspection	tool edges preser-vation	use-wear analysis	3D-scan	schist-osety
BU-067	5.2	2.0	3.4	6.0	sharp edges and preserved surface	edges preserved	NO	NO	NO
BU-068	5.9	1.5	4.0	11.0	sharp edges and preserved surface	edges preserved	NO	NO	NO
BU-069	6.0	1.8	3.8	7.0	sharp edges and preserved surface	edges preserved	YES	YES	YES
BU-070	5.7	2.6	4.0	12.0	sharp edges and preserved surface	edges preserved	NO	YES	NO
BU-071	6.5	2.5	3.7	6.0	sharp edges and preserved surface	edges preserved	NO	NO	NO
BU-072	5.8	2.4	3.0	14.0	sharp edges and preserved surface	edges preserved	YES	YES	NO
BU-073	8.5	1.2	7.6	21.0	sharp edges and preserved surface	edges preserved	NO	YES	NO
BU-073	6.3	3.5	5.1	13.0	sharp edges and preserved surface	edges preserved	NO	NO	NO
BU-074	3.6	1.0	3.2	7.0	sharp edges and preserved surface	edges preserved	YES	YES	NO
BU-075	10.4	3.5	5.8	26.0	sharp edges and preserved surface	edges preserved	YES	YES	NO
BU-076	6.8	3.3	6.2	16.0	sharp edges and preserved surface	edges preserved	YES	YES	NO
BU-077	6.8	2.4	4.1	14.0	sharp edges and preserved surface	edges preserved	YES	YES	NO
BU-078	5.0	2.2	4.7	8.0	sharp edges and preserved surface	edges preserved	YES	YES	NO

ID	loan	excavation year	artefact labelling	stratigraphy	level	artefact drawing	raw material	artefact state
BU-079	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 162 IIIb	YES	III b	NO	silicified schist	complete
BU-080	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 /128 F	N/A	N/A	NO	silicified schist	complete
BU-081	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 169 IIIb2 53	YES	III b	NO	silicified schist	distal fragment
BU-082	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 166 IIIc 70-80	YES	III c	YES by Jöris	silicified schist	Keilmesser tip
BU-083	Depot Hessisches Landesmuseum Kassel	N/A	Bu ?? 138 II	YES	II	NO	silicified schist	Keilmesser tip
BU-084	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 165 III c1	YES	III c	YES by Jöris	silicified schist	Keilmesser tip
BU-085	Depot Hessisches Landesmuseum Kassel	1960s	Bu66 117 IIIb	YES	III b	NO	silicified schist	Keilmesser tip
BU-086	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 169 IIIb2	YES	III b	YES by Jöris	silicified schist	Keilmesser tip
BU-087	Depot Hessisches Landesmuseum Kassel	1960s	Bu66 117 IIIb x	YES	III b	NO	silicified schist	Keilmesser tip
BU-088	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 /138 II	YES	II	NO	silicified schist	Keilmesser tip
BU-089	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 162 IIIb2 /84	YES	III b	NO	silicified schist	proximal fragment
BU-090	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 172 IIIb2	YES	III b	YES by Jöris	silicified schist	Keilmesser tip
BU-091	Depot Hessisches Landesmuseum Kassel	1960s	Bu69 III	YES	III	YES by Jöris	silicified schist	Keilmesser tip

ID	blank	*Keilmesser* shape	cortex	cortex percentage	cortex location	morpho-logy back	retouch active edge	retouch type edge
BU-079	flake	Pradnik	NO	N/A	N/A	cortex partly retouched	YES	bifacial
BU-080	core	Pradnik	YES	<25	back	cortex partly retouched	YES	bifacial
BU-081	N/A	N/A	NO	N/A	N/A	N/A	N/A	N/A
BU-082	N/A	N/A	NO	N/A	N/A	N/A	YES	bifacial
BU-083	N/A	N/A	NO	N/A	N/A	N/A	YES	bifacial
BU-084	N/A	N/A	NO	N/A	N/A	N/A	YES	bifacial
BU-085	N/A	N/A	NO	N/A	N/A	N/A	YES	bifacial
BU-086	N/A	N/A	NO	N/A	N/A	N/A	YES	semi-bifacial
BU-087	N/A	N/A	YES	N/A	back	N/A	YES	bifacial
BU-088	N/A	N/A	YES	N/A	back	N/A	YES	bifacial
BU-089	flake	N/A	NO	N/A	N/A	N/A	N/A	N/A
BU-090	N/A	N/A	NO	N/A	N/A	N/A	YES	bifacial
BU-091	N/A	N/A	NO	N/A	N/A	N/A	YES	bifacial

ID	tip morphology	application Pradnik method	frequency application Pradnik method	tool lateral-isation	length [mm]	width [mm]	thick-ness [mm]	weight [kg]
BU-079	rounded	YES	one	sin.	62.0	31.0	12.0	0.0244
BU-080	rounded	NO	N/A	sin.	47.0	25.0	16.0	0.0223
BU-081	rounded	N/A	N/A	dex.	22.0	44.0	12.0	0.0074
BU-082	rounded	N/A	N/A	dex.	18.0	32.0	12.0	0.0072
BU-083	rounded	YES	one	dex.	26.0	42.0	13.0	0.011
BU-084	pointed	NO	N/A	N/A	28.0	30.0	13.0	0.0093
BU-085	rounded	NO	N/A	dex.	28.0	27.0	8.0	0.007
BU-086	rounded	YES	one	dex.	19.0	28.0	10.0	0.0063
BU-087	rounded	YES	one	dex.	46.0	34.0	11.0	0.0169
BU-088	rounded	YES	one	dex.	30.0	32.0	10.0	0.0098
BU-089	N/A	N/A	N/A	N/A	25.0	38.0	10.0	0.0095
BU-090	rounded	YES	one	dex.	23.0	19.0	9.0	0.0071
BU-091	rounded	YES	one	dex.	13.0	30.0	11.0	0.0055

ID	peri-meter basis + back [cm]	peri-meter distal posterior part [cm]	peri-meter active edge [cm]	thick-ness back [mm]	taphonomic visual inspection	tool edges preser-vation	use-wear analysis	3D-scan	schist-osety
BU-079	6.2	2.1	7.1	12.0	sharp edges and preserved surface	edges preserved	YES	YES	NO
BU-080	5.3	2.0	5.0	14.0	sharp edges and preserved surface	edges preserved	NO	NO	NO
BU-081	0.0	0.0	0.0	0.0	sharp edges and preserved surface	edges preserved	NO	NO	NO
BU-082	0.0	0.0	0.0	0.0	sharp edges and preserved surface	edges preserved	NO	YES	NO
BU-083	0.0	0.0	0.0	0.0	sharp edges and preserved surface	edges preserved	YES	YES	NO
BU-084	0.0	0.0	0.0	0.0	sharp edges and preserved surface	edges preserved	NO	NO	NO
BU-085	0.0	0.0	0.0	0.0	sharp edges and preserved surface	edges preserved	YES	YES	NO
BU-086	0.0	0.0	0.0	0.0	sharp edges and preserved surface	edges preserved	YES	YES	NO
BU-087	0.0	0.0	0.0	0.0	sharp edges and preserved surface	edges preserved	YES	YES	NO
BU-088	0.0	0.0	0.0	0.0	sharp edges and preserved surface	edges preserved	YES	YES	NO
BU-089	0.0	0.0	0.0	0.0	sharp edges and preserved surface	edges preserved	NO	NO	NO
BU-090	0.0	0.0	0.0	0.0	sharp edges and preserved surface	edges preserved	YES	YES	NO
BU-091	0.0	0.0	0.0	0.0	sharp edges and preserved surface	edges preserved	NO	NO	NO

ID	loan	excavation year	artefact labelling	stratigraphy	level	artefact drawing	raw material	artefact state
BU-092	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 160 IIIc 0-10?	YES	III c	NO	silicified schist	Keilmesser tip
BU-093	Depot Hessisches Landesmuseum Kassel	1960s	Bu66 118 IIIb	YES	III b	YES by unknown	silicified schist	Keilmesser tip
BU-094	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 172 IIIb2 ...	YES	III b	YES by Jöris	silicified schist	Keilmesser tip
BU-095	Depot Hessisches Landesmuseum Kassel	1960s	Bu66 119 IIIb	YES	III b	NO	silicified schist	Keilmesser tip
BU-096	Depot Hessisches Landesmuseum Kassel	1960s	Bu66 118 IIIb	YES	III b	NO	silicified schist	Keilmesser tip
BU-097	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 /127 E	N/A	N/A	NO	silicified schist	Keilmesser tip
BU-098	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 168 IIIb2 /9	YES	III b	NO	silicified schist	proximal fragment
BU-158	Ausstellung Hessisches Landesmuseum Kassel	1960s	Bu67 /120 IIIb7 x	YES	III b	YES by Jöris	silicified schist	complete
BU-160	Ausstellung Hessisches Landesmuseum Kassel	1960s	Bu66 117 IIIb	YES	III b	YES by Jöris	silicified schist	complete
BU-161	Ausstellung Hessisches Landesmuseum Kassel	1960s	Bu 67 100L	N/A	N/A	YES by Jöris	silicified schist	complete
BU-162	Ausstellung Hessisches Landesmuseum Kassel	1960s	Bu67 1446	N/A	N/A	YES by Jöris	silicified schist	complete
BU-163	Ausstellung Hessisches Landesmuseum Kassel	1960s	Bu67 171 IIIb2/17	YES	III b	YES by Jöris	silicified schist	complete
BU-164	Ausstellung Hessisches Landesmuseum Kassel	1960s	Bu67 162 IIIb2 86 x	YES	III b	YES by Jöris	silicified schist	complete

ID	blank	*Keilmesser* shape	cortex	cortex percentage	cortex location	morpho-logy back	retouch active edge	retouch type edge
BU-092	N/A	N/A	NO	N/A	N/A	N/A	YES	bifacial
BU-093	N/A	N/A	NO	N/A	N/A	N/A	YES	bifacial
BU-094	N/A	N/A	NO	N/A	N/A	N/A	YES	bifacial
BU-095	N/A	N/A	YES	N/A	back	N/A	YES	bifacial
BU-096	N/A	N/A	NO	N/A	N/A	N/A	YES	semi-bifacial
BU-097	N/A	N/A	NO	N/A	N/A	N/A	YES	bifacial
BU-098	core	N/A	NO	N/A	N/A	N/A	YES	bifacial
BU-158	core	Pradnik	YES	25-50	base	cortex unworked	YES	bifacial
BU-160	core	Pradnik	YES	<25	base	cortex unworked	YES	bifacial
BU-161	core	Buhlen	YES	<25	back	cortex unworked	YES	bifacial
BU-162	core	Klausennische	YES	50-75	back	cortex unworked	YES	bifacial
BU-163	core	Pradnik	YES	<25	back	cortex partly retouched	YES	bifacial
BU-164	core	Balve	YES	<25	back	cortex partly retouched	YES	bifacial

ID	tip morphology	application Pradnik method	frequency application Pradnik method	tool lateral-isation	length [mm]	width [mm]	thick-ness [mm]	weight [kg]
BU-092	rounded	NO	N/A	N/A	29.0	36.0	13.0	0.0133
BU-093	pointed	YES	one	dex.	30.0	25.0	13.0	0.0071
BU-094	rounded	NO	N/A	dex.	23.0	23.0	14.0	0.007
BU-095	rounded	N/A	N/A	dex.	42.0	40.0	20.0	0.0235
BU-096	pointed	YES	one	dex.	35.0	20.0	14.0	0.0078
BU-097	rounded	NO	N/A	dex.	31.0	32.0	18.0	0.0161
BU-098	N/A	N/A	N/A	dex.	54.0	54.0	26.0	0.0659
BU-158	rounded	YES	one	dex.	80.0	50.0	24.0	0.0073
BU-160	rounded	YES	one	dex.	68.0	41.0	18.0	0.0489
BU-161	rounded	N/A	N/A	dex.	79.2	47.6	14.1	0.0618
BU-162	pointed	NO	N/A	dex.	68.4	35.5	20.4	0.0414
BU-163	rounded	N/A	N/A	dex.	113.5	48.8	19.5	0.1202
BU-164	rounded	YES	one	dex.	68.3	43.0	15.8	0.0474

ID	peri-meter basis + back [cm]	peri-meter distal posterior part [cm]	peri-meter active edge [cm]	thick-ness back [mm]	taphonomic visual inspection	tool edges preser-vation	use-wear analysis	3D-scan	schist-osety
BU-092	0.0	0.0	0.0	0.0	sharp edges and preserved surface	edges preserved	NO	NO	NO
BU-093	0.0	0.0	0.0	0.0	sharp edges and preserved surface	edges preserved	YES	YES	NO
BU-094	0.0	0.0	0.0	0.0	sharp edges and preserved surface	edges preserved	NO	NO	NO
BU-095	0.0	0.0	0.0	0.0	sharp edges and preserved surface	edges preserved	NO	NO	NO
BU-096	0.0	0.0	0.0	0.0	sharp edges and preserved surface	edges preserved	NO	NO	NO
BU-097	0.0	0.0	0.0	0.0	sharp edges and preserved surface	edges preserved	YES	YES	NO
BU-098	0.0	0.0	0.0	0.0	sharp edges and preserved surface	edges preserved	NO	NO	NO
BU-158	10.5	2.4	8.0	10.0	sharp edges and preserved surface	edges preserved	YES	YES	YES
BU-160	7.6	3.9	6.7	15.0	sharp edges and preserved surface	edges preserved	YES	YES	YES
BU-161	7.6	5.6	5.6	14.2	sharp edges and preserved surface	edges preserved	NO	YES	YES
BU-162	9.6	1.5	6.5	17.8	sharp edges and preserved surface	edges preserved	YES	YES	YES
BU-163	12.0	5.2	11.3	11.1	sharp edges and preserved surface	edges preserved	YES	YES	YES
BU-164	7.7	4.0	6.0	9.9	sharp edges and preserved surface	edges preserved	YES	YES	N/A

ID	loan	excavation year	artefact labelling	stratigraphy	level	artefact drawing	raw material	artefact state
BU-165	Ausstellung Hessisches Landesmuseum Kassel	1960s	Bu67 143 IIIb2 /48	YES	III b	NO	silicified schist	semifinished product
BU-166	Ausstellung Hessisches Landesmuseum Kassel	1960s	Bu67 /121 IIIb2 x	YES	III b	YES by Jöris	silicified schist	complete
BU-168	Ausstellung Hessisches Landesmuseum Kassel	1960s	Bu67 175IIIb2	YES	III b	YES by Jöris	silicified schist	complete
BU-170	Ausstellung Hessisches Landesmuseum Kassel	1960s	Bu66 118 IIIb x	YES	III b	NO	silicified schist	complete
BU-171	Ausstellung Hessisches Landesmuseum Kassel	1960s	Bu69 /187 II 20-30	YES	II	YES by Jöris	silicified schist	complete
BU-172	Ausstellung Hessisches Landesmuseum Kassel	1960s	Bu67 /144 IIIb /11 x	YES	III b	YES by Jöris	silicified schist	complete
BU-173	Ausstellung Hessisches Landesmuseum Kassel	1960s	Bu66 117 IIIb	YES	III b	YES by Jöris	silicified schist	complete
BU-174	Ausstellung Hessisches Landesmuseum Kassel	1960s	Bu67 138 IIIb2/43 x	YES	III b	YES by Jöris	silicified schist	complete
BU-199	Ausstellung Hessisches Landesmuseum Kassel	1960s	Bu66 108 III2 x	YES	III	YES by Jöris	silicified schist	complete
BU-175	Ausstellung Hessisches Landesmuseum Kassel	1960s	Bu67 172 IIIb2/39 x	YES	III b	YES by Jöris	silicified schist	complete
BU-176	Ausstellung Hessisches Landesmuseum Kassel	1960s	Bu67 138 IIIb2/116	YES	III b	YES by Jöris	silicified schist	complete
BU-177	Ausstellung Hessisches Landesmuseum Kassel	1960s	Bu66 120 IIIb	YES	III b	YES by Jöris	silicified schist	complete
BU-178	Ausstellung Hessisches Landesmuseum Kassel	1960s	Bu67 IIIb	YES	III b	YES by Jöris	silicified schist	complete

ID	blank	*Keilmesser* shape	cortex	cortex percentage	cortex location	morphology back	retouch active edge	retouch type edge
BU-165	core	N/A	YES	<25	base	partly retouched	YES	semi-bifacial
BU-166	core	Klausennische	YES	<25	medial ventral	cortex partly retouched	YES	bifacial
BU-168	core	Klausennische	YES	<25	back	partly retouched	YES	bifacial
BU-170	core	Bockstein	YES	25-50	base	cortex partly retouched	YES	bifacial
BU-171	core	Buhlen	YES	50-75	medial dorsal	cortex partly retouched	YES	bifacial
BU-172	core	Pradnik	YES	<25	back	cortex partly retouched	YES	bifacial
BU-173	core	Buhlen	YES	<25	base	partly retouched	YES	bifacial
BU-174	core	Balve	YES	<25	base	cortex partly retouched	YES	bifacial
BU-199	core	Buhlen	NO	N/A	N/A	retouched	YES	bifacial
BU-175	core	Pradnik	NO	N/A	N/A	retouched	YES	bifacial
BU-176	core	Balve	YES	<25	base	retouched	YES	bifacial
BU-177	core	Pradnik	NO			cortex unworked	YES	semi-bifacial
BU-178	core	Pradnik	YES	<25	base	retouched	YES	bifacial

ID	tip morphology	application Pradnik method	frequency application Pradnik method	tool lateral-isation	length [mm]	width [mm]	thick-ness [mm]	weight [kg]
BU-165	pointed	N/A	N/A	dex.	82.6	52.4	17.4	0.0865
BU-166	pointed	NO	N/A	dex.	106.4	47.3	24.0	0.1287
BU-168	rounded	YES	one	dex.	49.8	38.1	19.8	0.0419
BU-170	pointed	YES	one	dex.	69.8	36.8	24.7	0.0441
BU-171	pointed	YES	one	sin.	84.1	71.9	21.0	0.1223
BU-172	rounded	YES	multiple	dex.	101.9	46.2	27.2	0.1224
BU-173	rounded	YES	multiple	dex.	56.5	49.0	24.8	0.0619
BU-174	rounded	YES	multiple	dex.	42.0	32.9	12.2	0.02
BU-199	rounded	YES	one	dex.	57.8	41.5	11.7	0.0262
BU-175	rounded	YES	multiple	dex.	63.6	33.8	14.9	0.0315
BU-176	rounded	YES	one	dex.	52.3	40.1	18.6	0.033
BU-177	rounded	N/A	N/A	dex.	33.1	17.7	17.2	0.0104
BU-178	rounded	YES	one	dex.	79.2	38.0	17.6	0.0469

ID	peri-meter basis + back [cm]	peri-meter distal posterior part [cm]	peri-meter active edge [cm]	thick-ness back [mm]	taphonomic visual inspection	tool edges preser-vation	use-wear analysis	3D-scan	schist-osety
BU-165	0.0	0.0	7.5	13.7	sharp edges and patinated surface	edges preserved	NO	YES	NO
BU-166	10.3	5.8	11.2	12.9	sharp edges and preserved surface	edges preserved	YES	YES	YES
BU-168	7.9	1.8	5.6	18.5	sharp edges and preserved surface	edges preserved	YES	YES	YES
BU-170	10.8	1.5	5.6	14.8	sharp edges and preserved surface	edges preserved	NO	YES	NO
BU-171	8.2	9.2	8.3	12.4	sharp edges and preserved surface	edges preserved	YES	YES	N/A
BU-172	11.1	5.4	9.0	26.8	sharp edges and preserved surface	edges preserved	YES	YES	NO
BU-173	6.5	5.5	5.7	18.3	sharp edges and preserved surface	edges preserved	YES	YES	NO
BU-174	5.3	3.3	3.7	7.6	sharp edges and preserved surface	edges preserved	YES	YES	NO
BU-199	5.3	5.3	5.5	12.9	sharp edges and preserved surface	edges preserved	NO	YES	NO
BU-175	8.0	2.7	5.8	7.8	sharp edges and preserved surface	edges preserved	NO	YES	NO
BU-176	6.9	4.3	5.3	4.6	sharp edges and preserved surface	edges preserved	NO	YES	YES
BU-177	4.0	1.7	3.0	17.2	sharp edges and preserved surface	edges preserved	YES	YES	NO
BU-178	7.5	4.5	7.8	16.1	sharp edges and preserved surface	edges preserved	YES	YES	N/A

ID	loan	excavation year	artefact labelling	stratigraphy	level	artefact drawing	raw material	artefact state
BU-179	Ausstellung Hessisches Landesmuseum Kassel	1960s	Bu66 119 II?	N/A	N/A	YES by Jöris	silicified schist	complete
BU-180	Ausstellung Hessisches Landesmuseum Kassel	1960s	Bu67 /139 II	YES	II	YES by Jöris	silicified schist	complete
BU-181	Ausstellung Hessisches Landesmuseum Kassel	1960s	Bu67 158 IIb-6	YES	II b	YES by Jöris	silicified schist	complete
BU-182	Ausstellung Hessisches Landesmuseum Kassel	1960s	Bu67 143 Z	No	N/A	YES by Jöris	silicified schist	complete
BU-183	Ausstellung Hessisches Landesmuseum Kassel	1960s	Bu67 145 IIIb 2-1	YES	III b	YES by Jöris	silicified schist	complete
BU-184	Ausstellung Hessisches Landesmuseum Kassel	1960s	Bu67 138 IIIb2 107	YES	III b	YES by Jöris	silicified schist	complete
BU-185	Ausstellung Hessisches Landesmuseum Kassel	1960s	Bu67 139 IIIb 3	YES	III b	YES by Jöris	silicified schist	complete
BU-186	Ausstellung Hessisches Landesmuseum Kassel	1960s	Bu67 143 IIIb 2/44 x	YES	III b	YES by Jöris	silicified schist	complete
BU-187	Ausstellung Hessisches Landesmuseum Kassel	1960s	Bu67 /120 IIIb x	YES	III b	YES by Jöris	silicified schist	complete
BU-188	Ausstellung Hessisches Landesmuseum Kassel	1960s	Bu67 169 IIIb2/7	YES	III b	NO	Baltic flint	complete
BU-190	Ausstellung Hessisches Landesmuseum Kassel	1960s	Bu67 120 IIIb	YES	III b	NO	silicified schist	complete
BU-191	Ausstellung Hessisches Landesmuseum Kassel	1960s	Bu66 118 IIIb	YES	III b	NO	silicified schist	complete
BU-198	Ausstellung Hessisches Landesmuseum Kassel	1960s	Bu67 /120 IIIb x	YES	III b	YES by Jöris	silicified schist	complete

ID	blank	*Keilmesser* shape	cortex	cortex percentage	cortex location	morpho-logy back	retouch active edge	retouch type edge
BU-179	core	Pradnik	YES	<25	back	cortex partly retouched	YES	bifacial
BU-180	core	Pradnik	NO	N/A	N/A	retouched	YES	bifacial
BU-181	core	Pradnik	NO	N/A	N/A	partly retouched	YES	bifacial
BU-182	core	Pradnik	NO	N/A	N/A	retouched	YES	bifacial
BU-183	N/A	Pradnik	YES	<25	proximal dorsal	cortex partly retouched	YES	bifacial
BU-184	N/A	Buhlen	NO	N/A	N/A	cortex partly retouched	YES	bifacial
BU-185	core	Klausennische	NO	N/A	N/A	retouched	YES	bifacial
BU-186	core	Pradnik	YES	25-50	base	cortex unworked	YES	bifacial
BU-187	core	Pradnik	NO	N/A	N/A	retouched	YES	bifacial
BU-188	core	Lichtenberg	YES	<25	base	partly retouched	YES	unifacial
BU-190	N/A	Lichtenberg	NO	N/A	N/A	partly retouched	YES	bifacial
BU-191	N/A	Balve	NO	N/A	N/A	cortex unworked	YES	bifacial
BU-198	N/A	Pradnik	NO	N/A	N/A	retouched	YES	bifacial

ID	tip morphology	application Pradnik method	frequency application Pradnik method	tool lateral-isation	length [mm]	width [mm]	thick-ness [mm]	weight [kg]
BU-179	rounded	N/A	N/A	sin.	46.2	23.7	12.1	0.0155
BU-180	rounded	YES	one	dex.	84.5	41.1	15.0	0.0489
BU-181	rounded	NO	N/A	dex.	50.1	32.9	16.3	0.0274
BU-182	rounded	N/A	N/A	dex.	43.3	27.9	13.2	0.0145
BU-183	rounded	YES	one	dex.	56.4	32.1	16.2	0.029
BU-184	rounded	YES	one	dex.	30.3	23.2	8.3	0.006
BU-185	pointed	NO	N/A	dex.	65.7	35.8	20.0	0.0477
BU-186	rounded	NO	N/A	dex.	46.2	27.7	24.5	0.0254
BU-187	rounded	YES	one	dex.	40.4	24.8	13.6	0.0137
BU-188	rounded	NO	N/A	sin.	42.1	23.5	12.4	0.0136
BU-190	rounded	NO	N/A	sin.	43.6	29.4	13.0	0.0172
BU-191	pointed	YES	one	dex.	51.4	25.5	9.8	0.0107
BU-198	rounded	YES	one	dex.	51.87	29.1	13.53	0.0235

ID	peri-meter basis + back [cm]	peri-meter distal posterior part [cm]	peri-meter active edge [cm]	thick-ness back [mm]	taphonomic visual inspection	tool edges preser-vation	use-wear analysis	3D-scan	schist-osety
BU-179	5.2	2.4	4.5	6.8	sharp edges and preserved surface	edges preserved	NO	YES	YES
BU-180	8.5	5.3	8.0	6.4	sharp edges and preserved surface	edges preserved	YES	YES	NO
BU-181	6.5	3.0	5.2	13.6	sharp edges and preserved surface	edges preserved	NO	YES	YES
BU-182	4.2	3.3	4.5	7.6	sharp edges and preserved surface	edges preserved	NO	YES	NO
BU-183	5.9	3.0	5.9	7.9	sharp edges and preserved surface	edges preserved	NO	YES	YES
BU-184	3.3	3.0	3.1	4.2	sharp edges and preserved surface	edges preserved	YES	YES	NO
BU-185	8.0	3.5	6.3	8.6	sharp edges and preserved surface	edges preserved	NO	YES	YES
BU-186	6.0	2.5	4.6	20.4	sharp edges and preserved surface	edges preserved	NO	YES	NO
BU-187	4.0	2.6	4.4	5.8	sharp edges and preserved surface	edges preserved	NO	YES	YES
BU-188	4.5	2.0	4.9	8.3	sharp edges and preserved surface	edges preserved	YES	YES	N/A
BU-190	5.0	2.3	3.5	6.0	sharp edges and patinated surface	edges preserved	NO	YES	NO
BU-191	4.1	3.4	5.8	9.7	sharp edges and patinated surface	edges preserved	NO	YES	NO
BU-198	5.4	3.3	4.9	7.4	sharp edges and preserved surface	edges preserved	NO	YES	NO

ID	loan	exca-vation year	artefact labelling	strati-graphy	level	artefact drawing	raw material	artefact state
BU-099	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 163 IIIc 0-10	YES	III c	YES by Jöris	silicified schist	complete
BU-100	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 /138 IIIb2 /72	YES	III b	NO	silicified schist	complete
BU-101	Depot Hessisches Landesmuseum Kassel	1960s	Bu66 119 IIIb x	YES	III b	NO	silicified schist	complete
BU-102	Depot Hessisches Landesmuseum Kassel	1960s	BU6? 168 IIIb2 10	YES	III b	YES by Jöris	silicified schist	complete
BU-103	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 /120 IIIb	YES	III b	NO	silicified schist	complete
BU-104	Depot Hessisches Landesmuseum Kassel	1960s	Bu66 119 IIIb	YES	III b	NO	silicified schist	complete
BU-105	Depot Hessisches Landesmuseum Kassel	1960s	BU67 143 IIIb /70 x	YES	III b	NO	silicified schist	complete
BU-106	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 /168 IIIb2 33	YES	III b	YES by Jöris	silicified schist	complete
BU-107	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 /144 I	YES	I	YES by Jöris	silicified schist	complete
BU-108	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 172 IIIb2 444	YES	III b	YES by unknown	silicified schist	complete
BU-109	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 143 IIIb2 :	YES	III b	NO	silicified schist	complete
BU-110	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 163 II	YES	II	YES by unknown	silicified schist	complete
BU-111	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 143 IIIb2 /22	YES	III b	NO	silicified schist	complete

ID	blank	cortex	cortex percentage	cortex location	morpho-logy back	retouch active edge	retouch type edge
BU-099	flake	NO	N/A	N/A	retouched	YES	unifacial
BU-100	flake	NO	N/A	N/A	retouched	YES	unifacial
BU-101	flake	NO	N/A	N/A	retouched	YES	unifacial
BU-102	flake	NO	N/A	N/A	partly retouched	YES	unifacial
BU-103	flake	YES	<25	base	partly retouched	YES	unifacial
BU-104	flake	NO	N/A	N/A	partly retouched	YES	unifacial
BU-105	flake	YES	<25	back	cortex partly retouched	YES	unifacial
BU-106	flake	YES	<25	back	cortex unworked	YES	semi-bifacial
BU-107	flake	NO	N/A	N/A	partly retouched	YES	semi-bifacial
BU-108	flake	NO	N/A	N/A	partly retouched	YES	unifacial
BU-109	flake	NO	N/A	N/A	partly retouched	YES	bifacial
BU-110	flake	NO	N/A	N/A	retouched	YES	unifacial
BU-111	flake	YES	<25	back	cortex unworked	YES	semi-bifacial

ID	tip morphology	application Pradnik method	frequency application Pradnik method	tool lateral-isation	length [mm]	width [mm]	thick-ness [mm]	weight [kg]
BU-099	rounded	YES	one	dex.	32.0	22.0	7.0	0.0063
BU-100	pointed	YES	one	dex.	38.0	25.0	4.0	0.0044
BU-101	pointed	YES	one	dex.	33.0	22.0	8.0	0.0049
BU-102	pointed	YES	one	dex.	37.0	29.0	7.0	0.0105
BU-103	rounded	YES	one	dex.	57.0	29.0	10.0	0.0147
BU-104	rounded	YES	one	dex.	42.0	23.0	10.0	0.0111
BU-105	pointed	YES	one	dex.	57.0	31.0	8.0	0.0156
BU-106	rounded	YES	one	dex.	45.0	24.0	11.0	0.0122
BU-107	pointed	YES	one	dex.	34.0	26.0	10.0	0.0088
BU-108	rounded	YES	one	N/A	37.0	29.0	10.0	0.0113
BU-109	rounded	YES	one	dex.	27.0	18.0	7.0	0.003
BU-110	rounded	YES	one	dex.	78.0	48.0	13.0	0.0605
BU-111	pointed	YES	one	dex.	38.0	24.0	11.0	0.0104

ID	thick-ness back [mm]	taphonomic visual inspection	tool edges preservation	use-wear analysis	3D-scan	schist-osety
BU-099	7.0	sharp edges and preserved surface	edges preserved	YES	YES	NO
BU-100	1.0	sharp edges and preserved surface	edges preserved	YES	YES	NO
BU-101	3.0	sharp edges and preserved surface	edges preserved	YES	YES	NO
BU-102	5.0	sharp edges and preserved surface	edges preserved	NO	NO	NO
BU-103	4.0	sharp edges and preserved surface	edges preserved	YES	YES	NO
BU-104	5.0	sharp edges and preserved surface	edges preserved	YES	YES	NO
BU-105	8.0	sharp edges and preserved surface	edges preserved	YES	YES	NO
BU-106	10.0	sharp edges and preserved surface	edges preserved	YES	YES	NO
BU-107	3.0	sharp edges and preserved surface	edges preserved	YES	YES	NO
BU-108	8.0	sharp edges and preserved surface	edges preserved	NO	NO	NO
BU-109	3.0	sharp edges and preserved surface	edges preserved	NO	NO	NO
BU-110	5.0	sharp edges and preserved surface	edges preserved	YES	YES	NO
BU-111	11.0	sharp edges and preserved surface	edges preserved	NO	NO	NO

ID	loan	exca-vation year	artefact labelling	strati-graphy	level	artefact drawing	raw material	artefact state
BU-112	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 144 I	YES	I	NO	silicified schist	complete
BU-113	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 120 IIIb	YES	III b	NO	silicified schist	complete
BU-114	Depot Hessisches Landesmuseum Kassel	1960s	BU67 159 IIIb 2	YES	III b	NO	silicified schist	complete
BU-115	Depot Hessisches Landesmuseum Kassel	1960s	Bu66 108 x	N/A	N/A	YES by unknown	silicified schist	complete
BU-116	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 120 IIIb	YES	III b	NO	silicified schist	complete
BU-117	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 172 IIIc	YES	III c	YES by unknown	silicified schist	complete
BU-118	Depot Hessisches Landesmuseum Kassel	1960s	BU67 171 IIIb2 44	YES	III b	NO	silicified schist	complete
BU-159	Ausstellung Hessisches Landesmuseum Kassel	1960s	Bu67 /162 IIIb1/10	YES	III b	YES by Jöris	silicified schist	complete
BU-167	Ausstellung Hessisches Landesmuseum Kassel	1960s	Bu66 118IIIb x	YES	III b	YES by Jöris	silicified schist	complete
BU-193	Ausstellung Hessisches Landesmuseum Kassel	1960s	Bu67 /166 II	YES	II	YES by Jöris	silicified schist	complete
BU-194	Ausstellung Hessisches Landesmuseum Kassel	1960s	Bu? 119 IIIb	YES	III b	YES by Jöris	silicified schist	complete

ID	blank	cortex	cortex percentage	cortex location	morpho-logy back	retouch active edge	retouch type edge
BU-112	flake	NO	N/A	N/A	partly retouched	YES	unifacial
BU-113	flake	NO	N/A	N/A	retouched	YES	bifacial
BU-114	flake	YES	<25	back	cortex partly retouched	YES	semi-bifacial
BU-115	flake	NO	N/A	N/A	retouched	YES	bifacial
BU-116	flake	NO	N/A	N/A	partly retouched	YES	semi-bifacial
BU-117	flake	NO	N/A	N/A	cortex unworked	YES	semi-bifacial
BU-118	flake	NO	N/A	N/A	retouched	YES	semi-bifacial
BU-159	flake	NO	N/A	N/A	partly retouched	YES	unifacial
BU-167	flake	NO	N/A	N/A	retouched	YES	bifacial
BU-193	flake	NO	N/A	N/A	partly retouched	YES	bifacial
BU-194	flake	NO	N/A	N/A	retouched	YES	bifacial

ID	tip morphology	application Pradnik method	frequency application Pradnik method	tool lateral-isation	length [mm]	width [mm]	thick-ness [mm]	weight [kg]
BU-112	rounded	YES	one	dex.	31.0	28.0	9.0	0.0076
BU-113	rounded	YES	one	dex.	46.0	25.0	11.0	0.013
BU-114	rounded	YES	multiple	N/A	43.0	29.0	9.0	0.014
BU-115	rounded	YES	one	dex.	46.0	26.0	9.0	0.014
BU-116	rounded	YES	one	dex.	37.0	27.0	8.0	0.0085
BU-117	rounded	YES	one	sin.	33.0	29.0	8.0	0.0081
BU-118	rounded	YES	one	sin.	57.0	29.0	10.0	0.018
BU-159	rounded	YES	one	dex.	41.0	36.0	6.0	0.0013
BU-167	rounded	YES	multiple	sin.	47.9	37.9	9.1	0.0216
BU-193	rounded	YES	one	dex.	41.8	27.5	9.7	0.0109
BU-194	rounded	YES	multiple	dex.	65.0	39.2	15.8	0.0365

ID	thick-ness back [mm]	taphonomic visual inspection	tool edges preservation	use-wear analysis	3D-scan	schist-osety
BU-112	3.0	sharp edges and preserved surface	edges preserved	NO	NO	NO
BU-113	6.0	sharp edges and preserved surface	edges preserved	NO	NO	NO
BU-114	10.0	sharp edges and preserved surface	edges preserved	NO	NO	NO
BU-115	4.0	sharp edges and preserved surface	edges preserved	YES	YES	NO
BU-116	4.0	sharp edges and preserved surface	edges preserved	NO	YES	NO
BU-117	6.0	sharp edges and preserved surface	edges preserved	YES	YES	NO
BU-118	6.0	sharp edges and preserved surface	edges preserved	YES	YES	NO
BU-159	6.0	sharp edges and preserved surface	edges preserved	NO	YES	NO
BU-167	5.4	sharp edges and preserved surface	edges preserved	NO	YES	N/A
BU-193	3.0	sharp edges and preserved surface	edges preserved	YES	YES	NO
BU-194	5.5	sharp edges and preserved surface	edges preserved	YES	YES	YES

ID	loan	exca-vation year	artefact labelling	strati-graphy	level	artefact drawing	raw material	artefact state
BU-120	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 /119 IIIc2	YES	III c	NO	silicified schist	complete
BU-121	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 /120 IIIb	YES	III b	YES by Jöris	silicified schist	complete
BU-122	Depot Hessisches Landesmuseum Kassel	1960s	Bu66 117 IIIb	YES	III b	NO	silicified schist	complete
BU-123	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 120 IIIb 1002	YES	III b	NO	silicified schist	complete
BU-124	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 /144 IIIb 34	YES	III b	NO	silicified schist	complete
BU-125	Depot Hessisches Landesmuseum Kassel	1960s	Bu66 119 IIIb 44	YES	III b	NO	silicified schist	complete
BU-126	Depot Hessisches Landesmuseum Kassel	1960s	Bu66 /110 D1 10	N/A	N/A	YES by Jöris	silicified schist	complete
BU-127	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 /120 IIIb	YES	III b	YES by Jöris	silicified schist	complete
BU-128	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 150 I 1000	YES	I	YES by Jöris	silicified schist	complete
BU-129	Depot Hessisches Landesmuseum Kassel	1960s	Bu66 117 IIIc	YES	III c	NO	silicified schist	complete
BU-130	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 /138 IIIb2 /51	YES	III b	YES by Jöris	silicified schist	complete
BU-131	Depot Hessisches Landesmuseum Kassel	1960s	Bu66 119 IIIb	YES	III b	YES by Jöris	silicified schist	complete
BU-132	Depot Hessisches Landesmuseum Kassel	1960s	BU 66 /116 IIIb x	YES	III b	YES by unknown	silicified schist	complete

ID	blank	cortex	type lateral sharpening spall	tool lateralisation	length [mm]	width [mm]	thickness [mm]
BU-120	flake	NO	primary	dex.	22.0	14.0	3.0
BU-121	flake	NO	secondary	dex.	28.0	8.0	5.0
BU-122	flake	NO	primary	N/A	25.0	10.0	6.0
BU-123	flake	NO	primary	dex.	35.0	29.0	13.0
BU-124	flake	NO	secondary	dex.	50.0	21.0	4.0
BU-125	flake	NO	primary	dex.	37.0	14.0	2.0
BU-126	flake	NO	N/A	dex.	40.0	17.0	4.0
BU-127	flake	NO	primary	dex.	41.0	15.0	7.0
BU-128	flake	NO	secondary	dex.	28.0	14.0	4.0
BU-129	flake	NO	primary	sin.	39.0	16.0	4.0
BU-130	flake	NO	primary	sin.	37.0	27.0	7.0
BU-131	flake	NO	primary	dex.	40.0	16.0	6.0
BU-132	flake	NO	primary	dex.	56.0	11.0	6.0

ID	weight [kg]	taphonomic visual inspection	tool edges preservation	use-wear analysis	3D-scan
BU-120	0.0013	sharp edges and preserved surface	edges preserved	YES	YES
BU-121	0.0005	sharp edges and preserved surface	edges preserved	YES	YES
BU-122	0.0013	sharp edges and preserved surface	edges preserved	NO	NO
BU-123	0.0116	sharp edges and preserved surface	edges preserved	NO	YES
BU-124	0.0056	sharp edges and preserved surface	edges preserved	YES	YES
BU-125	0.002	sharp edges and preserved surface	edges preserved	NO	NO
BU-126	0.0021	sharp edges and preserved surface	edges preserved	NO	NO
BU-127	0.0045	sharp edges and preserved surface	edges preserved	YES	YES
BU-128	0.0017	sharp edges and preserved surface	edges preserved	YES	YES
BU-129	0.0033	sharp edges and preserved surface	edges preserved	YES	YES
BU-130	0.0053	sharp edges and preserved surface	edges preserved	NO	NO
BU-131	0.0035	sharp edges and preserved surface	edges preserved	YES	YES
BU-132	0.0035	sharp edges and preserved surface	edges preserved	YES	YES

ID	loan	excavation year	artefact labelling	stratigraphy	level	artefact drawing	raw material	artefact state
BU-133	Depot Hessisches Landesmuseum Kassel	1960s	Bu66 119 IIIb	YES	III b	YES by Jöris	silicified schist	complete
BU-134	Depot Hessisches Landesmuseum Kassel	1960s	Bu66 /119 IIIb x	YES	III b	YES by Jöris	silicified schist	complete
BU-135	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 168 IIIb2 /48	YES	III b	YES by Jöris	silicified schist	distal fragment
BU-136	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 138 IIIb2 142x	YES	III b	YES by Jöris	silicified schist	complete
BU-137	Depot Hessisches Landesmuseum Kassel	1960s	Bu66 114/115 IIIc	YES	III c	YES by Jöris	Baltic flint	complete
BU-138	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 138 IIIb2:	YES	III b	YES by Jöris	silicified schist	complete
BU-139	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 138 IIIb2:	YES	III b	YES by Jöris	silicified schist	complete
BU-140	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 179 IIIa 1000	YES	III a	YES by Jöris	silicified schist	proximal fragment
BU-141	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 162IIIb2	YES	III b	YES by Jöris	silicified schist	complete
BU-142	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 172 IIIb2	YES	III b	YES by Jöris	silicified schist	complete
BU-143	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 /121 IIIb x1000	YES	III b	YES by Jöris	silicified schist	complete
BU-144	Depot Hessisches Landesmuseum Kassel	1960s	?	N/A	N/A	YES by Jöris	silicified schist	complete
BU-145	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 166 IIIb2 1001	YES	III b	YES by Jöris	silicified schist	complete

ID	blank	cortex	type lateral sharpening spall	tool lateralisation	length [mm]	width [mm]	thickness [mm]
BU-133	flake	NO	secondary	dex.	45.0	17.0	8.0
BU-134	flake	NO	primary	dex.	34.0	14.0	3.0
BU-135	flake	NO	primary	dex.	36.0	19.0	4.0
BU-136	flake	NO	secondary	dex.	46.0	20.0	5.0
BU-137	flake	NO	primary	dex.	34.0	31.0	7.0
BU-138	flake	NO	primary	dex.	29.0	8.0	2.0
BU-139	flake	NO	primary	dex.	27.0	11.0	3.0
BU-140	flake	NO	primary	sin.	26.0	21.0	5.0
BU-141	flake	NO	primary	sin.	33.0	16.0	3.0
BU-142	flake	NO	secondary	dex.	34.0	18.0	3.0
BU-143	flake	NO	primary	dex.	38.0	20.0	5.0
BU-144	flake	NO	primary	dex.	24.0	10.0	4.0
BU-145	flake	NO	primary	dex.	37.0	11.0	3.0

ID	weight [kg]	taphonomic visual inspection	tool edges preservation	use-wear analysis	3D-scan
BU-134	0.0014	sharp edges and preserved surface	edges preserved	YES	YES
BU-135	0.0038	sharp edges and preserved surface	edges preserved	NO	NO
BU-136	0.0033	sharp edges and preserved surface	edges preserved	YES	YES
BU-137	0.0089	sharp edges and preserved surface	edges preserved	NO	NO
BU-138	0.0006	sharp edges and preserved surface	edges preserved	NO	NO
BU-139	0.0009	sharp edges and preserved surface	edges preserved	YES	YES
BU-140	0.0029	sharp edges and preserved surface	edges preserved	NO	NO
BU-141	0.0018	sharp edges and preserved surface	edges preserved	NO	NO
BU-142	0.0026	sharp edges and preserved surface	edges preserved	YES	YES
BU-143	0.0047	sharp edges and preserved surface	edges preserved	NO	NO
BU-144	0.0009	sharp edges and preserved surface	edges preserved	NO	NO
BU-145	0.0015	sharp edges and preserved surface	edges preserved	NO	NO

ID	loan	exca-vation year	artefact labelling	strati-graphy	level	artefact drawing	raw material	artefact state
BU-146	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 168 IIId	YES	III d	YES by Jöris	silicified schist	distal fragment
BU-147	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 138 IIIb? 1000	YES	III b	YES by Jöris	silicified schist	complete
BU-148	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 178 II	YES	II	YES by Jöris	silicified schist	proximal fragment
BU-149	Depot Hessisches Landesmuseum Kassel	1960s	Bu66 113 IIIc	YES	III c	YES by Jöris	silicified schist	complete
BU-150	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 172 IIIa 1000	YES	III a	YES by Jöris	silicified schist	distal fragment
BU-151	Depot Hessisches Landesmuseum Kassel	1960s	Bu? IIb ?? 1009	YES	II b	YES by Jöris	silicified schist	complete
BU-152	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 /162 II	YES	II	YES by Jöris	silicified schist	complete
BU-153	Depot Hessisches Landesmuseum Kassel	1960s	Bu66 /110 III x 1000	YES	III	YES by Jöris	silicified schist	complete
BU-154	Depot Hessisches Landesmuseum Kassel	1960s	Bu66 /112 D116	N/A	N/A	YES by Jöris	silicified schist	complete
BU-155	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 138 IIIb2 106	YES	III b	YES by Jöris	silicified schist	proximal fragment
BU-156	Depot Hessisches Landesmuseum Kassel	1960s	Bu67 /120 IIIb	YES	III b	YES by Jöris	silicified schist	complete
BU-157	Depot Hessisches Landesmuseum Kassel	1960s	Bu66 118 IIIa	YES	III a	YES by Jöris	silicified schist	complete
BU-169	Ausstellung Hessisches Landesmuseum Kassel	1960s	Bu67 160 IIIc 10-20	YES	III c	YES by Jöris	silicified schist	complete

ID	blank	cortex	type lateral sharpening spall	tool lateralisation	length [mm]	width [mm]	thickness [mm]
BU-146	flake	NO	primary	sin.	37.0	33.0	6.0
BU-147	flake	NO	secondary	dex.	26.0	11.0	9.0
BU-148	flake	NO	primary	sin.	26.0	27.0	11.0
BU-149	flake	NO	secondary	dex.	31.0	18.0	3.0
BU-150	flake	NO	primary	dex.	35.0	16.0	4.0
BU-151	flake	NO	primary	dex.	42.0	16.0	4.0
BU-152	flake	NO	secondary	dex.	28.0	19.0	2.0
BU-153	flake	NO	secondary	dex.	35.0	15.0	4.0
BU-154	flake	NO	primary	N/A	30.0	18.0	5.0
BU-155	flake	NO	primary	dex.	29.0	19.0	7.0
BU-156	flake	NO	primary	dex.	21.0	9.0	3.0
BU-157	flake	NO	primary	dex.	45.0	13.0	5.0
BU-169	flake	NO	secondary	dex.	25.1	15.4	4.1

ID	weight [kg]	taphonomic visual inspection	tool edges preservation	use-wear analysis	3D-scan
BU-146	0.0059	sharp edges and preserved surface	edges preserved	NO	NO
BU-147	0.0016	sharp edges and preserved surface	edges preserved	NO	NO
BU-148	0.007	sharp edges and preserved surface	edges preserved	NO	NO
BU-149	0.0026	sharp edges and preserved surface	edges preserved	NO	NO
BU-150	0.0032	sharp edges and preserved surface	edges preserved	NO	NO
BU-151	0.0024	sharp edges and preserved surface	edges preserved	YES	YES
BU-152	0.0017	sharp edges and preserved surface	edges preserved	NO	NO
BU-153	0.0025	sharp edges and preserved surface	edges preserved	NO	NO
BU-154	0.0033	sharp edges and preserved surface	edges preserved	NO	NO
BU-155	0.0039	sharp edges and preserved surface	edges preserved	NO	NO
BU-156	0.0004	sharp edges and preserved surface	edges preserved	NO	NO
BU-157	0.0035	sharp edges and preserved surface	edges preserved	YES	YES
BU-169	0.0012	sharp edges and preserved surface	edges preserved	YES	YES

ID	loan	excavation year	artefact labelling	stratigraphy	level	artefact drawing	raw material	artefact state
BU-195	Ausstellung Hessisches Landesmuseum Kassel	1960s	Bu67 177 IIIb2 27	YES	III b	YES by Jöris	silicified schist	complete
BU-196	Ausstellung Hessisches Landesmuseum Kassel	1960s	Bu67 144 IIIb2 14	YES	III b	YES by Jöris	silicified schist	complete
BU-197	Ausstellung Hessisches Landesmuseum Kassel	1960s	Bu67 166 IIIb2....	YES	III b	NO	silicified schist	complete

ID	blank	cortex	type lateral sharpening spall	tool lateralisation	length [mm]	width [mm]	thickness [mm]
BU-195	flake	NO	primary	sin.	54.5	19.3	4.8
BU-196	flake	NO	secondary	dex.	41.3	19.2	5.2
BU-197	flake	NO	primary	dex.	26.1	14.4	3.0

ID	weight [kg]	taphonomic visual inspection	tool edges preservation	use-wear analysis	3D-scan
BU-195	0.0033	sharp edges and preserved surface	edges preserved	YES	YES
BU-196	0.0029	sharp edges and preserved surface	edges preserved	NO	YES
BU-197	0.005	sharp edges and preserved surface	edges preserved	YES	YES

Balver Höhle

ID	loan	excavation year	artefact labelling	stratigraphy	level	artefact drawing	raw material	artefact state
HE-012	LWL Musem Herne	N/A	III	YES	2	NO	Baltic flint	complete
HE-013	LWL Musem Herne	N/A	III/I/a 9	YES	4	NO	silicified schist	semi-finished product
HE-014	LWL Musem Herne	N/A	III/a 43	YES	4	NO	silicified schist	complete
HE-015	LWL Musem Herne	N/A	III	YES	2	NO	silicified schist	complete
HE-016	LWL Musem Herne	N/A	III/I/a 9	YES	4	YES by Jöris	silicified schist	complete
HE-017	LWL Musem Herne	N/A	III/II/a 41	YES	2	NO	silicified schist	complete
HE-018	LWL Musem Herne	N/A	III/I/a 670	YES	4	NO	silicified schist	complete
HE-019	LWL Musem Herne	N/A	III St 22	YES	2	NO	silicified schist	*Keilmesser* tip
HE-020	LWL Musem Herne	N/A	III St 14	YES	2	NO	silicified schist	complete
HE-021	LWL Musem Herne	N/A	III St 18	YES	2	NO	silicified schist	complete
HE-022	LWL Musem Herne	N/A	III/c St 5	YES	2	NO	silicified schist	complete
HE-023	LWL Musem Herne	N/A	III/IIIa	YES	2	NO	silicified schist	complete
HE-024	LWL Musem Herne	N/A	III/c St 19	YES	2	NO	silicified schist	complete
HE-025	LWL Musem Herne	N/A	III/III a 22	YES	2	NO	silicified schist	semi-finished product
HE-026	Sauer-land Museum Arnsberg	N/A	III St 27	YES	2	NO	silicified schist	complete
HE-027	LWL Musem Herne	N/A	III St 31	YES	2	NO	silicified schist	semi-finished product
HE-028	LWL Musem Herne	N/A	III	YES	2	NO	silicified schist	complete

ID	blank	*Keilmesser* shape	cortex	cortex percentage	cortex location	morpho-logy back	retouch active edge	retouch type edge
HE-012	core	Bockstein	YES	N/A	back	cortex/ unworked	YES	bifacial
HE-013	core	Bockstein	YES	N/A	back	cortex/ unworked	YES	bifacial
HE-014	flake	Balve	YES	N/A	back	cortex/ unworked	YES	bifacial
HE-015	core	Pradnik	N/A	N/A	N/A	partly retouched	YES	bifacial
HE-016	core	Bockstein	YES	N/A	back	cortex unworked	YES	bifacial
HE-017	core	Pradnik	N/A	N/A	N/A	cortex unworked	YES	bifacial
HE-018	core	Bockstein	NO	N/A	N/A	cortex partly retouched	YES	bifacial
HE-019	core	Pradnik	YES	N/A	back	cortex unworked	YES	bifacial
HE-020	core	Klausennische	N/A	N/A	N/A	partly retouched	YES	bifacial
HE-021	core	Bockstein	N/A	N/A	N/A	partly retouched	YES	bifacial
HE-022	core	Pradnik	YES	N/A	back	cortex unworked	YES	bifacial
HE-023	core	Klausennische	N/A	N/A	N/A	partly retouched	YES	bifacial
HE-024	core	Bockstein	YES	N/A	back	cortex unworked	YES	bifacial
HE-025	core	Bockstein	YES	N/A	back	cortex unworked	YES	bifacial
HE-026	core	Klausennische	N/A	N/A	N/A	partly retouched	YES	bifacial
HE-027	core	Bockstein	NO	N/A	N/A	partly retouched	YES	N/A
HE-028	core	Bockstein	YES	N/A	back	cortex unworked	YES	bifacial

ID	tip morphology	application Pradnik method	frequency application Pradnik method	tool lateral-isation	length [mm]	width [mm]	thick-ness [mm]	weight [kg]
HE-012	N/A	YES	N/A	sin.	72.5	41.6	17.8	0.058
HE-013	N/A	NO	N/A	sin.	142.9	69.7	24.2	0.129
HE-014	N/A	NO	N/A	dex.	52.4	38.3	20.9	0.035
HE-015	N/A	NO	N/A	sin.	48.3	34.0	11.6	0.022
HE-016	N/A	YES	N/A	sin.	58.9	30.5	19.7	0.037
HE-017	N/A	NO	N/A	sin.	70.1	48.0	19.2	0.073
HE-018	N/A	NO	N/A	sin.	49.9	25.0	17.7	0.024
HE-019	N/A	NO	N/A	dex.	57.2	37.2	23.6	0.054
HE-020	N/A	YES	N/A	dex.	56.0	28.0	11.4	0.02
HE-021	N/A	YES	N/A	dex.	65.7	45.0	23.9	0.057
HE-022	N/A	NO	N/A	sin.	49.4	28.6	15.9	0.02
HE-023	N/A	YES	N/A	sin.	66.4	46.2	23.7	0.057
HE-024	N/A	NO	N/A	sin.	68.6	34.0	13.7	0.034
HE-025	N/A	NO	N/A	dex.	77.3	39.0	15.1	0.061
HE-026	N/A	YES	N/A	dex.	51.1	28.1	8.8	0.02
HE-027	N/A	NO	N/A	dex.	83.0	39.5	13.6	0.053
HE-028	N/A	NO	N/A	sin.	50.3	30.2	14.6	0.023

ID	perimeter basis + back [cm]	perimeter distal posterior part [cm]	perimeter active edge [cm]	thickness back [mm]	taphonomic visual inspection	tool edges preservation	use-wear analysis	3D-scan	schistosety
HE-012	10.6	1.0	6.7	17.2	N/A	N/A	N/A	N/A	N/A
HE-013	18.7	4.0	11.4	22.1	N/A	N/A	N/A	N/A	N/A
HE-014	5.7	4.0	4.7	19.0	N/A	N/A	N/A	N/A	N/A
HE-015	4.1	4.6	4.4	7.1	N/A	N/A	N/A	N/A	N/A
HE-016	9.6	1.3	4.4	20.0	N/A	N/A	N/A	N/A	N/A
HE-017	7.6	4.0	6.4	18.9	N/A	N/A	N/A	N/A	N/A
HE-018	6.3	0.0	5.9	14.1	N/A	N/A	N/A	N/A	N/A
HE-019	8.5	1.7	5.4	23.0	N/A	N/A	N/A	N/A	N/A
HE-020	4.6	2.6	5.9	7.5	N/A	N/A	N/A	N/A	N/A
HE-021	10.8	0.0	5.4	6.4	N/A	N/A	N/A	N/A	N/A
HE-022	3.4	3.7	3.8	17.1	N/A	N/A	N/A	N/A	N/A
HE-023	6.0	5.3	5.6	9.1	N/A	N/A	N/A	N/A	N/A
HE-024	7.9	0.0	7.8	8.2	N/A	N/A	N/A	N/A	N/A
HE-025	10.6	0.0	8.7	15.2	N/A	N/A	N/A	N/A	N/A
HE-026	5.5	2.7	4.9	7.2	N/A	N/A	N/A	N/A	N/A
HE-027	12.9	0.0	6.1	5.7	N/A	N/A	N/A	N/A	N/A
HE-028	6.9	0.0	5.0	12.0	N/A	N/A	N/A	N/A	N/A

ID	loan	exca-vation year	artefact labelling	strati-graphy	level	artefact drawing	raw material	artefact state
HE-029	LWL Musem Herne	N/A	III/c St 25	YES	2	NO	silicified schist	complete
HE-030	LWL Musem Herne	N/A	III/IIIa 10	YES	2	NO	silicified schist	complete
HE-031	LWL Musem Herne	N/A	III/a	YES	4	NO	silicified schist	complete
HE-032	LWL Musem Herne	N/A	III/III/a	YES	4	NO	silicified schist	complete
HE-001	LWL Musem Herne	N/A	III	YES	2	NO	Baltic flint	complete
HE-002	LWL Musem Herne	N/A	III	YES	2	NO	silicified schist	complete
HE-003	LWL Musem Herne	N/A	III/a 34	YES	4	NO	silicified schist	complete
SM-001	Sauer-land Museum Arnsberg	1959	N/A	N/A	N/A	YES by Jöris	silicified schist	complete
SM-002	Sauer-land Museum Arnsberg	1959	N/A	N/A	N/A	YES by Jöris	silicified schist	complete
SM-003	Sauerland Museum Arnsberg	1959	N/A	N/A	N/A	YES by Jöris	silicified schist	complete
HE-005°	LWL Musem Herne	N/A	N/A	N/A	N/A	NO	silicified schist	complete
HE-007°	LWL Musem Herne	N/A	N/A	N/A	N/A	NO	silicified schist	complete
HE-008°	LWL Musem Herne	N/A	N/A	N/A	N/A	NO	silicified schist	semi-finished product
HE-009°	LWL Musem Herne	N/A	N/A	N/A	N/A	NO	silicified schist	complete
HE-010°	LWL Musem Herne	N/A	N/A	N/A	N/A	NO	silicified schist	complete
HE-011°	LWL Musem Herne	N/A	N/A	N/A	N/A	NO	silicified schist	complete
HE-012°	LWL Musem Herne	N/A	N/A	N/A	N/A	NO	silicified schist	complete

ID	blank	*Keilmesser* shape	cortex	cortex percentage	cortex location	morpho-logy back	retouch active edge	retouch type edge
HE-029	core	Bockstein	N/A	N/A	N/A	cortex unworked	YES	bifacial
HE-030	core	Bockstein	N/A	N/A	N/A	partly retouched	YES	bifacial
HE-031	core	Klausennische	YES	N/A	back	cortex unworked	YES	bifacial
HE-032	core	Bockstein	YES	N/A	back	cortex unworked	YES	bifacial
HE-001	core	Pradnik	N/A	N/A	N/A	retouched	YES	bifacial
HE-002	core	Klausennische	YES	N/A	back	cortex unworked	YES	bifacial
HE-003	core	Pradnik	N/A	N/A	N/A	cortex unworked	YES	bifacial
SM-001	core	Klausennische	YES	<25	back	cortex unworked	YES	bifacial
SM-002	core	Pradnik	YES	25-50	back	cortex unworked	YES	bifacial
SM-003	core	Pradnik	YES	25-50	back	cortex unworked	YES	bifacial
HE-005°	core	Klausennische	N/A	N/A	N/A	cortex unworked	YES	bifacial
HE-007°	core	Klausennische	YES	N/A	back	cortex unworked	YES	bifacial
HE-008°	flake	Balve	YES	N/A	back	cortex unworked	YES	bifacial
HE-009°	core	Balve	N/A	N/A	N/A	cortex unworked	YES	bifacial
HE-010°	core	Balve	N/A	N/A	N/A	cortex unworked	YES	bifacial
HE-011°	core	Balve	YES	N/A	back	cortex unworked	YES	bifacial
HE-012°	core	Pradnik	N/A	N/A	N/A	partly retouched	YES	bifacial

ID	tip morphology	application Pradnik method	frequency application Pradnik method	tool lateral-isation	length [mm]	width [mm]	thick-ness [mm]	weight [kg]
HE-029	N/A	YES	N/A	dex.	47.3	36.3	15.4	0.025
HE-030	N/A	YES	N/A	dex.	55.4	37.0	14.2	0.033
HE-031	N/A	NO	N/A	dex.	47.7	38.4	19.9	0.033
HE-032	N/A	NO	N/A	dex.	39.4	32.4	11.3	0.014
HE-001	N/A	YES	N/A	dex.	41.5	21.0	9.6	0.007
HE-002	N/A	YES	N/A	dex.	60.2	37.2	14.4	0.032
HE-003	N/A	YES	N/A	dex.	62.5	35.7	19.9	0.047
SM-001	rounded	YES	N/A	dex.	79.0	34.8	17.8	N/A
SM-002	rounded	YES	N/A	dex.	79.7	42.2	28.2	N/A
SM-003	rounded	YES	one	dex.	110.1	42.2	20.4	N/A
HE-005°	N/A	YES	N/A	dex.	95.5	51.2	20.1	0.115
HE-007°	N/A	NO	N/A	dex.	84.7	30.4	14.2	0.049
HE-008°	N/A	NO	N/A	sin.	154.7	84.8	24.1	0.448
HE-009°	N/A	NO	N/A	sin.	58.2	29.3	13.9	0.026
HE-010°	N/A	YES	N/A	dex.	57.9	32.8	14.4	0.027
HE-011°	N/A	NO	N/A	dex.	45.7	28.2	15.2	0.021
HE-012°	N/A	YES	N/A	sin.	35.4	30.4	13.7	0.013

ID	perimeter basis + back [cm]	perimeter distal posterior part [cm]	perimeter active edge [cm]	thickness back [mm]	taphonomic visual inspection	tool edges preservation	use-wear analysis	3D-scan	schistosety
HE-029	7.2	1.5	4.1	14.7	N/A	N/A	N/A	N/A	N/A
HE-030	8.9	0.0	5.7	6.9	N/A	N/A	N/A	N/A	N/A
HE-031	5.7	2.9	4.8	16.7	N/A	N/A	N/A	N/A	N/A
HE-032	4.2	3.0	4.1	9.8	N/A	N/A	N/A	N/A	N/A
HE-001	4.1	3.3	3.9	4.7	N/A	N/A	N/A	N/A	N/A
HE-002	6.9	3.7	5.0	7.8	N/A	N/A	N/A	N/A	N/A
HE-003	8.7	2.1	4.9	19.2	N/A	N/A	N/A	N/A	N/A
SM-001	6.8	3.7	8.6	14.8	sharp edges, preserved surface	edges preserved	N/A	N/A	N/A
SM-002	10.2	3.6	6.4	27.9	sharp edges, preserved surface	edges preserved	N/A	N/A	N/A
SM-003	8.5	7.4	10.3	17.9	sharp edges, preserved surface	edges preserved	N/A	N/A	N/A
HE-005°	10.2	4.5	7.5	19.5	N/A	N/A	N/A	N/A	N/A
HE-007°	11.1	1.7	6.7	19.3	N/A	N/A	N/A	N/A	N/A
HE-008°	12.9	9.6	14.1	20.1	N/A	N/A	N/A	N/A	N/A
HE-009°	5.4	3.0	5.1	11.4	N/A	N/A	N/A	N/A	N/A
HE-010°	6.0	3.0	6.1	9.8	N/A	N/A	N/A	N/A	N/A
HE-011°	4.2	3.6	5.3	14.3	N/A	N/A	N/A	N/A	N/A
HE-012°	3.6	3.3	3.9	7.1	N/A	N/A	N/A	N/A	N/A

ID	loan	exca-vation year	artefact labelling	strati-graphy	level	artefact drawing	raw material	artefact state
HE-013°	LWL Musem Herne	N/A	N/A	N/A	N/A	NO	silicified schist	complete
HE-016°	LWL Musem Herne	N/A	N/A	N/A	N/A	NO	silicified schist	*Keilmesser* tip
HE-017°	LWL Musem Herne	N/A	N/A	N/A	N/A	NO	silicified schist	complete
HE-018°	LWL Musem Herne	N/A	N/A	N/A	N/A	NO	silicified schist	complete
HE-019°	LWL Musem Herne	N/A	N/A	N/A	N/A	NO	silicified schist	complete
HE-020°	LWL Musem Herne	N/A	N/A	N/A	N/A	NO	silicified schist	complete
HE-021	LWL Musem Herne	N/A	N/A	N/A	N/A	NO	silicified schist	complete
HE-022°	LWL Musem Herne	N/A	N/A	N/A	N/A	NO	Baltic flint	complete
HE-023°	LWL Musem Herne	N/A	N/A	N/A	N/A	NO	silicified schist	complete
HE-024°	LWL Musem Herne	N/A	N/A	N/A	N/A	NO	silicified schist	complete
HE-025°	LWL Musem Herne	N/A	N/A	N/A	N/A	NO	silicified schist	complete
HE-026°	LWL Musem Herne	N/A	N/A	N/A	N/A	NO	silicified schist	complete
HE-028°	LWL Musem Herne	N/A	N/A	N/A	N/A	NO	silicified schist	complete
HE-029°	LWL Musem Herne	N/A	N/A	N/A	N/A	NO	silicified schist	complete
MU-210	LWL Archäologie Münster	N/A	N/A	N/A	N/A	NO	silicified schist	*Keilmesser* tip
MU-294	LWL Archäologie Münster	N/A	St.	YES	3	NO	silicified schist	complete
MU-206	LWL Archäologie Münster	N/A	N/A	N/A	N/A	NO	silicified schist	complete

ID	blank	*Keilmesser* shape	cortex	cortex percentage	cortex location	morpho-logy back	retouch active edge	retouch type edge
HE-013°	core	Klausennische	N/A	N/A	N/A	partly retouched	YES	bifacial
HE-016°	core	Pradnik	YES	N/A	back	cortex unworked	YES	bifacial
HE-017°	flake	Pradnik	N/A	N/A	N/A	partly retouched	YES	bifacial
HE-018°	core	Buhlen	YES	N/A	back	cortex unworked	YES	bifacial
HE-019°	core	Balve	YES	N/A	back	cortex unworked	YES	bifacial
HE-020°	core	Klausennische	YES	N/A	back	cortex unworked	YES	bifacial
HE-021	core	Balve	YES	N/A	back	N/A	YES	bifacial
HE-022°	core	Balve	N/A	N/A	N/A	partly retouched	YES	bifacial
HE-023°	core	Buhlen	N/A	N/A	N/A	partly retouched	YES	bifacial
HE-024°	core	Klausennische	YES	N/A	back	cortex unworked	YES	bifacial
HE-025°	core	Pradnik	N/A	N/A	N/A	partly retouched	YES	bifacial
HE-026°	core	Klausennische	YES	N/A	back	cortex unworked	YES	bifacial
HE-028°	core	Balve	N/A	N/A	N/A	cortex unworked	YES	bifacial
HE-029°	core	Balve	N/A	N/A	N/A	partly retouched	YES	bifacial
MU-210	core	Balve	YES	<25	back	cortex unworked	YES	semi-bifacial
MU-294	flake	Pradnik	NO	N/A	N/A	cortex unworked	YES	bifacial
MU-206	core	Balve	YES	25-50	back	cortex partly retouched	YES	semi-bifacial

ID	tip morphology	application Pradnik method	frequency application Pradnik method	tool lateral-isation	length [mm]	width [mm]	thick-ness [mm]	weight [kg]
HE-013°	N/A	NO	N/A	dex.	72.8	50.6	28.7	0.092
HE-016°	N/A	NO	N/A	dex.	40.8	31.7	14.9	0.024
HE-017°	N/A	YES	N/A	dex.	56.9	43.2	14.7	0.037
HE-018°	N/A	NO	N/A	sin.	36.7	27.7	9.7	0.01
HE-019°	N/A	YES	N/A	dex.	68.1	46.6	20.8	0.077
HE-020°	N/A	YES	N/A	dex.	135.6	81.4	22.8	0.321
HE-021	N/A	YES	N/A	sin.	69.0	49.8	22.8	0.077
HE-022°	N/A	YES	N/A	dex.	52.1	39.8	16.1	0.032
HE-023°	N/A	YES	N/A	dex.	64.4	26.6	11.1	0.028
HE-024°	N/A	YES	N/A	dex.	48.4	38.1	14.9	0.028
HE-025°	N/A	NO	N/A	sin.	56.3	36.2	15.6	0.027
HE-026°	N/A	NO	N/A	dex.	85.0	38.9	18.5	0.066
HE-028°	N/A	NO	N/A	sin.	47.2	27.0	16.7	0.020
HE-029°	N/A	YES	N/A	dex.	70.3	46.3	19.2	0.056
MU-210	pointed	YES	one	dex.	58.7	37.0	19.9	0.037
MU-294	rounded	YES	N/A	dex.	52.7	30.9	15.7	0.033
MU-206	pointed	YES	one	dex.	39.1	23.5	17.1	0.011

ID	perimeter basis + back [cm]	perimeter distal posterior part [cm]	perimeter active edge [cm]	thickness back [mm]	taphonomic visual inspection	tool edges preservation	use-wear analysis	3D-scan	schistosety
HE-013°	8.0	4.6	6.3	9.9	N/A	N/A	N/A	N/A	N/A
HE-016°	6.2	1.1	4.7	14.4	N/A	N/A	N/A	N/A	N/A
HE-017°	5.7	3.7	5.4	4.7	N/A	N/A	N/A	N/A	N/A
HE-018°	3.2	2.1	3.8	9.2	N/A	N/A	N/A	N/A	N/A
HE-019°	5.6	4.9	5.2	19.5	N/A	N/A	N/A	N/A	N/A
HE-020°	12.3	9.3	12.7	15.8	N/A	N/A	N/A	N/A	N/A
HE-021	8.1	5.2	5.5	15.9	N/A	N/A	N/A	N/A	N/A
HE-022°	4.4	4.7	6.0	8.1	N/A	N/A	N/A	N/A	N/A
HE-023°	5.8	4.0	5.6	7.1	N/A	N/A	N/A	N/A	N/A
HE-024°	5.2	3.4	4.1	13.6	N/A	N/A	N/A	N/A	N/A
HE-025°	4.7	3.1	6.2	8.9	N/A	N/A	N/A	N/A	N/A
HE-026°	8.6	3.4	6.9	17.1	N/A	N/A	N/A	N/A	N/A
HE-028°	4.9	2.5	4.7	7.4	N/A	N/A	N/A	N/A	N/A
HE-029°	5.4	5.6	6.9	13.4	N/A	N/A	N/A	N/A	N/A
MU-210	5.4	4.6	5.5	16.4	sharp edges, preserved surface	edges preserved	YES	YES	YES
MU-294	5.6	3.7	4.4	13.9	smoothed edges, patinated surface	edges not preserved	NO	NO	YES
MU-206	4.2	2.0	4.1	15.1	sharp edges, preserved surface	edges preserved	NO	NO	YES

ID	loan	exca-vation year	artefact labelling	strati-graphy	level	artefact drawing	raw material	artefact state
MU-083	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-114	LWL Archäologie Münster	N/A	D/a/1	YES	N/A	NO	silicified schist	complete
MU-255	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	*Keilmesser* tip
MU-017	LWL Archäologie Münster	N/A	II/a	YES	N/A	NO	silicified schist	complete
MU-081	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-021	LWL Archäologie Münster	N/A	Lesefund	No	N/A	NO	silicified schist	complete
MU-258	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-033	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-023	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-041	LWL Archäologie Münster	N/A	unhorizont-iert	No	N/A	NO	silicified schist	*Keilmesser* tip
MU-105	LWL Archäologie Münster	N/A	Graben E (1), E III	No	N/A	NO	silicified schist	complete
MU-044	LWL Archäologie Münster	N/A	Graben B	No	N/A	NO	silicified schist	complete
MU-085	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-020	LWL Archäologie Münster	N/A	Lesefund	No	N/A	NO	silicified schist	semi-finished product
MU-001	LWL Archäologie Münster	N/A	I/a 578 904	YES	6	NO	silicified schist	*Keilmesser* tip

ID	blank	*Keilmesser* shape	cortex	cortex percentage	cortex location	morpho-logy back	retouch active edge	retouch type edge
MU-083	flake	Balve	YES	25-50	back	cortex unworked	YES	semi-bifacial
MU-114	core	Klausennische	YES	<25	back	cortex unworked	YES	bifacial
MU-255	N/A	Klausennische	NO	N/A	N/A	retouched	YES	bifacial
MU-017	flake	Klausennische	YES	<25	back	cortex partly retouched	YES	semi-bifacial
MU-081	N/A	Klausennische	YES	<25	back	cortex unworked	YES	semi-bifacial
MU-021	flake	Bockstein	YES	25-50	back	cortex partly retouched	YES	semi-bifacial
MU-258	N/A	Bockstein	NO	N/A	N/A	retouched	YES	semi-bifacial
MU-033	core	Balve	YES	25-50	back	cortex unworked	YES	semi-bifacial
MU-023	core	Bockstein	YES	<25	back	cortex unworked	YES	bifacial
MU-041	core	Klausennische	YES	<25	back	cortex partly retouched	YES	semi-bifacial
MU-105	N/A	Balve	N/A	N/A	N/A	cortex partly retouched	YES	bifacial
MU-044	core	Klausennische	YES	25-50	back	cortex unworked	YES	bifacial
MU-085	N/A	Klausennische	NO	N/A	N/A	cortex unworked	YES	bifacial
MU-020	core	Pradnik	YES	50-75	back	cortex partly retouched	YES	unifacial
MU-001	N/A	Bockstein	YES	<25	back	cortex unworked	YES	bifacial

ID	tip morphology	application Pradnik method	frequency application Pradnik method	tool lateral-isation	length [mm]	width [mm]	thick-ness [mm]	weight [kg]
MU-083	pointed	YES	one	dex.	44.2	30.0	15.6	0.018
MU-114	rounded	YES	N/A	dex.	61.5	29.7	16.9	0.036
MU-255	pointed	YES	one	dex.	52.5	43.2	13.3	0.031
MU-017	rounded	NO	N/A	sin.	55.1	36.8	16.0	0.043
MU-081	pointed	NO	N/A	sin.	38.3	22.1	14.2	0.008
MU-021	rounded	NO	N/A	sin.	71.4	43.4	18.1	0.062
MU-258	rounded	NO	N/A	sin.	56.7	33.0	12.4	0.025
MU-033	rounded	NO	N/A	sin.	49.9	32.5	15.6	0.031
MU-023	rounded	NO	N/A	sin.	46.8	21.7	10.8	0.012
MU-041	pointed	NO	N/A	sin.	36.2	26.4	12.5	0.012
MU-105	rounded	NO	N/A	sin.	72.0	53.3	26.5	0.096
MU-044	pointed	NO	N/A	sin.	63.4	33.8	16.5	0.035
MU-085	rounded	NO	N/A	sin.	40.5	22.3	13.4	0.012
MU-020	pointed	NO	N/A	sin.	65.7	37.9	18.2	0.038
MU-001	rounded	NO	N/A	sin.	61.9	38.3	14.9	0.043

ID	peri-meter basis + back [cm]	peri-meter distal posterior part [cm]	peri-meter active edge [cm]	thick-ness back [mm]	tapho-nomic visual inspection	tool edges preser-vation	use-wear analysis	3D-scan	schist-osety
MU-083	5.6	2.8	3.8	15.2	smoothed edges, patinated surface	edges not preserved	NO	YES	YES
MU-114	5.4	3.7	6.3	14.5	sharp edges, preserved surface	edges preserved	YES	YES	NO
MU-255	6.3	3.6	4.7	6.4	smoothed edges, patinated surface	edges not preserved	NO	NO	YES
MU-017	6.1	3.3	4.8	15.6	smoothed edges, patinated surface	edges preserved	NO	YES	YES
MU-081	4.1	2.3	2.9	11.5	sharp edges, preserved surface	edges preserved	NO	NO	N/A
MU-021	10.1	0.0	10.7	18.4	sharp edges, preserved surface	edges preserved	YES	YES	YES
MU-258	8.4	0.0	5.7	6.4	smoothed edges, patinated surface	edges preserved	NO	NO	YES
MU-033	4.7	3.3	4.6	12.4	sharp edges, preserved surface	edges preserved	NO	YES	N/A
MU-023	5.2	0.0	5.8	7.6	smoothed edges, fresh surfaces	edges preserved	YES	YES	N/A
MU-041	5.4	1.2	3.3	10.9	sharp edges, preserved surface	edges preserved	YES	YES	N/A
MU-105	7.4	4.9	6.0	25.8	smoothed edges, patinated surface	edges not preserved	NO	NO	N/A
MU-044	4.9	2.9	7.7	17.5	sharp edges, preserved surface	edges preserved	YES	YES	YES
MU-085	5.6	1.1	3.7	9.0	smoothed edges, fresh surfaces	edges preserved	NO	NO	N/A
MU-020	8.3	2.5	6.8	18.3	sharp edges, preserved surface	edges preserved	YES	YES	YES
MU-001	10.1	0.0	5.7	13.4	smoothed edges, fresh surfaces	edges preserved	NO	NO	NO

ID	loan	exca-vation year	artefact labelling	strati-graphy	level	artefact drawing	raw material	artefact state
MU-007	LWL Archäologie Münster	N/A	Lesefund	No	N/A	NO	silicified schist	complete
HE-004	LWL Musem Herne	N/A	Balve Böschung	No	N/A	YES by Jöris	silicified schist	complete
HE-005	LWL Musem Herne	N/A	III/a 26	YES	4	YES by Jöris	silicified schist	complete
HE-006	LWL Musem Herne	N/A	III	YES	2	NO	silicified schist	complete
HE-007	LWL Musem Herne	N/A	III	YES	2	NO	silicified schist	complete
HE-008	LWL Musem Herne	N/A	III	YES	2	NO	silicified schist	complete
HE-009	LWL Musem Herne	N/A	III/IIIc	YES	2	NO	silicified schist	complete
HE-010	LWL Musem Herne	N/A	III	YES	2	NO	silicified schist	complete
HE-011	LWL Musem Herne	N/A	III/I/a	YES	4	NO	silicified schist	complete
MU-016	LWL Archäologie Münster	N/A	II/a	YES	N/A	NO	Baltic flint	complete
MU-011	LWL Archäologie Münster	N/A	Lesefund	No	N/A	NO	Baltic flint	complete
MU-106	LWL Archäologie Münster	N/A	I/a	YES	6	NO	silicified schist	complete
MU-069	LWL Archäologie Münster	1939	1939 Rest	No	N/A	NO	silicified schist	*Keilmesser* tip
MU-240	LWL Archäologie Münster	N/A	unhorizont-iert	No	N/A	NO	silicified schist	complete
MU-090	LWL Archäologie Münster	N/A	II/a	YES	N/A	NO	silicified schist	complete
MU-089	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-086	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete

ID	blank	*Keilmesser* shape	cortex	cortex percentage	cortex location	morpho-logy back	retouch active edge	retouch type edge
MU-007	core	Balve	NO	N/A	N/A	retouched	YES	bifacial
HE-004	core	Pradnik	YES	N/A	back	cortex partly retouched	YES	bifacial
HE-005	core	Pradnik	N/A	N/A	N/A	partly retouched	YES	bifacial
HE-006	core	Pradnik	YES	N/A	back	cortex unworked	YES	bifacial
HE-007	core	Pradnik	N/A	N/A	N/A	cortex unworked	YES	bifacial
HE-008	core	Balve	YES	N/A	back	cortex unworked	YES	bifacial
HE-009	core	Pradnik	YES	N/A	back	cortex unworked	YES	bifacial
HE-010	core	Pradnik	N/A	N/A	N/A	partly retouched	YES	bifacial
HE-011	core	Pradnik	YES	N/A	back	cortex unworked	YES	bifacial
MU-016	core	Klausennische	YES	<25	medial ventral	retouched	YES	bifacial
MU-011	N/A	Balve	NO	N/A	N/A	retouched	YES	bifacial
MU-106	core	Bockstein	YES	<25	back	cortex unworked	YES	bifacial
MU-069	N/A	Bockstein	NO	N/A	N/A	cortex unworked	YES	bifacial
MU-240	flake	Königsaue	N/A	N/A	N/A	retouched	YES	unifacial
MU-090	core	Balve	YES	<25	back	cortex unworked	YES	bifacial
MU-089	core	Pradnik	YES	<25	back	cortex unworked	YES	bifacial
MU-086	core	Buhlen	YES	<25	back	cortex partly retouched	YES	bifacial

ID	tip morphology	application Pradnik method	frequency application Pradnik method	tool lateral-isation	length [mm]	width [mm]	thick-ness [mm]	weight [kg]
MU-007	rounded	NO	N/A	sin.	69.4	45.4	18.5	0.057
HE-004	N/A	YES	N/A	dex.	88.3	42.0	15.5	0.075
HE-005	N/A	YES	N/A	dex.	31.8	23.2	15.5	0.009
HE-006	N/A	YES	N/A	dex.	44.0	30.2	13.1	0.015
HE-007	N/A	YES	N/A	dex.	80.3	36.2	20.7	0.07
HE-008	N/A	YES	N/A	dex.	63.3	27.5	17.1	0.034
HE-009	N/A	YES	N/A	sin.	60.3	35.9	20.0	0.038
HE-010	N/A	YES	N/A	dex.	40.0	23.5	11.8	0.01
HE-011	N/A	YES	N/A	dex.	62.5	37.5	13.9	0.047
MU-016	pointed	NO	N/A	sin.	55.6	37.1	16.0	0.042
MU-011	broken	NO	N/A	sin.	37.1	27.4	10.4	0.01
MU-106	rounded	NO	N/A	sin.	84.8	46.9	18.8	0.075
MU-069	rounded	NO	N/A	sin.	55.8	23.5	15.8	0.019
MU-240	rounded	NO	N/A	dex.	73.4	28.6	11.9	0.024
MU-090	rounded	NO	N/A	dex.	42.0	24.0	13.1	0.015
MU-089	rounded	NO	N/A	dex.	67.8	41.2	29.3	0.08
MU-086	rounded	NO	N/A	dex.	91.9	53.2	18.4	0.084

ID	peri-meter basis + back [cm]	peri-meter distal posterior part [cm]	peri-meter active edge [cm]	thick-ness back [mm]	tapho-nomic visual inspection	tool edges preser-vation	use-wear analysis	3D-scan	schist-osety
MU-007	6.3	4.2	7.2	8.0	sharp edges and preserved surface	edges preserved	NO	YES	YES
HE-004	7.2	6.2	8.0	14.7	N/A	N/A	N/A	N/A	N/A
HE-005	3.6	3.1	2.9	2.9	N/A	N/A	N/A	N/A	N/A
HE-006	4.2	3.7	4.1	10.2	N/A	N/A	N/A	N/A	N/A
HE-007	7.2	4.7	6.8	15.8	N/A	N/A	N/A	N/A	N/A
HE-008	6.0	1.1	6.1	16.2	N/A	N/A	N/A	N/A	N/A
HE-009	8.7	1.5	4.8	13.7	N/A	N/A	N/A	N/A	N/A
HE-010	3.9	1.7	3.3	3.3	N/A	N/A	N/A	N/A	N/A
HE-011	7.4	3.3	6.0	13.3	N/A	N/A	N/A	N/A	N/A
MU-016	6.1	3.4	5.0	15.3	smoothed edges, fresh surfaces	edges preserved	NO	YES	YES
MU-011	4.1	3.1	3.5	5.7	sharp edges, preserved surface	edges preserved	YES	YES	N/A
MU-106	11.5	0.0	8.9	14.2	sharp edges, preserved surface	edges preserved	NO	YES	YES
MU-069	7.7	0.0	6.3	16.2	sharp edges, preserved surface	edges preserved	NO	YES	YES
MU-240	3.4	5.7	7.5	10.9	sharp edges, preserved surface	edges preserved	YES	YES	YES
MU-090	5.3	2.2	2.9	9.2	smoothed edges, patinated surface	edges preserved	NO	YES	NO
MU-089	9.3	4.2	4.5	26.9	smoothed edges, fresh surfaces	edges preserved	NO	YES	YES
MU-086	14.2	1.6	7.6	13.6	smoothed edges, patinated surface	edges preserved	NO	YES	YES

ID	loan	exca-vation year	artefact labelling	strati-graphy	level	artefact drawing	raw material	artefact state
MU-022	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-084	LWL Archäologie Münster	N/A	III/III 206	YES	2	NO	silicified schist	*Keilmesser* tip
MU-199	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-253	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-197	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	Baltic flint	complete
MU-076	LWL Archäologie Münster	N/A	III/III 36	YES	2	NO	silicified schist	complete
MU-236	LWL Archäologie Münster	N/A	unhorizont-iert	No	N/A	NO	silicified schist	complete
MU-260	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	Baltic flint	complete
MU-035	LWL Archäologie Münster	N/A	Balve Böschung	No	N/A A	NO	silicified schist	complete
MU-064	LWL Archäologie Münster	N/A	St.	YES	3	NO	silicified schist	complete
MU-080	LWL Archäologie Münster	N/A	III/III 18	YES	2	NO	silicified schist	complete
MU-268	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	*Keilmesser* tip
MU-259	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-052	LWL Archäologie Münster	N/A	I/a	YES	6	NO	silicified schist	*Keilmesser* tip

ID	blank	*Keilmesser* shape	cortex	cortex percentage	cortex location	morpho-logy back	retouch active edge	retouch type edge
MU-022	N/A	Balve	N/A	N/A	N/A	cortex partly retouched	YES	semi-bifacial
MU-084	core	Bockstein	NO	N/A	N/A	cortex unworked	YES	bifacial
MU-199	core	Klausennische	YES	<25	medial ventral	retouched	YES	bifacial
MU-253	core	Klausennische	NO	N/A	N/A	retouched	YES	semi-bifacial
MU-197	core	Balve	YES	<25	medial dorsal	cortex partly retouched	YES	bifacial
MU-076	N/A	Buhlen	YES	<25	back	cortex partly retouched	YES	semi-bifacial
MU-236	core	Pradnik	NO	N/A	N/A	cortex partly retouched	YES	bifacial
MU-260	N/A	Balve	NO	N/A	N/A	retouched	YES	bifacial
MU-035	core	Pradnik	YES	<25	medial ventral	retouched	YES	bifacial
MU-064	N/A	Bockstein	YES	<25	back	cortex unworked	YES	bifacial
MU-080	core	Klausennische	NO	N/A	N/A	retouched	YES	bifacial
MU-268	N/A	Bockstein	NO	N/A	N/A	cortex unworked	YES	bifacial
MU-259	N/A	Klausennische	YES	<25	medial ventral	retouched	YES	bifacial
MU-052	N/A	Bockstein	N/A	N/A	N/A	retouched	YES	semi-bifacial

ID	tip morphology	application Pradnik method	frequency application Pradnik method	tool lateral-isation	length [mm]	width [mm]	thick-ness [mm]	weight [kg]
MU-022	rounded	NO	N/A	dex.	51.8	23.5	13.6	0.018
MU-084	rounded	NO	N/A	dex.	91.9	53.2	18.4	0.084
MU-199	pointed	NO	N/A	dex.	64.1	38.3	12.4	0.034
MU-253	rounded	NO	N/A	dex.	59.4	38.4	11.3	0.034
MU-197	pointed	NO	N/A	dex.	57.2	30.8	16.6	0.028
MU-076	rounded	NO	N/A	dex.	42.4	29.1	15.1	0.021
MU-236	pointed	NO	N/A	dex.	43.1	37.2	19.3	0.031
MU-260	rounded	NO	N/A	dex.	50.2	26.6	15.8	0.02
MU-035	pointed	NO	N/A	dex.	58.2	37.8	13.5	0.03
MU-064	rounded	NO	N/A	dex.	45.7	27.2	13.5	0.015
MU-080	pointed	NO	N/A	dex.	68.5	42.5	26.6	0.08
MU-268	rounded	NO	N/A	dex.	47.5	37.2	18.8	0.034
MU-259	rounded	NO	N/A	dex.	48.3	34.9	12.7	0.023
MU-052	pointed	NO	N/A	dex.	25.2	35.6	11.4	0.011

ID	peri-meter basis + back [cm]	peri-meter distal posterior part [cm]	peri-meter active edge [cm]	thick-ness back [mm]	tapho-nomic visual inspection	tool edges preser-vation	use-wear analysis	3D-scan	schist-osety
MU-022	5.2	1.7	5.0	12.3	sharp edges, preserved surface	edges preserved	YES	YES	YES
MU-084	14.2	1.6	7.6	13.6	smoothed edges, patinated surface	edges preserved	NO	NO	YES
MU-199	5.4	4.1	7.5	10.2	sharp edges, preserved surface	edges preserved	YES	YES	YES
MU-253	6.0	4.4	5.3	8.2	smoothed edges, patinated surface	edges preserved	NO	YES	YES
MU-197	6.1	3.0	5.1	13.5	sharp edges, preserved surface	edges preserved	YES	YES	N/A
MU-076	5.0	1.4	4.2	12.8	smoothed edges, patinated surface	edges preserved	NO	NO	YES
MU-236	5.8	3.1	3.6	6.3	smoothed edges, patinated surface	edges preserved	NO	YES	YES
MU-260	4.1	2.8	4.7	6.5	smoothed edges, fresh surfaces	edges preserved	NO	YES	N/A
MU-035	5.7	3.3	6.8	5.9	smoothed edges, patinated surface	edges preserved	NO	YES	YES
MU-064	6.5	0.0	5.2	14.2	smoothed edges, fresh surfaces	edges preserved	NO	NO	NO
MU-080	7.4	3.5	7.1	9.0	sharp edges, preserved surface	edges preserved	NO	NO	YES
MU-268	8.3	0.0	4.1	13.5	smoothed edges, patinated surface	edges preserved	NO	YES	NO
MU-259	5.4	3.1	5.2	4.2	sharp edges, preserved surface	edges preserved	NO	YES	YES
MU-052	3.5	3.6	3.2	8.2	smoothed edges, patinated surface	edges preserved	NO	YES	YES

ID	loan	exca-vation year	artefact labelling	strati-graphy	level	artefact drawing	raw material	artefact state
MU-092	LWL Archäologie Münster	N/A	unhorizont-iert	No	N/A	NO	silicified schist	complete
MU-224	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	Baltic flint	complete
MU-229	LWL Archäologie Münster	N/A	unhorizont-iert	No	N/A	NO	silicified schist	complete
MU-212	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-072	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-247	LWL Archäologie Münster	N/A	unhorizont-iert	No	N/A	NO	silicified schist	*Keilmesser* tip
MU-077	LWL Archäologie Münster	N/A	III/III 31	YES	2	NO	silicified schist	complete
MU-082	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-004	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-225	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	*Keilmesser* tip
MU-249	LWL Archäologie Münster	N/A	unhorizont-iert	No	N/A	NO	silicified schist	complete
MU-267	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	*Keilmesser* tip

ID	blank	*Keilmesser* shape	cortex	cortex percentage	cortex location	morpho-logy back	retouch active edge	retouch type edge
MU-092	core	Bockstein	YES	<25	medial ventral	cortex unworked	YES	bifacial
MU-224	N/A	Balve	NO	N/A	N/A	retouched	YES	bifacial
MU-229	core	Pradnik	NO	N/A	N/A	cortex partly retouched	YES	bifacial
MU-212	N/A	Pradnik	YES	<25	back	cortex partly retouched	YES	bifacial
MU-072	core	Balve	YES	<25	back	cortex partly retouched	YES	bifacial
MU-247	N/A	Klausennische	NO	N/A	N/A	retouched	YES	bifacial
MU-077	core	Buhlen	YES	<25	distal ventral	retouched	YES	bifacial
MU-082	N/A	Buhlen	N/A	N/A	N/A	cortex partly retouched	YES	bifacial
MU-004	core	Bockstein	YES	<25	distal ventral	partly retouched	YES	bifacial
MU-225	N/A	Klausennische	NO	N/A	N/A	partly retouched	YES	bifacial
MU-249	core	Klausennische	YES	<25	back	cortex unworked	YES	bifacial
MU-267	N/A	Buhlen	NO	N/A	N/A	cortex partly retouched	YES	bifacial

ID	tip morphology	application Pradnik method	frequency application Pradnik method	tool lateral-isation	length [mm]	width [mm]	thick-ness [mm]	weight [kg]
MU-092	rounded	NO	N/A	dex.	48.1	36.1	16.3	0.035
MU-224	rounded	NO	N/A	dex.	42.5	28.1	14.0	0.016
MU-229	rounded	NO	N/A	dex.	65.0	44.7	20.3	0.055
MU-212	rounded	YES	N/A	dex.	41.6	21.8	7.4	0.006
MU-072	rounded	NO	N/A	dex.	51.9	21.5	19.7	0.02
MU-247	rounded	NO	N/A	dex.	28.8	22.9	12.9	0.01
MU-077	rounded	NO	N/A	dex.	64.5	40.5	19.7	0.056
MU-082	pointed	NO	N/A	dex.	42.3	23.8	14.0	0.01
MU-004	pointed	NO	N/A	dex.	65.5	35.8	16.3	0.033
MU-225	pointed	NO	N/A	dex.	27.1	27.0	9.5	0.007
MU-249	rounded	YES	N/A	dex.	45.4	23.7	16.2	0.02
MU-267	rounded	NO	N/A	dex.	48.1	33.2	17.0	0.023

ID	peri-meter basis + back [cm]	peri-meter distal posterior part [cm]	peri-meter active edge [cm]	thick-ness back [mm]	tapho-nomic visual inspection	tool edges preser-vation	use-wear analysis	3D-scan	schist-osety
MU-092	8.8	0.0	5.3	15.9	smoothed edges, patinated surface	edges preserved	NO	YES	YES
MU-224	4.6	1.6	4.2	6.8	smoothed edges, patinated surface	edges preserved	YES	YES	N/A
MU-229	6.3	5.6	5.7	11.2	sharp edges and preserved surface	edges preserved	NO	NO	YES
MU-212	3.2	3.1	3.9	5.4	sharp edges and preserved surface	edges preserved	NO	NO	YES
MU-072	4.4	2.7	4.6	7.6	sharp edges and preserved surface	edges preserved	NO	NO	N/A
MU-247	4.4	2.1	2.6	7.4	sharp edges and preserved surface	edges preserved	NO	NO	NO
MU-077	7.5	3.2	4.5	17.3	sharp edges and preserved surface	edges preserved	NO	NO	NO
MU-082	3.5	2.9	3.7	6.1	sharp edges and preserved surface	edges preserved	NO	NO	NO
MU-004	9.5	0.0	5.9	10.9	smoothed edges, patinated surface	edges preserved	NO	NO	YES
MU-225	3.2	2.7	2.3	5.4	sharp edges and preserved surface	edges preserved	NO	YES	NO
MU-249	5.3	1.8	4.6	10.1	sharp edges and preserved surface	edges preserved	YES	YES	YES
MU-267	2.1	3.3	6.0	18.2	sharp edges and patinated surface	edges preserved	NO	NO	NO

ID	loan	exca-vation year	artefact labelling	strati-graphy	level	artefact drawing	raw material	artefact state
MU-242	LWL Archäologie Münster	N/A	unhorizont-iert	No	N/A	NO	silicified schist	complete
MU-024	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-040	LWL Musem Herne	N/A	unhorizont-iert	No	N/A	NO	silicified schist	complete
MU-261	LWL Archäologie Münster	N/A	N/A	No	N/A	needed	silicified schist	complete
MU-048	LWL Archäologie Münster	N/A	I/a	YES	6	NO	silicified schist	complete
MU-074	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-034	LWL Archäologie Münster	1939	N/A	No	N/A	NO	silicified schist	complete
MU-039	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-248	LWL Archäologie Münster	N/A	unhorizont-iert	No	N/A	NO	silicified schist	complete
MU-243	LWL Archäologie Münster	N/A	unhorizont-iert	No	N/A	NO	silicified schist	complete
MU-235	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	*Keilmesser* tip
MU-094	LWL Archäologie Münster	N/A	unhorizont-iert	No	N/A	NO	silicified schist	semi-finished product

ID	blank	*Keilmesser* shape	cortex	cortex percentage	cortex location	morpho-logy back	retouch active edge	retouch type edge
MU-242	N/A	Pradnik	YES	<25	medial dorsal	partly retouched	YES	semi-bifacial
MU-024	core	Balve	YES	25-50	medial ventral	retouched	YES	semi-bifacial
MU-040	N/A	Bockstein	YES	<25	back	cortex unworked	YES	semi-bifacial
MU-261	core	Balve	YES	<25	proximal dorsal	partly retouched	YES	bifacial
MU-048	N/A	Buhlen	YES	<25	back	cortex unworked	YES	bifacial
MU-074	core	Pradnik	NO	N/A	N/A	retouched	YES	bifacial
MU-034	core	Balve	YES	<25	back	cortex unworked	YES	bifacial
MU-039	core	Bockstein	YES	<25	back	cortex unworked	YES	unifacial
MU-248	N/A	Klausennische	YES	<25	back	cortex partly retouched	YES	bifacial
MU-243	core	Pradnik	NO	N/A	N/A	partly retouched	YES	bifacial
MU-235	N/A	Pradnik	YES	<25	medial dorsal	partly retouched	YES	bifacial
MU-094	N/A	Bockstein	YES	<25	back	cortex unworked	YES	bifacial

ID	tip morphology	application Pradnik method	frequency application Pradnik method	tool lateral-isation	length [mm]	width [mm]	thick-ness [mm]	weight [kg]
MU-242	rounded	NO	N/A	dex.	57.9	31.2	13.6	0.026
MU-024	rounded	NO	N/A	dex.	71.9	40.5	25.8	0.06
MU-040	pointed	N/A	N/A	dex.	68.7	29.2	15.0	0.03
MU-261	broken	NO	N/A	dex.	41.6	35.0	13.3	0.023
MU-048	rounded	N/A	N/A	dex.	35.9	24.8	13.0	0.012
MU-074	pointed	NO	N/A	dex.	48.9	27.3	17.4	0.024
MU-034	rounded	NO	N/A	dex.	43.7	22.8	13.2	0.017
MU-039	pointed	N/A	N/A	dex.	48.1	23.4	17.2	0.019
MU-248	rounded	NO	N/A	dex.	41.4	21.0	9.9	0.008
MU-243	broken	NO	N/A	dex.	41.4	27.6	11.5	0.013
MU-235	rounded	NO	N/A	dex.	18.0	48.8	14.2	0.022
MU-094	rounded	NO	N/A	dex.	42.7	41.7	16.3	0.025

ID	peri-meter basis + back [cm]	peri-meter distal posterior part [cm]	peri-meter active edge [cm]	thick-ness back [mm]	tapho-nomic visual inspection	tool edges preser-vation	use-wear analysis	3D-scan	schist-osety
MU-242	7.0	7.3	2.6	15.5	sharp edges and preserved surface	edges preserved	NO	NO	YES
MU-024	7.2	2.3	7.9	16.1	sharp edges and preserved surface	edges preserved	NO	NO	YES
MU-040	8.2	0.0	7.1	13.8	sharp edges and patinated surface	edges preserved	NO	NO	NO
MU-261	4.7	3.2	4.3	10.5	sharp edges and patinated surface	edges preserved	YES	NO	NO
MU-048	4.3	2.1	3.5	12.3	smoothed edges, patinated surface	edges preserved	NO	NO	NO
MU-074	3.5	3.3	5.1	7.6	sharp edges and preserved surface	edges preserved	NO	NO	YES
MU-034	4.0	2.0	4.6	13.9	smoothed edges, patinated surface	edges preserved	NO	NO	YES
MU-039	6.3	0.0	5.1	10.7	sharp edges and preserved surface	edges preserved	YES	NO	YES
MU-248	4.6	1.7	3.6	6.0	sharp edges and preserved surface	edges preserved	NO	NO	NO
MU-243	3.7	2.7	4.7	4.6	sharp edges and preserved surface	edges preserved	NO	NO	NO
MU-235	4.7	3.9	3.4	6.5	smoothed edges, patinated surface	edges preserved	NO	NO	YES
MU-094	8.6	0.0	4.5	14.1	sharp edges and preserved surface	edges preserved	NO	NO	NO

ID	loan	exca-vation year	artefact labelling	strati-graphy	level	artefact drawing	raw material	artefact state
MU-049	LWL Archäologie Münster	N/A	I/a	YES	6	NO	silicified schist	complete
MU-073	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	Baltic flint	complete
MU-288	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-093	LWL Archäologie Münster	N/A	unhorizont-iert	No	N/A	NO	silicified schist	complete
MU-250	LWL Archäologie Münster	N/A	unhorizont-iert	No	N/A	NO	silicified schist	complete
MU-232	LWL Archäologie Münster	N/A	unhorizont-iert	No	N/A	NO	silicified schist	complete
MU-293	LWL Archäologie Münster	N/A	St/17	YES	3	NO	silicified schist	complete
MU-065	LWL Archäologie Münster	N/A	III/a	YES	4	NO	silicified schist	complete
MU-100	LWL Archäologie Münster	N/A	III/II 33	YES	2	NO	silicified schist	complete
MU-008	LWL Archäologie Münster	N/A	Lesefund	No	N/A	NO	silicified schist	complete
MU-252	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-038	LWL Archäologie Münster	N/A	unhorizont-iert	No	N/A	NO	silicified schist	complete

ID	blank	*Keilmesser* shape	cortex	cortex percentage	cortex location	morpho-logy back	retouch active edge	retouch type edge
MU-049	core	Bockstein	YES	<25	back	cortex unworked	YES	bifacial
MU-073	flake	Pradnik	NO	N/A	N/A	retouched	YES	unifacial
MU-288	N/A	Pradnik	N/A	N/A	N/A	cortex partly retouched	YES	semi-bifacial
MU-093	N/A	Pradnik	YES	<25	back	cortex partly retouched	YES	bifacial
MU-250	core	Pradnik	NO	N/A	N/A	partly retouched	YES	bifacial
MU-232	core	Buhlen	YES	25-50	back	cortex unworked	YES	semi-bifacial
MU-293	N/A	Pradnik	YES	<25	back	cortex partly retouched	YES	bifacial
MU-065	core	Pradnik	N/A	N/A	N/A	cortex partly retouched	YES	semi-bifacial
MU-100	core	Balve	YES	<25	back	cortex partly retouched	YES	bifacial
MU-008	core	Klausennische	YES	25-50	back	cortex unworked	YES	bifacial
MU-252	core	Klausennische	YES	<25	back	cortex unworked	YES	semi-bifacial
MU-038	N/A	Pradnik	YES	<25	back	cortex partly retouched	YES	unifacial

ID	tip morphology	application Pradnik method	frequency application Pradnik method	tool lateral-isation	length [mm]	width [mm]	thick-ness [mm]	weight [kg]
MU-049	broken	YES	one	dex.	32.1	26.5	18.5	0.018
MU-073	rounded	YES	one	dex.	50.3	37.6	23.0	0.041
MU-288	pointed	YES	one	dex.	41.2	29.5	11.4	0.016
MU-093	rounded	YES	one	dex.	60.9	38.6	12.8	0.038
MU-250	rounded	YES	one	dex.	51.5	36.7	14.1	0.031
MU-232	broken	YES	N/A	dex.	49.7	29.9	19.1	0.030
MU-293	rounded	YES	multiple	dex.	47.9	33.7	13.6	0.027
MU-065	rounded	YES	one	dex.	52.8	27.6	23.3	0.026
MU-100	rounded	YES	one	dex.	100.2	55.6	13.6	0.084
MU-008	rounded	YES	N/A	dex.	53.2	33.7	17.0	0.034
MU-252	rounded	YES	N/A	dex.	48.4	29.3	16.5	0.024
MU-038	pointed	YES	one	dex.	50.0	34.8	13.5	0.025

ID	peri-meter basis + back [cm]	peri-meter distal posterior part [cm]	peri-meter active edge [cm]	thick-ness back [mm]	tapho-nomic visual inspection	tool edges preser-vation	use-wear analysis	3D-scan	schist-osety
MU-049	4.7	0.0	4.5	15.6	sharp edges and preserved surface	edges preserved	YES	YES	N/A
MU-073	4.3	4.1	5.3	8.6	smoothed edges and fresh surfaces	edges preserved	YES	YES	N/A
MU-288	4.6	3.6	4.5	8.1	smoothed edges and fresh surfaces	edges preserved	YES	YES	NO
MU-093	7.3	4.3	4.8	10.7	sharp edges and patinated surface	edges preserved	YES	YES	YES
MU-250	4.9	5.4	5.5	13.4	smoothed edges, patinated surface	edges preserved	NO	YES	YES
MU-232	3.0	3.8	5.0	18.3	sharp edges and preserved surface	edges preserved	YES	YES	YES
MU-293	5.7	2.8	3.9	5.8	smoothed edges and fresh surfaces	edges preserved	YES	YES	N/A
MU-065	4.3	2.7	5.8	22.1	sharp edges and preserved surface	edges preserved	NO	NO	N/A
MU-100	10.4	6.6	6.9	12.7	smoothed edges, patinated surface	edges preserved	YES	YES	YES
MU-008	6.5	2.3	5.7	16.2	sharp edges and preserved surface	edges preserved	YES	YES	N/A
MU-252	5.4	1.6	5.5	15.1	sharp edges and preserved surface	edges preserved	NO	YES	N/A
MU-038	5.5	2.7	5.2	4.8	smoothed edges, patinated surface	edges preserved	NO	YES	YES

ID	loan	exca-vation year	artefact labelling	strati-graphy	level	artefact drawing	raw material	artefact state
MU-032	LWL Archäologie Münster	N/A	1972.13	No	4	NO	silicified schist	complete
MU-227	LWL Archäologie Münster	N/A	unhorizont-iert	No	N/A	NO	silicified schist	*Keilmesser* tip
MU-047	LWL Archäologie Münster	N/A	I/a	YES	6	NO	silicified schist	complete
MU-068	LWL Archäologie Münster	N/A	III/III	YES	2	NO	silicified schist	*Keilmesser* tip
MU-078	LWL Archäologie Münster	N/A	III/III 13	YES	2	NO	silicified schist	*Keilmesser* tip
MU-096	LWL Archäologie Münster	1939	Rest D 1939	No	N/A	NO	silicified schist	complete
MU-112	LWL Archäologie Münster	N/A	1981:105,27; Ia/1	YES	6	NO	silicified schist	complete
MU-012	LWL Archäologie Münster	N/A	Lesefund	No	N/A	NO	silicified schist	semi-finished product
MU-091	LWL Archäologie Münster	N/A	unhorizont-iert	No	N/A	NO	silicified schist	complete
MU-202	LWL Archäologie Münster	1939	Andree 1939	No	N/A	needed	silicified schist	complete
MU-195	LWL Archäologie Münster	N/A	Ia/374	YES	6	NO	silicified schist	complete
MU-262	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete

ID	blank	*Keilmesser* shape	cortex	cortex percentage	cortex location	morpho-logy back	retouch active edge	retouch type edge
MU-032	core	Bockstein	YES	25-50	back	cortex partly retouched	YES	bifacial
MU-227	N/A	Pradnik	NO	N/A	N/A	partly retouched	YES	bifacial
MU-047	core	Pradnik	YES	<25	base	partly retouched	YES	bifacial
MU-068	N/A	Pradnik	NO	N/A	N/A	partly retouched	YES	unifacial
MU-078	N/A	Pradnik	YES	<25	back	cortex partly retouched	YES	bifacial
MU-096	core	Klausennische	YES	50-75	distal dorsal	cortex partly retouched	YES	semi-bifacial
MU-112	core	Balve	YES	50-75	total	cortex unworked	YES	semi-bifacial
MU-012	core	Bockstein	YES	25-50	back	cortex unworked	YES	semi-bifacial
MU-091	core	Pradnik	YES	<25	back	cortex unworked	YES	bifacial
MU-202	core	Klausennische	YES	<25	distal ventral	retouched	YES	bifacial
MU-195	N/A	Balve	N/A	N/A	N/A	partly retouched	YES	bifacial
MU-262	core	Balve	YES	<25	medial ventral	retouched	YES	semi-bifacial

ID	tip morphology	application Pradnik method	frequency application Pradnik method	tool lateral-isation	length [mm]	width [mm]	thick-ness [mm]	weight [kg]
MU-032	rounded	N/A	N/A	dex.	50.0	33.9	13.5	0.027
MU-227	rounded	YES	one	dex.	57.2	48.2	17.2	0.055
MU-047	rounded	YES	N/A	dex.	39.7	38.5	17.3	0.029
MU-068	rounded	YES	one	dex.	26.0	31.1	15.6	0.011
MU-078	rounded	YES	one	dex.	54.3	45.0	20.1	0.047
MU-096	pointed	YES	N/A	dex.	39.1	39.4	13.1	0.024
MU-112	pointed	YES	multiple	dex.	99.9	52.4	18.7	0.096
MU-012	rounded	N/A	N/A	N/A	105.0	69.6	26.1	0.181
MU-091	rounded	YES	multiple	dex.	62.0	30.5	20.9	0.035
MU-202	pointed	YES	one	dex.	109.3	51.2	16.6	0.101
MU-195	rounded	YES	one	dex.	52.0	38.7	12.0	0.025
MU-262	rounded	YES	one	dex.	54.9	37.7	16.3	0.036

ID	peri-meter basis + back [cm]	peri-meter distal posterior part [cm]	peri-meter active edge [cm]	thick-ness back [mm]	tapho-nomic visual inspection	tool edges preser-vation	use-wear analysis	3D-scan	schist-osety
MU-032	8.2	0.0	5.3	13.1	smoothed edges, patinated surface	edges preserved	NO	YES	YES
MU-227	7.3	4.2	6.3	9.5	sharp edges and patinated surface	edges preserved	NO	YES	YES
MU-047	4.7	3.0	4.8	8.1	sharp edges and patinated surface	edges preserved	NO	YES	N/A
MU-068	4.3	3.1	2.7	6.8	sharp edges and preserved surface	edges preserved	NO	YES	NO
MU-078	6.4	4.1	4.9	13.2	smoothed edges and fresh surfaces	edges preserved	NO	NO	YES
MU-096	4.4	2.8	5.7	9.7	smoothed edges, patinated surface	edges preserved	NO	NO	YES
MU-112	6.8	6.8	9.2	17.6	sharp edges and preserved surface	edges preserved	YES	YES	YES
MU-012	17.5	0.0	7.4	18.6	sharp edges and preserved surface	edges preserved	NO	NO	YES
MU-091	7.9	2.2	6.2	18.4	sharp edges and preserved surface	edges preserved	NO	NO	NO
MU-202	8.9	7.0	9.9	7.8	sharp edges and preserved surface	edges preserved	YES	YES	YES
MU-195	6.4	4.2	3.3	9.2	smoothed edges, patinated surface	edges preserved	NO	NO	YES
MU-262	7.2	3.3	5.1	7.8	smoothed edges, patinated surface	edges preserved	NO	NO	YES

ID	loan	excavation year	artefact labelling	stratigraphy	level	artefact drawing	raw material	artefact state
MU-067	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	*Keilmesser* tip
MU-280	LWL Archäologie Münster	N/A	III a/35	YES	4	YES by Rutkowski	silicified schist	complete
MU-265	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-066	LWL Archäologie Münster	N/A	III/a	YES	4	NO	silicified schist	complete
MU-063	LWL Archäologie Münster	N/A	St/15	YES	3	NO	silicified schist	complete
MU-046	LWL Archäologie Münster	N/A	I/a	YES	6	NO	silicified schist	complete
MU-075	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-003	LWL Archäologie Münster	N/A	N/A	No	N/A	needed	silicified schist	complete
MU-058	LWL Archäologie Münster	N/A	I/a	YES	6	NO	silicified schist	complete
MU-037	LWL Archäologie Münster	N/A	III/a	YES	4	NO	silicified schist	*Keilmesser* tip
MU-231	LWL Archäologie Münster	N/A	unhorizontiert	No	N/A	NO	silicified schist	complete
MU-214	LWL Archäologie Münster	N/A	A	No	N/A	NO	silicified schist	complete

ID	blank	*Keilmesser* shape	cortex	cortex percentage	cortex location	morpho-logy back	retouch active edge	retouch type edge
MU-067	N/A	Klausennische	NO	N/A	N/A	partly retouched	YES	bifacial
MU-280	N/A	Pradnik	NO	N/A	N/A	retouched	YES	bifacial
MU-265	core	Bockstein	YES	50-75	base	cortex unworked	YES	semi-bifacial
MU-066	core	Bockstein	YES	25-50	back	cortex unworked	YES	semi-bifacial
MU-063	core	Balve	YES	<25	medial ventral	cortex unworked	YES	bifacial
MU-046	core	Klausennische	YES	25-50	back	cortex unworked	YES	unifacial
MU-075	core	Pradnik	YES	25-50	medial dorsal	cortex unworked	YES	semi-bifacial
MU-003	core	Klausennische	YES	25-50	back	cortex unworked	YES	semi-bifacial
MU-058	core	Pradnik	YES	<25	back	cortex unworked	YES	semi-bifacial
MU-037	N/A	Klausennische	YES	<25	back	cortex unworked	YES	bifacial
MU-231	core	Pradnik	YES	<25	back	cortex partly retouched	YES	bifacial
MU-214	core	Balve	YES	25-50	medial dorsal	cortex unworked	YES	semi-bifacial

ID	peri-meter basis + back [cm]	peri-meter distal posterior part [cm]	peri-meter active edge [cm]	thick-ness back [mm]	tapho-nomic visual inspection	tool edges preser-vation	use-wear analysis	3D-scan	schist-osety
MU-067	3.2	2.5	4.6	9.9	sharp edges and preserved surface	edges preserved	NO	YES	NO
MU-280	5.7	3.2	5.5	14.3	sharp edges and preserved surface	edges preserved	YES	YES	NO
MU-265	10.2	0.0	8.2	20.5	smoothed edges, patinated surface	edges preserved	NO	NO	NO
MU-066	4.7	0.0	4.5	17.2	sharp edges and preserved surface	edges preserved	NO	YES	NO
MU-063	4.5	3.3	7.5	18.0	sharp edges and preserved surface	edges preserved	YES	YES	YES
MU-046	5.2	1.8	3.6	12.9	sharp edges and preserved surface	edges preserved	NO	YES	NO
MU-075	8.1	2.6	5.6	11.8	smoothed edges, patinated surface	edges preserved	NO	YES	YES
MU-003	12.9	3.7	8.6	27.3	sharp edges and preserved surface	edges preserved	YES	YES	NO
MU-058	5.2	2.9	4.2	12.4	sharp edges and preserved surface	edges preserved	NO	YES	NO
MU-037	5.3	2.6	2.8	15.4	sharp edges and preserved surface	edges preserved	NO	YES	NO
MU-231	6.7	1.6	5.5	11.2	sharp edges and preserved surface	edges preserved	YES	YES	YES
MU-214	4.4	3.4	5.2	6.6	sharp edges and preserved surface	edges preserved	YES	YES	YES

ID	loan	excavation year	artefact labelling	stratigraphy	level	artefact drawing	raw material	artefact state
MU-284	LWL Archäologie Münster	N/A	III a/11	YES	4	YES by Rutkowski	silicified schist	complete
MU-273	LWL Archäologie Münster	N/A	St/198	YES	3	YES by Rutkowski	silicified schist	semi-finished product
MU-276	LWL Archäologie Münster	N/A	III/21	N/A	N/A	YES by Rutkowski	silicified schist	complete
MU-281	LWL Archäologie Münster	N/A	III a/21	YES	4	NO	silicified schist	complete
MU-045	LWL Archäologie Münster	N/A	I/a 603	YES	6	NO	silicified schist	complete
MU-234	LWL Archäologie Münster	N/A	unhorizontiert	No	N/A	NO	silicified schist	complete
MU-061	LWL Archäologie Münster	N/A	N/A	YES	6	NO	silicified schist	complete
MU-107	LWL Archäologie Münster	N/A	II/a	YES	N/A	NO	silicified schist	complete
MU-244	LWL Archäologie Münster	N/A	unhorizontiert	No	N/A	NO	silicified schist	complete
MU-228	LWL Archäologie Münster	N/A	unhorizontiert	No	N/A	NO	silicified schist	complete
MU-239	LWL Archäologie Münster	N/A	unhorizontiert	No	N/A	NO	silicified schist	complete
MU-289	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-233	LWL Archäologie Münster	N/A	unhorizontiert	No	N/A	NO	silicified schist	complete

ID	blank	*Keilmesser* shape	cortex	cortex percentage	cortex location	morpho-logy back	retouch active edge	retouch type edge
MU-284	N/A	Pradnik	NO	N/A	N/A	cortex unworked	YES	bifacial
MU-273	core	Buhlen	YES	<25	back	cortex partly retouched	YES	bifacial
MU-276	core	Bockstein	YES	<25	back	cortex unworked	YES	semi-bifacial
MU-281	core	Klausennische	YES	<25	back	cortex partly retouched	YES	N/A
MU-045	core	Pradnik	NO	N/A	N/A	cortex partly retouched	YES	bifacial
MU-234	N/A	Pradnik	NO	N/A	N/A	retouched	YES	bifacial
MU-061	core	Balve	YES	25-50	back	cortex partly retouched	YES	bifacial
MU-107	core	Klausennische	YES	50-75	total	cortex partly retouched	YES	bifacial
MU-244	core	Bockstein	YES	<25	back	cortex partly retouched	YES	bifacial
MU-228	core	Bockstein	YES	<25	back	cortex unworked	YES	bifacial
MU-239	core	Balve	YES	<25	back	cortex partly retouched	YES	bifacial
MU-289	N/A	Balve	NO	N/A	N/A	partly retouched	YES	semi-bifacial
MU-233	N/A	Klausennische	NO	N/A	N/A	retouched	YES	semi-bifacial

ID	tip morphology	application Pradnik method	frequency application Pradnik method	tool lateral-isation	length [mm]	width [mm]	thick-ness [mm]	weight [kg]
MU-284	rounded	NO	N/A	sin.	51.5	28.4	17.9	0.027
MU-273	pointed	NO	N/A	N/A	63.1	46.1	18.5	0.048
MU-276	rounded	NO	N/A	dex.	67.5	36.6	17.4	0.041
MU-281	rounded	N/A	N/A	sin.	62.8	45.8	22.8	0.075
MU-045	broken	NO	N/A	sin.	56.9	39.0	17.6	0.035
MU-234	rounded	NO	N/A	sin.	29.7	30.4	7.6	0.012
MU-061	rounded	NO	N/A	dex.	50.2	33.2	11.7	0.019
MU-107	rounded	NO	N/A	dex.	43.0	41.5	20.1	0.045
MU-244	rounded	NO	N/A	dex.	42.4	25.5	15.5	0.021
MU-228	rounded	NO	N/A	dex.	39.5	24.6	14.7	0.016
MU-239	rounded	NO	N/A	dex.	50.1	32.4	12.9	0.023
MU-289	rounded	NO	N/A	dex.	37.1	28.6	13.8	0.013
MU-233	rounded	YES	one	dex.	40.1	38.5	14.3	0.024

ID	peri-meter basis + back [cm]	peri-meter distal posterior part [cm]	peri-meter active edge [cm]	thick-ness back [mm]	tapho-nomic visual inspection	tool edges preser-vation	use-wear analysis	3D-scan	schist-osety
MU-284	5.3	1.9	5.7	13.5	sharp edges and preserved surface	edges preserved	NO	YES	YES
MU-273	10.0	0.0	8.2	16.8	sharp edges and preserved surface	edges preserved	YES	YES	NO
MU-276	9.5	0.0	7.6	5.1	sharp edges and preserved surface	edges preserved	YES	YES	NO
MU-281	7.0	2.8	7.1	21.8	sharp edges and preserved surface	edges preserved	NO	NO	NO
MU-045	6.0	3.6	5.9	13.4	sharp edges, preserved surface	edges preserved	NO	NO	YES
MU-234	3.4	2.7	2.6	7.9	sharp edges, patinated surface	edges preserved	YES	YES	N/A
MU-061	5.5	2.2	4.9	6.1	sharp edges, preserved surface	edges preserved	YES	YES	YES
MU-107	9.2	2.2	4.3	9.1	sharp edges, preserved surface	edges preserved	YES	YES	YES
MU-244	5.7	0.0	5.2	13.2	smoothed edges, patinated surface	edges preserved	NO	YES	YES
MU-228	6.8	0.0	4.3	12.4	sharp edges and preserved surface	edges preserved	NO	NO	YES
MU-239	5.5	2.9	4.6	13.1	sharp edges and preserved surface	edges preserved	NO	NO	NO
MU-289	5.8	1.4	3.3	12.1	smoothed edges, patinated surface	edges preserved	NO	NO	NO
MU-233	4.8	2.3	3.2	9.3	smoothed edges, patinated surface	edges preserved	NO	YES	YES

ID	loan	exca-vation year	artefact labelling	strati-graphy	level	artefact drawing	raw material	artefact state
MU-271	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	semi-finished product
MU-062	LWL Archäologie Münster	N/A	St	YES	3	NO	silicified schist	complete
MU-286	LWL Archäologie Münster	N/A	St/16	YES	3	NO	silicified schist	complete
MU-230	LWL Archäologie Münster	N/A	unhorizont-iert	No	N/A	NO	silicified schist	complete
MU-226	LWL Archäologie Münster	N/A	unhorizont-iert	No	N/A	NO	silicified schist	complete
MU-109	LWL Archäologie Münster	N/A	unhorizont-iert	No	N/A	needed	silicified schist	complete
MU-031	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-269	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-200	LWL Archäologie Münster	1939	Andree 1939	No	N/A	NO	silicified schist	complete
MU-264	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	*Keilmesser* tip
MU-099	LWL Archäologie Münster	N/A	unhorizont-iert	No	N/A	NO	silicified schist	*Keilmesser* tip

ID	blank	*Keilmesser* shape	cortex	cortex percentage	cortex location	morpho-logy back	retouch active edge	retouch type edge
MU-271	core	Pradnik	YES	<25	back	cortex partly retouched	YES	semi-bifacial
MU-062	core	Balve	N/A	N/A	N/A	cortex unworked	YES	bifacial
MU-286	N/A	Klausennische	YES	<25	back	cortex unworked	YES	bifacial
MU-230	core	Pradnik	YES	<25	back	cortex partly retouched	YES	semi-bifacial
MU-226	core	Bockstein	YES	25-50	back	cortex unworked	YES	semi-bifacial
MU-109	core	Klausennische	YES	25-50	back	cortex unworked	YES	semi-bifacial
MU-031	core	Klausennische	YES	25-50	base	retouched	YES	bifacial
MU-269	N/A	Pradnik	YES	<25	back	cortex unworked	YES	bifacial
MU-200	core	Bockstein	YES	<25	base	cortex partly retouched	YES	bifacial
MU-264	N/A	N/A	N/A	N/A	N/A	cortex partly retouched	YES	bifacial
MU-099	core	Pradnik	YES	25-50	medial ventral	cortex partly retouched	YES	semi-bifacial

ID	tip morphology	application Pradnik method	frequency application Pradnik method	tool lateral-isation	length [mm]	width [mm]	thick-ness [mm]	weight [kg]
MU-271	rounded	NO	N/A	dex.	50.6	41.3	14.6	0.03
MU-062	rounded	YES	one	dex.	50.4	27.8	21.2	0.034
MU-286	pointed	YES	N/A	dex.	55.6	31.5	12.5	0.026
MU-230	rounded	YES	multiple	dex.	52.1	36.2	13.5	0.036
MU-226	rounded	YES	one	dex.	52.4	38.4	15.1	0.035
MU-109	rounded	YES	one	dex.	31.9	18.7	11.2	0.006
MU-031	rounded	YES	one	dex.	39.9	29.4	18.2	0.022
MU-269	rounded	YES	one	dex.	45.9	31.5	14.0	0.025
MU-200	rounded	YES	one	dex.	56.6	27.1	16.3	0.016
MU-264	rounded	YES	N/A	dex.	42.1	44.6	11.9	0.02
MU-099	rounded	YES	one	sin.	38.1	34.2	15.3	0.019

ID	perimeter basis + back [cm]	perimeter distal posterior part [cm]	perimeter active edge [cm]	thickness back [mm]	taphonomic visual inspection	tool edges preservation	use-wear analysis	3D-scan	schistosety
MU-271	5.8	4.4	4.4	14.6	smoothed edges, patinated surface	edges preserved	NO	NO	YES
MU-062	5.4	1.6	6.0	11.6	sharp edges and preserved surface	edges preserved	NO	YES	N/A
MU-286	7.6	2.4	5.0	11.1	sharp edges and preserved surface	edges preserved	YES	YES	YES
MU-230	6.6	3.7	4.5	12.0	sharp edges and preserved surface	edges preserved	YES	YES	YES
MU-226	6.3	2.3	6.5	15.6	sharp edges and preserved surface	edges preserved	YES	YES	N/A
MU-109	3.2	2.2	2.9	11.1	sharp edges and preserved surface	edges preserved	YES	YES	NO
MU-031	4.5	2.6	4.3	15.9	sharp edges and preserved surface	edges preserved	NO	NO	NO
MU-269	4.9	2.8	4.0	10.6	smoothed edges, patinated surface	edges preserved	NO	NO	YES
MU-200	9.3	0.0	3.8	4.0	sharp edges and preserved surface	edges preserved	NO	NO	YES
MU-264	5.3	2.2	5.4	6.2	sharp edges and preserved surface	edges preserved	NO	NO	YES
MU-099	4.9	3.1	2.8	12.4	sharp edges and preserved surface	edges preserved	NO	YES	YES

ID	loan	excavation year	artefact labelling	stratigraphy	level	artefact drawing	raw material	artefact state
MU-111	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-051	LWL Archäologie Münster	N/A	I/a	YES	6	NO	silicified schist	complete
MU-287	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	semi-finished product
MU-043	LWL Archäologie Münster	N/A	Graben D	No	N/A	NO	silicified schist	semi-finished product
MU-113	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	semi-finished product
MU-272	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-241	LWL Archäologie Münster	N/A	unhorizontiert	No	N/A	NO	silicified schist	complete
MU-246	LWL Archäologie Münster	N/A	unhorizontiert	No	N/A	NO	silicified schist	complete
MU-196	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-283	LWL Archäologie Münster	N/A	St/30	YES	3	NO	silicified schist	complete

ID	blank	*Keilmesser* shape	cortex	cortex percentage	cortex location	morpho-logy back	retouch active edge	retouch type edge
MU-111	core	Balve	YES	<25	back	cortex unworked	YES	bifacial
MU-051	core	Pradnik	YES	<25	back	cortex partly retouched	YES	bifacial
MU-287	core	N/A	YES	>75	total	cortex unworked	YES	bifacial
MU-043	core	Bockstein	YES	<25	base	retouched	YES	partly retouched
MU-113	core	N/A	YES	<25	base	retouched	YES	bifacial
MU-272	core	Pradnik	YES	<25	back	cortex unworked	YES	semi-bifacial
MU-241	core	Klausennische	YES	<25	back	cortex unworked	YES	bifacial
MU-246	core	Bockstein	YES	25-50	back	cortex partly retouched	YES	bifacial
MU-196	N/A	Pradnik	N/A	N/A	N/A	cortex unworked	YES	bifacial
MU-283	core	Bockstein	YES	<25	back	cortex unworked	YES	bifacial

ID	tip morphology	application Pradnik method	frequency application Pradnik method	tool lateral-isation	length [mm]	width [mm]	thick-ness [mm]	weight [kg]
MU-111	pointed	YES	one	dex.	59.4	25.6	20.4	0.039
MU-051	rounded	YES	one	dex.	42.7	25.3	14.0	0.015
MU-287	N/A	N/A	N/A	N/A	101.2	91.7	15.6	0.229
MU-043	rounded	NO	N/A	N/A	67.9	38.7	20.1	0.054
MU-113	rounded	NO	N/A	N/A	60.7	48.0	20.8	0.051
MU-272	rounded	YES	one	dex.	64.2	40.5	18.0	0.051
MU-241	rounded	YES	one	dex.	52.4	27.9	16.9	0.032
MU-246	rounded	YES	N/A	dex.	54.2	22.7	13.4	0.019
MU-196	pointed	YES	one	dex.	48.4	24.4	11.1	0.012
MU-283	rounded	YES	multiple	dex.	54.3	29.9	17.5	0.031

ID	peri-meter basis + back [cm]	peri-meter distal posterior part [cm]	peri-meter active edge [cm]	thick-ness back [mm]	tapho-nomic visual inspection	tool edges preser-vation	use-wear analysis	3D-scan	schist-osety
MU-111	4.6	4.5	5.7	14.0	sharp edges and preserved surface	edges preserved	YES	YES	YES
MU-051	5.3	2.6	3.8	11.2	sharp edges and preserved surface	edges preserved	NO	YES	NO
MU-287	0.0	0.0	0.0	0.0	smoothed edges, patinated surface	edges preserved	NO	NO	YES
MU-043	10.2	0.0	6.7	12.1	sharp edges and preserved surface	edges preserved	NO	NO	NO
MU-113	0.0	0.0	0.0	0.0	sharp edges and preserved surface	edges preserved	NO	NO	NO
MU-272	7.5	3.2	6.1	13.4	sharp edges and patinated surface	edges preserved	YES	YES	YES
MU-241	5.6	2.2	4.9	13.9	smoothed edges and fresh surfaces	edges preserved	YES	YES	YES
MU-246	6.5	0.0	5.9	11.7	sharp edges and preserved surface	edges preserved	YES	YES	YES
MU-196	3.7	3.9	4.9	5.2	sharp edges and preserved surface	edges preserved	YES	YES	YES
MU-283	7.0	0.0	6.5	17.2	sharp edges and preserved surface	edges preserved	YES	YES	YES

ID	loan	excavation year	artefact labelling	stratigraphy	level	artefact drawing	raw material	artefact state
HE-033	LWL Musem Herne	N/A	III/IIIa	YES	4	NO	silicified schist	complete
HE-034	LWL Museum Herne	N/A	III/IIIa	YES	4	NO	silicified schist	complete
HE-002°	LWL Musem Herne	N/A	N/A	N/A	N/A	NO	silicified schist	complete
HE-015°	LWL Musem Herne	N/A	N/A	N/A	N/A	NO	silicified schist	complete
HE-031°	LWL Musem Herne	N/A	N/A	N/A	N/A	NO	silicified schist	complete
MU-098	LWL Archäologie Münster	N/A	unhorizont-iert	No	N/A	NO	silicified schist	complete
Mu-263	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-059	LWL Archäologie Münster	N/A	II/a	YES	N/A	NO	silicified schist	complete
MU-036	LWL Archäologie Münster	N/A	unhorizont-iert	No	N/A	YES by Jöris	silicified schist	complete
MU-028	LWL Archäologie Münster	N/A	1972:13:00	No	N/A	NO	silicified schist	complete
MU-251	LWL Archäologie Münster	N/A	1972:07:00	No	N/A	NO	silicified schist	complete
MU-198	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-015	LWL Archäologie Münster	N/A	II/a	YES	N/A	NO	silicified schist	complete
MU-266	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-006	LWL Archäologie Münster	N/A	Lesefunde	No	N/A	NO	silicified schist	complete
MU-071	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-211	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-290	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete

ID	blank	cortex	cortex percentage	cortex location	morpho-logy back	retouch active edge	retouch type edge
HE-033	N/A	YES	N/A	back	cortex/ unworked	YES	N/A
HE-034	N/A	N/A	N/A	N/A	retouched	YES	N/A
HE-002°	N/A	N/A	N/A	N/A	partly retouched	N/A	N/A
HE-015°	N/A	N/A	N/A	N/A	cortex/ unworked	N/A	N/A
HE-031°	flake	N/A	N/A	N/A	cortex/ unworked	N/A	N/A
MU-098	flake	YES	<25	distal dorsal	partly retouched	YES	semi-bifacial
Mu-263	flake	YES	<25	medial dorsa	partly retouched	YES	semi-bifacial
MU-059	flake	YES	<25	back	cortex/ partly retouched	YES	unifacial
MU-036	flake	NO	N/A	N/A	partly retouched	YES	unifacial
MU-028	flake	NO	N/A	N/A	retouched	YES	semi-bifacial
MU-251	flake	NO	N/A	N/A	retouched	YES	semi-bifacial
MU-198	flake	NO	N/A	N/A	partly retouched	YES	semi-bifacial
MU-015	flake	NO	N/A	N/A	retouched	YES	unifacial
MU-266	N/A	NO	N/A	N/A	cortex/ unworked	YES	semi-bifacial
MU-006	flake	YES	<25	back	cortex/ partly retouched	YES	semi-bifacial
MU-071	flake	YES	<25	back	cortex/ unworked	YES	unifacial
MU-211	flake	NO	N/A	N/A	partly retouched	YES	unifacial
MU-290	flake	NO	N/A	N/A	partly retouched	YES	semi-bifacial

ID	tip morphology	application Pradnik method	frequency application Pradnik method	tool lateral-isation	length [mm]	width [mm]	thick-ness [mm]	weight [kg]
HE-033	N/A	YES	N/A	dex.	49.7	39.4	12.0	0.021
HE-034	N/A	YES	N/A	dex.	46.2	35.5	1.2	0.019
HE-002°	N/A	YES	N/A	dex.	75.7	53.3	16.7	-
HE-015°	N/A	YES	N/A	sin.	37.2	24.6	9.2	0.009
HE-031°	N/A	YES	N/A	dex.	60.5	35.6	20.4	0.05
MU-098	rounded	YES	one	dex.	52.5	20.6	11.6	0.012
Mu-263	rounded	YES	N/A	dex.	52.9	38.8	14.2	0.036
MU-059	pointed	YES	one	dex.	52.4	33.6	13.5	0.024
MU-036	broken	YES	one	dex.	45.6	42.2	19.3	0.036
MU-028	pointed	YES	one	dex.	60.2	35.6	12.6	0.028
MU-251	rounded	YES	N/A	dex.	63.8	36.5	17.9	0.04
MU-198	rounded	YES	one	dex.	65.2	40.1	16.3	0.033
MU-015	rounded	YES	one	dex.	51.6	34.7	16.6	0.028
MU-266	rounded	YES	one	dex.	49.2	39.7	14.6	0.03
MU-006	pointed	YES	one	dex.	46.1	23.5	13.6	0.017
MU-071	rounded	YES	one	dex.	46.8	30.4	17.2	0.027
MU-211	rounded	YES	one	dex.	39.2	26.8	14.9	0.014
MU-290	pointed	YES	one	dex.	46.1	29.4	10.4	0.012

ID	thick-ness back [mm]	taphonomic visual inspection	tool edges preservation	use-wear analysis	3D-scan	schist-osety
HE-033	11.99	N/A	N/A	N/A	N/A	N/A
HE-034	8.29	N/A	N/A	N/A	N/A	N/A
HE-002°	9	N/A	N/A	N/A	N/A	N/A
HE-015°	5.42	N/A	N/A	N/A	N/A	N/A
HE-031°	17.7	N/A	N/A	N/A	N/A	N/A
MU-098		Sharp edges, preserved surface	edges preserved	YES	YES	N/A
Mu-263	13.76	N/A	edges not preserved	NO	NO	N/A
MU-059	10.74	Sharp edges, preserved surface	edges preserved	YES	YES	N/A
MU-036	10.96	Sharp edges, preserved surface	edges preserved	NO	NO	N/A
MU-028	6.72	smoothed edges and fresh surfaces	edges not preserved	NO	NO	N/A
MU-251	5.44	smoothed edges, patinated surface	edges not preserved	NO	NO	N/A
MU-198	4.6	Sharp edges, preserved surface	edges preserved	NO	NO	N/A
MU-015	7.31	smoothed edges, patinated surface	edges not preserved	NO	NO	N/A
MU-266	12.78	smoothed edges, patinated surface	edges not preserved	NO	NO	N/A
MU-006	12.77	Sharp edges, preserved surface	edges preserved	NO	NO	N/A
MU-071	18.12	smoothed edges and fresh surfaces	edges preserved	NO	YES	N/A
MU-211	14.12	smoothed edges, patinated surface	edges preserved	NO	YES	N/A
MU-290	4.57	Sharp edges, preserved surface	edges preserved	YES	YES	N/A

ID	loan	exca-vation year	artefact labelling	strati-graphy	level	artefact drawing	raw material	artefact state
MU-042	LWL Archäologie Münster	N/A	unhorizont-iert	No	N/A	NO	silicified schist	complete
MU-005	LWL Archäologie Münster	N/A	Ia/492 877	YES	N/A	NO	silicified schist	complete
MU-097	LWL Archäologie Münster	1939	Rest D 1939	N/A	N/A	NO	silicified schist	complete
MU-029	LWL Archäologie Münster	N/A	1972:13:00	No	N/A	NO	silicified schist	complete
MU-054	LWL Archäologie Münster	N/A	I/a	YES	6	NO	silicified schist	complete
MU-002	LWL Archäologie Münster	N/A	I/a	YES	6	NO	silicified schist	complete
MU-237	LWL Archäologie Münster	N/A	unhorizont-iert	No	N/A	NO	silicified schist	complete
MU-102	LWL Archäologie Münster	N/A	unhorizont-iert	No	N/A	NO	silicified schist	complete
MU-108	LWL Archäologie Münster	N/A	III/IIIa	YES	4	NO	silicified schist	complete

ID	blank	cortex	cortex percentage	cortex location	morpho-logy back	retouch active edge	retouch type edge
MU-042	N/A	NO	N/A	N/A	partly retouched	YES	semi-bifacial
MU-005	flake	NO	N/A	N/A	retouched	YES	bifacial
MU-097	flake	YES	<25	back	cortex/ unworked	YES	semi-bifacial
MU-029	flake	YES	25-50	back	cortex/ partly retouched	YES	unifacial
MU-054	flake	NO	N/A	N/A	partly retouched	YES	semi-bifacial
MU-002	flake	NO	N/A	N/A	partly retouched	YES	unifacial
MU-237	flake	YES	<25	back	cortex/ unworked	YES	unifacial
MU-102	flake	NO	N/A	N/A	partly retouched	YES	semi-bifacial
MU-108	flake	YES	<25	back	cortex/ unworked	YES	unifacial

ID	tip morphology	application Pradnik method	frequency application Pradnik method	tool lateral-isation	length [mm]	width [mm]	thick-ness [mm]	weight [kg]
MU-042	rounded	YES	one	sin.	33.4	26.6	11.8	0.012
MU-005	rounded	YES	one	sin.	46.4	26.2	11.7	0.014
MU-097	pointed	YES	one	sin.	58.8	35.5	14.3	0.039
MU-029	pointed	N/A		dex.	56.3	36.9	17.5	0.031
MU-054	rounded	YES	N/A	dex.	51.3	31.2	14.5	0.019
MU-002	rounded	YES	N/A	dex.	50.8	31.9	14.2	0.023
MU-237	rounded	YES	one	dex.	49.5	25.9	13.3	0.024
MU-102	pointed	YES	one	dex.	42.4	24.8	17.5	0.013
MU-108	rounded	YES	one	dex.	33.6	25.4	8.5	0.007

ID	thick-ness back [mm]	taphonomic visual inspection	tool edges preservation	use-wear analysis	3D-scan	schist-osety
MU-042	10.09	smoothed edges, patinated surface	edges not preserved	NO	NO	N/A
MU-005	5.46	Sharp edges, preserved surface	edges preserved	YES	YES	N/A
MU-097	13.69	Sharp edges, preserved surface	edges preserved	NO	NO	N/A
MU-029	6.03	Sharp edges, preserved surface	edges preserved	NO	YES	N/A
MU-054	6.88	Sharp edges, preserved surface	edges preserved	NO	YES	N/A
MU-002	6.62	smoothed edges and fresh surfaces	edges preserved	NO	NO	N/A
MU-237	14.06	Sharp edges, preserved surface	edges preserved	YES	YES	N/A
MU-102	13.1	Sharp edges, preserved surface	edges preserved	NO	NO	N/A
MU-108	7.69	Sharp edges, preserved surface	edges preserved	NO	NO	N/A

ID	loan	exca-vation year	artefact labelling	strati-graphy	level	artefact drawing	raw material	artefact state
HE-035	LWL Musem Herne	N/A	III St 59	YES	2	YES by Jöris	silicified schist	medial fragment
HE-036	LWL Musem Herne	N/A	III/III 236	YES	2	NO	silicified schist	distal fragment
HE-037	LWL Musem Herne	N/A	III St 225	YES	2	NO	silicified schist	complete
HE-038	LWL Musem Herne	N/A	C. St	YES	3	NO	silicified schist	complete
HE-039	LWL Musem Herne	N/A	III	YES	2	YES by Jöris	silicified schist	complete
MU-132	LWL Archäologie Münster	N/A	St/132	YES	3	NO	Baltic flint	complete
MU-163	LWL Archäologie Münster	N/A	St/237	YES	3	NO	silicified schist	complete
MU-305	LWL Archäologie Münster	N/A	I/a 824	YES	6	NO	silicified schist	complete
MU-179	LWL Archäologie Münster	N/A	St/271	YES	3	NO	silicified schist	complete
MU-303	LWL Archäologie Münster	N/A	I/a 776	YES	6	NO	silicified schist	complete
MU-221	LWL Archäologie Münster	N/A	St	YES	3	NO	silicified schist	complete
MU-152	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-122	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-121	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-161	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-170	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-169	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-127	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-162	LWL Musem Herne	N/A	N/A	No	N/A	NO	silicified schist	complete

ID	blank	Cortex	type lateral sharpening spall	tool lateralisation	length [mm]	width [mm]	thick-ness [mm]
HE-035	flake	N/A	primary	dex.	19.8	15.9	4.9
HE-036	flake	N/A	primary	dex.	52.9	19.0	7.7
HE-037	flake	N/A	primary	dex.	38.8	15.8	6.8
HE-038	flake	N/A	primary	dex.	36.8	20.7	6.5
HE-039	flake	N/A	primary	dex.	41.6	18.0	7.5
MU-132	flake	NO	primary	sin.	25.2	21.1	8.8
MU-163	flake	NO	secondary	sin.	35.3	21.8	5.2
MU-305	flake	NO	primary	sin.	32.0	23.5	5.8
MU-179	flake	NO	primary	sin.	32.0	17.6	5.4
MU-303	flake	NO	primary	sin.	39.4	22.6	7.0
MU-221	flake	NO	primary	sin.	37.7	29.9	6.3
MU-152	flake	NO	primary	sin.	30.4	18.7	5.8
MU-122	flake	NO	primary	sin.	18.1	11.2	4.9
MU-121	flake	N/A	primary	sin.	26.6	21.7	6.6
MU-161	flake	NO	primary	sin.	35.6	20.7	7.1
MU-170	flake	NO	primary	sin.	19.1	11.4	3.9
MU-169	flake	NO	primary	sin.	20.1	13.1	4.2
MU-127	flake	NO	primary	sin.	28.3	17.8	5.9
MU-162	flake	NO	secondary	sin.	27.2	20.9	6.4

ID	weight [kg]	taphonomic visual inspection	tool edges preservation	use-wear analysis	3D-scan
HE-035	0.002	N/A	N/A	N/A	N/A
HE-036	0.001	N/A	N/A	N/A	N/A
HE-037	0.006	N/A	N/A	N/A	N/A
HE-038	0.005	N/A	N/A	N/A	N/A
HE-039	0.006	N/A	N/A	N/A	N/A
MU-132	0.006	Sharp edges, preserved surface	edges preserved	NO	NO
MU-163	0.004	Sharp edges, preserved surface	edges preserved	NO	NO
MU-305	0.005	Sharp edges, preserved surface	edges preserved	NO	NO
MU-179	0.005	Sharp edges, preserved surface	edges preserved	NO	NO
MU-303	0.007	Sharp edges, preserved surface	edges preserved	NO	NO
MU-221	0.009	Sharp edges, preserved surface	edges preserved	NO	NO
MU-152	0.003	smoothed edges, patinated surface	edges preserved	NO	NO
MU-122	0.001	Sharp edges, preserved surface	edges preserved	NO	NO
MU-121	0.003	Sharp edges, preserved surface	edges preserved	NO	NO
MU-161	0.004	Sharp edges, preserved surface	edges preserved	YES	YES
MU-170	0.001	Sharp edges, preserved surface	edges preserved	NO	NO
MU-169	0.001	Sharp edges, preserved surface	edges preserved	NO	NO
MU-127	0.002	Sharp edges, preserved surface	edges preserved	NO	NO
MU-162	0.004	Sharp edges, preserved surface	edges preserved	NO	NO

ID	loan	excavation year	artefact labelling	stratigraphy	level	artefact drawing	raw material	artefact state
MU-120	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-148	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-131	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-136	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-194	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-116	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-150	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-190	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-124	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-140	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-139	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-144	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-145	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-186	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-203	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-095	LWL Archäologie Münster	N/A	unhorizontiert	No	N/A	NO	silicified schist	complete
MU-307	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete

ID	blank	Cortex	type lateral sharpening spall	tool lateralisation	length [mm]	width [mm]	thick-ness [mm]
MU-120	flake	NO	secondary	sin.	41.2	20.4	7.8
MU-148	flake	NO	primary	sin.	19.7	15.3	4.5
MU-131	flake	NO	primary	sin.	27.0	12.8	6.1
MU-136	flake	NO	primary	sin.	15.1	12.4	3.4
MU-194	flake	NO	primary	sin.	25.1	23.3	6.7
MU-116	flake	NO	secondary	sin.	30.3	15.2	6.6
MU-150	flake	NO	secondary	sin.	38.5	22.6	9.8
MU-190	flake	NO	secondary	sin.	33.0	20.7	5.2
MU-124	flake	NO	primary	sin.	19.9	15.6	4.0
MU-140	flake	N/A	secondary	sin.	20.9	16.2	7.8
MU-139	flake	NO	primary	sin.	27.8	16.1	6.1
MU-144	flake	NO	primary	sin.	21.1	15.9	4.0
MU-145	flake	NO	primary	sin.	18.4	13.4	3.2
MU-186	flake	NO	primary	sin.	37.2	21.5	6.4
MU-203	flake	NO	primary	sin.	40.5	15.2	6.3
MU-095	flake	NO	secondary	sin.	37.9	29.1	9.6
MU-307	flake	NO	primary	sin.	31.1	16.5	5.1

ID	weight [kg]	taphonomic visual inspection	tool edges preservation	use-wear analysis	3D-scan
MU-120	0.005	Sharp edges, preserved surface	edges preserved	NO	NO
MU-148	0.003	smoothed edges, patinated surface	edges preserved	NO	NO
MU-131	0.001	Sharp edges, preserved surface	edges preserved	NO	NO
MU-136	0.001	Sharp edges, preserved surface	edges preserved	NO	NO
MU-194	0.005	Sharp edges, preserved surface	edges preserved	YES	YES
MU-116	0.001	Sharp edges, preserved surface	edges preserved	NO	NO
MU-150	0.008	Sharp edges, preserved surface	edges preserved	NO	NO
MU-190	0.004	Sharp edges, preserved surface	edges preserved	YES	YES
MU-124	0.001	Sharp edges, preserved surface	edges preserved	NO	NO
MU-140	0.002	Sharp edges, preserved surface	edges preserved	NO	NO
MU-139	0.003	Sharp edges, preserved surface	edges preserved	NO	NO
MU-144	0.002	Sharp edges, preserved surface	edges preserved	NO	NO
MU-145	0.001	Sharp edges, preserved surface	edges preserved	NO	NO
MU-186	0.008	Sharp edges, preserved surface	edges preserved	YES	YES
MU-203	0.006	Sharp edges, preserved surface	edges preserved	YES	YES
MU-095	0.011	Sharp edges, preserved surface	edges preserved	YES	YES
MU-307	0.003	Sharp edges, preserved surface	edges preserved	YES	YES

ID	loan	excavation year	artefact labelling	stratigraphy	level	artefact drawing	raw material	artefact state
MU-208	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-207	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
Mu-204	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-056	LWL Archäologie Münster	N/A	I/a	YES	6	NO	silicified schist	complete
MU-137	LWL Archäologie Münster	N/A	St/189	YES	3	NO	silicified schist	complete
MU-055	LWL Archäologie Münster	N/A	I/a	YES	6	NO	silicified schist	complete
MU-220	LWL Archäologie Münster	N/A	a/203	N/A	N/A	NO	silicified schist	complete
MU-118	LWL Archäologie Münster	N/A	St/146	YES	3	NO	silicified schist	complete
MU-191	LWL Archäologie Münster	N/A	St/67	YES	6	NO	silicified schist	complete
MU-128	LWL Archäologie Münster	N/A	St/145	YES	3	NO	silicified schist	complete
MU-219	LWL Archäologie Münster	N/A	III/a/66	YES	4	NO	silicified schist	complete
MU-218	LWL Archäologie Münster	N/A	IIIa/63	YES	4	NO	silicified schist	complete
MU-164	LWL Archäologie Münster	N/A	C.St	YES	3	NO	silicified schist	complete
MU-130	LWL Archäologie Münster	N/A	St	YES	3	NO	silicified schist	complete
MU-119	LWL Archäologie Münster	N/A	St/258	YES	3	NO	silicified schist	complete
MU-050	LWL Archäologie Münster	N/A	I/a	YES	6	NO	silicified schist	complete
MU-149	LWL Archäologie Münster	N/A	St/56	YES	3	NO	silicified schist	complete

ID	blank	Cortex	type lateral sharpening spall	tool lateralisation	length [mm]	width [mm]	thick-ness [mm]
MU-208	flake	NO	primary	sin.	24.8	9.9	3.6
MU-207	flake	NO	secondary	sin.	38.4	17.0	8.9
Mu-204	flake	NO	secondary	sin.	40.1	17.5	9.9
MU-056	flake	NO	secondary	dex.	35.1	11.1	8.4
MU-137	flake	NO	secondary	dex.	34.0	19.0	7.0
MU-055	flake	NO	secondary	dex.	48.7	28.2	8.7
MU-220	flake	NO	primary	dex.	29.3	17.2	6.5
MU-118	flake	NO	secondary	dex.	55.8	23.1	10.1
MU-191	flake	NO	primary	dex.	29.9	18.2	9.3
MU-128	flake	NO	primary	dex.	27.2	24.3	5.5
MU-219	flake	NO	primary	dex.	34.9	25.4	7.2
MU-218	flake	NO	primary	dex.	30.2	18.8	7.4
MU-164	flake	NO	secondary	dex.	31.7	16.4	6.4
MU-130	flake	NO	secondary	dex.	39.3	24.2	8.7
MU-119	flake	NO	primary	dex.	38.5	19.4	6.1
MU-050	flake	NO	secondary	dex.	31.6	12.2	6.3
MU-149	flake	NO	primary	dex.	32.9	21.2	5.1

ID	weight [kg]	taphonomic visual inspection	tool edges preservation	use-wear analysis	3D-scan
MU-208	0.001	Sharp edges, preserved surface	edges preserved	YES	NO
MU-207	0.005	Sharp edges, preserved surface	edges preserved	NO	NO
Mu-204	0.007	Sharp edges, preserved surface	edges preserved	YES	YES
MU-056	0.003	Sharp edges, preserved surface	edges preserved	NO	NO
MU-137	0.004	Sharp edges, preserved surface	edges preserved	NO	NO
MU-055	0.01	Sharp edges, preserved surface	edges preserved	NO	NO
MU-220	0.004	Sharp edges, preserved surface	edges preserved	NO	NO
MU-118	0.011	Sharp edges, preserved surface	edges preserved	YES	YES
MU-191	0.007	Sharp edges, preserved surface	edges preserved	NO	NO
MU-128	0.004	Sharp edges, preserved surface	edges preserved	NO	NO
MU-219	0.005	Sharp edges, preserved surface	edges preserved	NO	NO
MU-218	0.005	Sharp edges, preserved surface	edges preserved	NO	NO
MU-164	0.003	Sharp edges, preserved surface	edges preserved	YES	YES
MU-130	0.006	Sharp edges, preserved surface	edges preserved	NO	NO
MU-119	0.004	Sharp edges, preserved surface	edges preserved	YES	YES
MU-050	0.002	Sharp edges, preserved surface	edges preserved	NO	NO
MU-149	0.005	Sharp edges, preserved surface	edges preserved	NO	NO

ID	loan	excavation year	artefact labelling	stratigraphy	level	artefact drawing	raw material	artefact state
MU-103	LWL Archäologie Münster	N/A	III/a und III/III	YES	4	NO	silicified schist	complete
MU-104	LWL Archäologie Münster	N/A	III/a und III/III	YES	4	NO	silicified schist	complete
MU-176	LWL Archäologie Münster	N/A	St/262	YES	3	NO	silicified schist	complete
MU-165	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-215	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-300	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-302	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-292	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-298	LWL Archäologie Münster	N/A	I/a	YES	6	NO	silicified schist	complete
MU-299	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-301	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-297	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-296	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-115	LWL Archäologie Münster	N/A	N/A	No	N/A	YES by Jöris	silicified schist	complete
MU-306	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-117	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-181	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete

ID	blank	Cortex	type lateral sharpening spall	tool lateralisation	length [mm]	width [mm]	thick-ness [mm]
MU-103	flake	NO	primary	dex.	41.5	19.7	9.9
MU-104	flake	NO	primary	dex.	42.1	14.1	6.6
MU-176	flake	NO	primary	dex.	32.9	21.8	5.0
MU-165	flake	NO	primary	dex.	27.4	17.1	7.3
MU-215	flake	NO	secondary	dex.	48.8	25.0	10.0
MU-300	flake	NO	primary	dex.	20.6	17.6	5.0
MU-302	flake	NO	primary	dex.	23.1	16.2	5.7
MU-292	flake	NO	primary	dex.	21.7	13.1	5.9
MU-298	flake	NO	primary	dex.	32.1	22.5	4.4
MU-299	flake	NO	primary	dex.	16.4	7.0	2.3
MU-301	flake	NO	primary	dex.	18.9	12.6	4.6
MU-297	flake	NO	primary	dex.	25.3	13.5	3.0
MU-296	flake	NO	primary	dex.	26.5	13.4	4.4
MU-115	flake	NO	primary	dex.	34.3	19.1	5.7
MU-306	flake	NO	primary	dex.	23.4	15.3	2.6
MU-117	flake	NO	primary	dex.	24.9	16.0	4.8
MU-181	flake	NO	primary	dex.	22.4	21.2	5.7

ID	weight [kg]	taphonomic visual inspection	tool edges preservation	use-wear analysis	3D-scan
MU-103	0.0016	Sharp edges, preserved surface	edges preserved	YES	YES
MU-104	0.004	Sharp edges, preserved surface	edges preserved	YES	YES
MU-176	0.004	Sharp edges, preserved surface	edges preserved	NO	NO
MU-165	0.004	Sharp edges, preserved surface	edges preserved	NO	NO
MU-215	0.016	Sharp edges, preserved surface	edges preserved	YES	YES
MU-300	0.001	Sharp edges, preserved surface	edges preserved	NO	NO
MU-302	0.001	Sharp edges, preserved surface	edges preserved	NO	NO
MU-292	0.001	Sharp edges, preserved surface	edges preserved	NO	NO
MU-298	0.003	Sharp edges, preserved surface	edges preserved	NO	NO
MU-299	0.001	Sharp edges, preserved surface	edges preserved	NO	NO
MU-301	0.001	Sharp edges, preserved surface	edges preserved	YES	YES
MU-297	0.001	Sharp edges, preserved surface	edges preserved	NO	NO
MU-296	0.001	Sharp edges, preserved surface	edges preserved	NO	NO
MU-115	0.003	Sharp edges, preserved surface	edges preserved	NO	NO
MU-306	0.001	Sharp edges, preserved surface	edges preserved	NO	NO
MU-117	0.001	Sharp edges, preserved surface	edges preserved	NO	NO
MU-181	0.004	Sharp edges, preserved surface	edges preserved	NO	NO

ID	loan	exca-vation year	artefact labelling	strati-graphy	level	artefact drawing	raw material	artefact state
MU-129	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-304	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	distal fragment
MU-155	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-143	LWL Archäologie Münster	N/A	MU-143	No	N/A	NO	silicified schist	medial fragment
MU-185	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-147	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-175	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-180	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-157	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-168	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-153	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-166	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-141	LWL Archäologie Münster	N/A	N/A	No	N/A	YES by Jöris	silicified schist	complete
MU-123	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-192	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-142	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-158	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete

ID	blank	Cortex	type lateral sharpening spall	tool lateralisation	length [mm]	width [mm]	thick-ness [mm]
MU-304	flake	NO	primary	dex.	35.0	20.6	6.1
MU-155	flake	NO	primary	dex.	26.8	28.6	8.3
MU-143	flake	NO	primary	dex.	13.7	13.3	2.3
MU-185	flake	NO	primary	dex.	20.6	13.4	3.9
MU-147	flake	NO	primary	dex.	13.5	11.0	4.1
MU-175	flake	NO	primary	dex.	25.2	16.6	5.6
MU-180	flake	NO	primary	dex.	22.3	10.9	3.9
MU-157	flake	NO	primary	dex.	21.9	18.5	5.3
MU-168	flake	NO	primary	dex.	20.7	12.1	3.4
MU-153	flake	NO	secondary	dex.	34.3	16.4	5.5
MU-166	flake	NO	primary	dex.	23.8	18.2	6.6
MU-141	flake	NO	primary	dex.	18.8	10.6	2.1
MU-123	flake	NO	primary	dex.	16.7	10.8	3.4
MU-192	flake	N/A	primary	dex.	20.8	11.6	3.5
MU-142	flake	NO	primary	dex.	23.7	11.3	4.3
MU-158	flake	NO	primary	dex.	24.9	16.8	5.5

ID	weight [kg]	taphonomic visual inspection	tool edges preservation	use-wear analysis	3D-scan
MU-129	0.003	Sharp edges, preserved surface	edges preserved	NO	NO
MU-304	0.004	Sharp edges, preserved surface	edges preserved	NO	NO
MU-155	0.009	Sharp edges, preserved surface	edges preserved	NO	NO
MU-143	0.001	Sharp edges, preserved surface	edges preserved	NO	NO
MU-185	0.001	Sharp edges, preserved surface	edges preserved	NO	NO
MU-147	0.001	Sharp edges, preserved surface	edges preserved	NO	NO
MU-175	0.003	Sharp edges, preserved surface	edges preserved	NO	NO
MU-180	0.001	Sharp edges, preserved surface	edges preserved	YES	YES
MU-157	0.002	Sharp edges, preserved surface	edges preserved	NO	NO
MU-168	0.001	Sharp edges, preserved surface	edges preserved	NO	NO
MU-153	0.005	Sharp edges, preserved surface	edges preserved	YES	YES
MU-166	0.003	Sharp edges, preserved surface	edges preserved	NO	NO
MU-141	0.001	Sharp edges, preserved surface	edges preserved	NO	NO
MU-123	0.001	Sharp edges, preserved surface	edges preserved	NO	NO
MU-192	0.001	Sharp edges, preserved surface	edges preserved	NO	NO
MU-142	0.002	Sharp edges, preserved surface	edges preserved	NO	NO
MU-158	0.006	Sharp edges, preserved surface	edges preserved	NO	NO

ID	loan	excavation year	artefact labelling	stratigraphy	level	artefact drawing	raw material	artefact state
MU-135	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-146	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-291	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-133	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-177	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-193	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	distal fragment
MU-223	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-167	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-171	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-295	LWL Archäologie Münster	N/A	N/A	No	N/A	needed	silicified schist	complete
MU-159	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-014	LWL Archäologie Münster	N/A	Lesefunde	No	N/A	NO	silicified schist	complete
MU-173	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-182	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	distal fragment
MU-126	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-183	LWL Musem Herne	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-178	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-172	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete

ID	blank	Cortex	type lateral sharpening spall	tool lateralisation	length [mm]	width [mm]	thick-ness [mm]
MU-135	flake	NO	primary	dex.	22.8	10.3	4.8
MU-146	flake	NO	primary	dex.	14.3	14.4	4.7
MU-291	flake	NO	primary	dex.	39.6	29.3	6.6
MU-133	flake	NO	primary	dex.	25.3	14.1	2.7
MU-177	flake	NO	primary	dex.	25.8	19.0	6.4
MU-193	flake	NO	primary	dex.	20.5	16.7	6.1
MU-223	flake	NO	primary	dex.	40.7	29.6	10.7
MU-167	flake	NO	primary	dex.	17.2	10.4	4.6
MU-171	flake	NO	secondary	dex.	18.8	11.1	3.8
MU-295	flake	NO	secondary	dex.	50.8	13.9	7.3
MU-159	flake	NO	primary	dex.	19.4	24.1	6.1
MU-014	flake	NO	primary	dex.	51.1	26.2	10.4
MU-173	flake	NO	secondary	dex.	18.3	10.0	2.8
MU-182	flake	NO	primary	dex.	25.4	17.0	5.7
MU-126	flake	NO	primary	dex.	24.7	13.3	5.7
MU-183	flake	NO	primary	dex.	25.4	15.4	5.9
MU-178	flake	NO	primary	dex.	26.4	19.5	6.5
MU-172	flake	NO	primary	dex.	14.3	11.3	5.3

ID	weight [kg]	taphonomic visual inspection	tool edges preservation	use-wear analysis	3D-scan
MU-135	0.001	Sharp edges, preserved surface	edges preserved	NO	NO
MU-146	0.001	Sharp edges, preserved surface	edges preserved	NO	NO
MU-291	0.01	Sharp edges, preserved surface	edges preserved	NO	NO
MU-133	0.001	Sharp edges, preserved surface	edges preserved	NO	NO
MU-177	0.003	Sharp edges, preserved surface	edges preserved	NO	NO
MU-193	0.004	Sharp edges, preserved surface	edges preserved	NO	NO
MU-223	0.014	Sharp edges, preserved surface	edges preserved	NO	NO
MU-167	0.001	Sharp edges, preserved surface	edges preserved	NO	NO
MU-171	0.001	Sharp edges, preserved surface	edges preserved	NO	NO
MU-295	0.01	Sharp edges, preserved surface	edges preserved	YES	YES
MU-159	0.002	Sharp edges, preserved surface	edges preserved	NO	NO
MU-014	0.011	Sharp edges, preserved surface	edges preserved	NO	NO
MU-173	0.001	Sharp edges, preserved surface	edges preserved	YES	YES
MU-182	0.003	sharp edges and patinated surface	edges preserved	NO	NO
MU-126	0.001	Sharp edges, preserved surface	edges preserved	NO	NO
MU-183	0.002	Sharp edges, preserved surface	edges preserved	NO	NO
MU-178	0.003	Sharp edges, preserved surface	edges preserved	NO	NO
MU-172	N/A	Sharp edges, preserved surface	edges preserved	NO	NO
MU-151	0.002	Sharp edges, preserved surface	edges preserved	NO	NO

ID	loan	excavation year	artefact labelling	stratigraphy	level	artefact drawing	raw material	artefact state
MU-151	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-189	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-205	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-209	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-216	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-217	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-188	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-138	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-187	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-160	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete
MU-184	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	medial fragment
MU-174	LWL Archäologie Münster	N/A	N/A	No	N/A	NO	silicified schist	complete

ID	blank	Cortex	type lateral sharpening spall	tool lateralisation	length [mm]	width [mm]	thick-ness [mm]
MU-151	flake	NO	primary	dex.	30.2	17.6	4.3
MU-189	flake	NO	primary	dex.	23.5	11.4	4.7
MU-205	flake	NO	secondary	dex.	40.0	26.3	11.0
MU-209	flake	NO	primary	dex.	37.2	12.2	5.5
MU-216	flake	NO	secondary	dex.	44.5	22.1	6.1
MU-217	flake	NO	secondary	dex.	34.0	19.7	9.0
MU-188	flake	NO	primary	dex.	29.4	17.3	7.2
MU-138	flake	NO	secondary	dex.	21.1	13.8	3.6
MU-187	flake	NO	primary	dex.	39.9	17.9	6.9
MU-160	flake	NO	secondary	dex.	34.2	21.4	8.6
MU-184	flake	NO	primary	dex.	8.2	11.9	3.0
MU-174	flake	NO	primary	dex.	12.4	8.5	3.6

ID	weight [kg]	taphonomic visual inspection	tool edges preservation	use-wear analysis	3D-scan
MU-151	0.002	Sharp edges, preserved surface	edges preserved	NO	NO
MU-189	0.001	Sharp edges, preserved surface	edges preserved	NO	NO
MU-205	0.009	Sharp edges, preserved surface	edges preserved	NO	NO
MU-209	0.001	Sharp edges, preserved surface	edges preserved	NO	NO
MU-216	0.007	Sharp edges, preserved surface	edges preserved	NO	NO
MU-217	0.006	Sharp edges, preserved surface	edges preserved	YES	YES
MU-188	0.004	Sharp edges, preserved surface	edges preserved	NO	NO
MU-138	0.001	Sharp edges, preserved surface	edges preserved	NO	NO
MU-187	0.004	Sharp edges, preserved surface	edges preserved	NO	NO
MU-160	0.004	Sharp edges, preserved surface	edges preserved	YES	YES
MU-184	0.001	Sharp edges, preserved surface	edges preserved	NO	NO
MU-174	0.001	Sharp edges, preserved surface	edges preserved	NO	NO

Ramioul

ID	loan	exca-vation year	artefact labelling	strati-graphy	artefact drawing	raw material	artefact state
R-001	Prehistomuseum Flémalle	1910th	5196	N/A	NO	flint	complete
R-002	Prehistomuseum Flémalle	1910th	5139	N/A	NO	flint	complete
R-006	Prehistomuseum Flémalle	1910th	5168	N/A	NO	flint	complete
R-007	Prehistomuseum Flémalle	1910th	5157	N/A	needed	flint	complete
R-008	Prehistomuseum Flémalle	1910th	5138	N/A	NO	flint	complete
R-011	Prehistomuseum Flémalle	1910th	5146	N/A	NO	flint	complete
R-018	Prehistomuseum Flémalle	1910th	5156	N/A	NO	flint	complete
R-019	Prehistomuseum Flémalle	1910th	5157	N/A	needed	flint	complete
R-020	Prehistomuseum Flémalle	1910th	5067	N/A	needed	silicified schist	complete

ID	blank	*Keilmesser* shape	cortex	cortex percentage	cortex location	morpho-logy back	retouch active edge	retouch type edge
R-001	core	Balve	YES	<25	back	cortex partly retouched	YES	bifacial
R-002	core	Klausennische	YES	<25	back	cortex/ unworked	YES	semi-bifacial
R-006	flake	Pradnik	NO	<25	N/A	retouched	YES	semi-bifacial
R-007	core	Klausennische	YES	25-50	back	cortex/ unworked	YES	bifacial
R-008	N/A	Balve	YES	<25	back	cortex partly retouched	YES	semi-bifacial
R-011	core	Klausennische	YES	25-50	back	cortex partly retouched	YES	unifacial
R-018	N/A	Pradnik	YES	<25	proximal dorsal	cortex partly retouched	YES	bifacial
R-019	N/A	Balve	YES	<25	back	retouched	YES	bifacial
R-020	N/A	Pradnik	YES	<25	back	cortex partly retouched	YES	semi-bifacial

ID	tip morphology	application Pradnik method	frequency application Pradnik method	tool lateral-isation	length [mm]	width [mm]	thick-ness [mm]	weight [kg]
R-001	rounded	YES	one	dex.	50.0	33.0	16.0	0.025
R-002	rounded	YES	one	dex.	44.0	27.0	21.0	0.02
R-006	rounded	NO	N/A	dex.	53.0	31.0	16.0	0.018
R-007	rounded	YES	one	dex.	76.0	37.0	21.0	0.062
R-008	rounded	YES	one	dex.	75.0	43.0	23.0	0.066
R-011	rounded	YES	one	dex.	42.0	28.0	18.0	0.024
R-018	broken	YES	one	sin.	78.0	31.0	14.0	0.037
R-019	rounded	YES	multiple	dex.	106.0	50.0	20.0	0.112
R-020	rounded	YES	one	dex.	117.0	57.0	19.0	0.14

ID	peri-meter basis + back [cm]	peri-meter distal posterior part [cm]	peri-meter active edge [cm]	thick-ness back [mm]	tapho-nomic visual inspection	tool edges preser-vation	use-wear analysis	3D-scan	schist-osety
R-001	6.7	3.0	5.0	16.0	sharp edges and patinated surface	edges preserved	YES	YES	N/A
R-002	6.4	2.5	4.0	21.0	sharp edges and patinated surface	edges preserved	YES	YES	N/A
R-006	5.7	3.1	4.4	6.0	sharp edges and patinated surface	edges preserved	YES	YES	N/A
R-007	9.5	1.9	6.5	21.0	sharp edges and preserved surface	edges preserved	YES	YES	N/A
R-008	7.3	4.4	7.6	17.0	sharp edges and patinated surface	edges preserved	YES	YES	N/A
R-011	6.4	2.5	4.3	16.0	sharp edges and preserved surface	edges preserved	YES	YES	N/A
R-018	6.5	4.0	7.8	7.0	smoothed edges and patinated surface	edges preserved	NO	YES	N/A
R-019	10.5	5.5	11.3	8.0	sharp edges and preserved surface	edges preserved	YES	YES	N/A
R-020	9.6	8.2	1.3	15.0	smoothed edges and patinated surface	edges preserved	YES	YES	N/A

ID	loan	excavation year	artefact labelling	stratigraphy	artefact drawing	raw material	artefact state
R-010	Prehistomuseum Flémalle	1910th	5044	N/A	needed	flint	complete
R-014	Prehistomuseum Flémalle	1910th	5147	N/A	NO	flint	complete
R-016	Prehistomuseum Flémalle	1910th	5132	N/A	NO	flint	complete

ID	blank	cortex	cortex percentage	cortex location	morphology back	retouch active edge	retouch type edge
R-010	flake	NO	N/A	N/A	retouched	YES	unifacial
R-014	flake	NO	N/A	N/A	retouched	YES	semi-bifacial
R-016	flake	NO	N/A	N/A	retouched	YES	unifacial

ID	tip morphology	application Pradnik method	frequency application Pradnik method	tool lateralisation	length [mm]	width [mm]	thickness [mm]	weight [kg]
R-010	rounded	YES	one	dex.	52.0	35.0	14.0	0.0017
R-014	broken	YES	one	sin.	48.0	37.0	11.0	0.02
R-016	pointed	N/A	N/A	dex.	45.0	35.0	11.0	0.016

ID	thickness back [mm]	taphonomic visual inspection	tool edges preservation	use-wear analysis	3D-scan	schistosety
R-010	5.0	sharp edges and patinated surface	edges preserved	YES	YES	N/A
R-014	6.0	sharp edges and patinated surface	edges preserved	YES	YES	N/A
R-016	6.0	sharp edges and patinated surface	edges preserved	NO	YES	N/A

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to attain the academic degree of
Dr. phil.,

submitted to the department 07
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at Johannes Gutenberg University Mainz

Lisa Schunk
born in Koblenz

Koblenz 2021

Römisch-Germanisches Zentralmuseum
Leibniz-Forschungsinstitut für Archäologie
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Volume 2

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Volume 1

Understanding Middle Palaeolithic asymmetric stone tool design and use: use-wear analysis and controlled experiments to assess Neanderthal technology

Volume 2

Appendix II.

List of all archaeological samples from Buhlen, Balver Höhle and Ramioul selected for the qualitative and quantitative use-wear analyses.

Buhlen

artefact category	ID	location	use-wear type	orientation	quantitative use-wear
Keilmesser	BU-003	d1-1	V. (C)	undefined	yes
		d1-2	V. (C)	undefined	
	BU-004	a2-1	I. (A)	undefined	
		a3-1	I. (A)	undefined	
	BU-006	a2-1	V. (C)	undefined	
		d1-1	I. (A)	undefined	
	BU-009	b2-1	V. (C)	undefined	
		d1-1	V. (C)	undefined	
	BU-012	b2-1	V. (C)	undefined	
	BU-016	d1-1	V. (C)	undefined	
	BU-017	c2-1	V. (C)	undefined	
	BU-019	b3-1	IV. (E)	undefined	
	BU-024	d3-1	I. (A)	undefined	
	BU-028	a2-1	I. (A)	undefined	
		d2-1	V. (C)	undefined	
	BU-032	b2-1	V. (C)	undefined	
		a3-1	VII. (D2)	parallel	yes
	BU-036	b2-1	V. (C)	undefined	
		d1-1	V. (C)	undefined	
	BU-039	c3-1	V. (C)	undefined	
	BU-040	b1-1	V. (C)	undefined	
		b3-1	V. (C)	undefined	
		a3-1	I. (A)	undefined	
	BU-046	d1-1	V. (C)	perpendicular	
	BU-048	d2-1	V. (C)	parallel	
	BU-051	b2-1	I. (A)	undefined	
	BU-054	b3-1	I. (A)	undefined	
	BU-056	b1-1	V. (C)	undefined	
		b2-1	V. (C)	parallel	
		b3-1	V. (C)	undefined	
	BU-057	b3-1	V. (C)	undefined	
	BU-058	b3-1	I. (A)	undefined	
	BU-060	b2-1	V. (C)	undefined	
		a2-1	V. (C)	undefined	
		d2-1	V. (C)	undefined	
	BU-066	b1-1	V. (C)	undefined	
		b2-1	V. (C)	undefined	
		b3-1	I. (A)	undefined	
		b3-2	I. (A)	undefined	
		d3-1	I. (A)	undefined	

		d3-2	V. (C)	undefined	
	BU-069	b2-1	V. (C)	parallel	
		d1-1	V. (C)	undefined	
	BU-074	d1-2	V. (C)	undefined	
		c1-2	V. (C)	undefined	
	BU-076	b1-1	V. (C)	undefined	
		d3-1	V. (C)	undefined	
		c1-1	V. (C)	undefined	
	BU-077	a3-1	V. (C)/IV. (E)	undefined	yes
	BU-078	c3-1	I. (A)	undefined	
		d1-1	V. (C)	undefined	
		d1-2	V. (C)	undefined	
		01. Jan	V. (C)	undefined	
	BU-079	d1-1	V. (C)	undefined	
	BU-160	d1-1	V. (C)	undefined	
	BU-163	a3-1	V. (C)	undefined	
		d2-1	V. (C)	undefined	
		d3-1	I. (A)	undefined	
	BU-158	d3-1	V. (C)	undefined	
	BU-173	d2-1	V. (C)	parallel	yes
	BU-174	b2-1	V. (C)	undefined	
Keilmesser tip	BU-085	c2-1	V. (C)	undefined	
	BU-086	b1-1	V. (C)	undefined	
		d1-1	V. (C)	undefined	
		d1-2	V. (C)	undefined	
	BU-087	a3-1	V. (C)	undefined	
		c1-1	V. (C)	undefined	
		b3-1	V. (C)	undefined	
	BU-088	d1-1	V. (C)	undefined	
		c2-1	IV. (E)	undefined	
	BU-090	b2-1	V. (C)	undefined	
		a1-1	I. (A)	undefined	
	BU-093	b1-1	I. (A)	undefined	
	BU-097	b1-1	I. (A)	undefined	
Pradnik scraper	BU-099	b3-1	I. (A)	undefined	
		d3-1	I. (A)	undefined	
		c3-1	I. (A)	undefined	
	BU-100	b1-1	I. (A)	undefined	
	BU-101	d3-1	V. (C)	undefined	
	BU-103	b1-1	V. (C)	undefined	
		b2-1	V. (C)	undefined	
	BU-104	b2-1	I. (A)	undefined	
	BU-105	b3-1	V. (C)	parallel	
		d1-1	V. (C)	parallel	

	BU-106	d3-1	V. (C)	undefined	
		c1-1	I. (A)	undefined	
	BU-107	b2-1	V. (C)	undefined	
		d3-1	IX. (G)	perpendicular	
		c1-1	V. (C)	undefined	
	BU-115	b2-1	V. (C)	perpendicular	yes
		b3-1	V. (C)	undefined	
		c1-1	V. (C)	undefined	
		d1-1	V. (C)	undefined	
		c3-1	I. (A)	undefined	
	BU-117	a3-1	V. (C)	undefined	
		d1-1	I. (A)	undefined	
		d2-1	V. (C)	parallel	
	BU-194	d1-1	VI. (D)	undefined	
Pradnik spall	BU-121	b1-1	V. (C)	undefined	
		b2-1	V. (C)	undefined	
		a1-1	V. (C)	undefined	
	BU-124	b1-2	V. (C)	undefined	
		c1-1	V. (C)	undefined	
	BU-127	b1-1	V. (C)	undefined	
		b1-2	V. (C)	undefined	
		d1-1	V. (C)	undefined	
	BU-128	c2-1	V. (C)	undefined	
		d2-1	V. (C)	undefined	yes
	BU-129	d2-1	I. (A)	undefined	
		b1-1	I. (A)	undefined	
	BU-131	d1-1	V. (C)	undefined	
	BU-132	c2-1	V. (C)	undefined	
	BU-136	b2-1	V. (C)	undefined	
	BU-139	a2-1	V. (C)	undefined	
	BU-157	b1-1	I. (A)	undefined	
		b2-1	I. (A)	undefined	
	BU-169	b2-1	V. (C)	parallel	
		d2-1	I. (A)	undefined	
scraper	BU-189	b1-1	V. (C)	perpendicular	

Balver Höhle

artefact category	ID	location	use-wear type	orientation	quantitative use-wear
Keilmesser	MU-003	b1-1	I. (A)	parallel	
		b1-2	I. (A)	parallel	
		b2-1	I. (A)	parallel	
		b3-1	I. (A)	parallel	
		d1-1	II. (B)	parallel	yes
	MU-008	b2-1	V. (C)	undefined	yes
		b2-2	V. (C)	undefined	
	MU-011	d1-1	V. (C)	parallel	
	MU-020	b1-1	VI. (D)	perpendicular	yes
		b1-2	VI. (D)	perpendicular	yes
		b2-1	VII. (D2)	perpendicular	yes
	MU-021	c3-1	II. (B)	perpendicular	yes
		d1-1	VII. (D2)	perpendicular	yes
		d1-2	VII. (D2)	perpendicular	
		d1-3	VII. (D2)	perpendicular	
	MU-023	d2-1	I. (A)	parallel	
		d2-2	II. (B)	parallel	
	MU-044	d3-1	II. (B)	parallel	
	MU-061	d1-1	V. (C)	parallel	
	MU-063	b1-1	II. (B)	parallel	
	MU-073	d1-1	II. (B)	perpendicular	
	MU-093	c3-1	V. (C)	parallel	
		c3-2	VII. (D2)	oblique	
	MU-100	b2-1	I. (A)	parallel	
		d3-1	I. (A)	oblique	
	MU-107	b1-1	V. (C)	parallel	yes
		d2-1	V. (C)	undefined	yes
	MU-109	b3-1	I. (A)	undefined	
	MU-111	b1-1	IV. (E)	parallel	yes
		d1-1	IV. (E)	undefined	
		d3-1	III. (C)	undefined	
	MU-112	c1-1	IV. (E)	parallel	yes
		c3-1	IV. (E)	parallel	
	MU-114	b3-1	II. (B)	undefined	
		d3-1	II. (B)	perpendicular	
		b3-2	II. (B)	undefined	
	MU-196	b1-1	V. (C)	parallel	
		d1-1	V. (C)	parallel	
		d1-2	V. (C)	parallel	
	MU-197	b1-1	VIII. (F)	oblique	

		b2-1	VIII. (F)	perpendicular	yes
		d3-2	V. (C)	undefined	
		d3-1	VIII. (F)	parallel	yes
	MU-199	a1-1	I. (A)	parallel	
		a2-1	IV. (E)	parallel	yes
		c3-1	V. (C)	parallel	yes
	MU-202	c2-1	I. (A)	undefined	yes
		d1-1	V. (C)	undefined	
		d2-1	V. (C)	perpendicular	yes
		a2-1	I. (A)	undefined	
		b1-1	II. (B)	perpendicular	
	MU-214	d1-2	V. (C)	parallel	
		d3-1	V. (C)	parallel	
		c2-1	V. (C)	parallel	
		d1-1	V. (C)	parallel	
	MU-224	d1-1	V. (C)	parallel	yes
		b1-1	III. (B2)	parallel	yes
	MU-226	b2-1	V. (C)	perpendicular	
		b2-2	IV. (E)	undefined	
		d2-1	V. (C)	undefined	
	MU-230	a2-1	II. (B)	undefined	
		d2-1	II. (B)	undefined	
	MU-231	a1-1	I. (A)	undefined	
		b1-1	V. (C)	parallel	
		b2-1	V. (C)	parallel	
	MU-232	b2-1	IV. (E)	undefined	yes
		b2-2	I. (A)	undefined	yes
		d1-1	V. (C)	undefined	
	MU-234	b2-1	V. (C)	parallel	
		b3-1	III. (B2)	parallel	
		a3-1	V. (C)	parallel	
		d2-1	IV. (E)	parallel	
	MU-240	a3-1	V. (C)	undefined	
		c2-1	V. (C) + I. (A)	undefined	yes
		d1-1	VIII. (F)	perpendicular	yes
	MU-241	b3-1	V. (C)	parallel	
		d2-1	V. (C)	parallel	
	MU-246	d1-1	IV. (E)	parallel	
		d1-2	V. (C)/IV. (E)	parallel	yes
		b1-1	V. (C)/IV. (E)	perpendicular	
	MU-249	a1-1	V. (C)	parallel	
	MU-272	d1-1	V. (C) + VIII. (F)	perpendicular	
	MU-273	b1-1	I. (A)	undefined	
		b3-1	V. (C)/IV. (E)	undefined	yes

	MU-276	b3-1	V. (C)/IV. (E)	parallel	
	MU-280	a3-1	I. (A)	perpendicular	
	MU-283	a2-1	II. (B)	perpendicular	
		b2-1	II. (B)	perpendicular	
		d1-1	I. (A)	undefined	
	MU-286	b2-2	VII. (D2)	parallel	
		d3-1	V. (C)	parallel	
	MU-288	d2-2	V. (C)	oblique	
		d2-1	II. (B)	oblique	
	MU-293	b3-1	VII. (D2)	perpendicular	
		c2-1	VI. (D)	parallel	
		d2-1	I. (A)	undefined	
***Keilmesser* tip**	MU-041	d1-1	IV. (E)	parallel	yes
		d2-1	IV. (E)	undefined	yes
	MU-210	b1-1	I. (A)	undefined	
		c2-1	I. (A)	undefined	
		d1-1	V. (C)	undefined	
		d1-2	II. (B)	undefined	
		d3-1	V. (C)	undefined	
Prądnik* *scraper	MU-005	b2-1	V. (C)	undefined	
		d2-1	I. (A)	parallel	
	MU-098	d1-1	VII. (D2)	parallel	
		d2-1	V. (C)	parallel	
		d3-1	V. (C)	parallel	
Prądnik spall	MU-095	b1-01	II. (B)	undefined	
	MU-104	a1-1	V. (C)	undefined	
		c1-1	V. (C)/IV. (E)	undefined	yes
	MU-118	d2-1	V. (C)/IV. (E)	undefined	
		d2-2	II. (B)	undefined	
		c2-1	V. (C)	undefined	
	MU-119	c2-1	I. (A)	undefined	
		b1-1	I. (A)	undefined	
		d1-1	V. (C)	undefined	yes
	MU-153	a1-1	V. (C)	undefined	
	MU-161	a2-1	V. (C)	parallel	
	MU-164	c1-1	II. (B)	undefined	
		c2-1	II. (B)	undefined	
	MU-173	a1-1	V. (C)	parallel	
		d2-1	V. (C)	undefined	
	MU-180	d1-1	V. (C)	undefined	
		b1-1	V. (C)	undefined	
		a2-1	V. (C)	undefined	
		b1-2	V. (C)	oblique	
		b2-1	VIII. (F)	undefined	

	MU-186	b2-1	V. (C)	undefined	
		c2-1	VIII. (F)	oblique	
		d1-1	V. (C)/IV. (E)	undefined	
	MU-190	d1-1	V. (C)	undefined	
		d1-2	VI. (D)	undefined	
	MU-194	c2-1	V. (C)	undefined	
		d1-2	V. (C)	parallel	
		d1-1	V. (C)	parallel	
		b2-1	V. (C)	undefined	
	MU-203	c2-1	VI. (D)	perpendicular	
	MU-204	d1-1	V. (C)	undefined	
	MU-217	b1-1	V. (C)/IV. (E)	parallel	
		b2-1	I. (A)	undefined	yes
	MU-301	d1-1	V. (C)	undefined	
scraper	MU-019	a2-1	VII. (D2)	undefined	
		a3-1	VII. (D2)	undefined	yes
	MU-025	a2-1	II. (B)	parallel	yes
	MU-030	d1-1	IV. (E)	perpendicular	
		d2-1	VIII. (F)	parallel	
		d2-2	I. (A)	undefined	
		c3-1	VIII. (F)	parallel	
	MU-201	b1-1	I. (A)	undefined	
	MU-274	b2-1	V. (C)	parallel	
	MU-278	b2-1	II. (B)	undefined	
		b3-1	II. (B)	undefined	
		d2-1	V. (C)	undefined	
		c1-1	V. (C)	undefined	
		c2-1	V. (C)	undefined	
	MU-279	b2-1	V. (C)	undefined	
		b3-1	IV. (E)	parallel	
		b3-2	IV. (E)	parallel	
		d1-1	IV. (E)	undefined	
		d2-2	V. (C)	undefined	yes
		d2-1	V. (C)	undefined	
		c2-1	V. (C)	undefined	
	MU-285	a3-1	V. (C)	parallel	
		d1-1	I. (A)	undefined	
		d1-2	I. (A)	undefined	
		a1-1	V. (C)	parallel	

Ramioul

artefact category	ID	location	use-wear type	orientation	quantitative use-wear
Keilmesser	R-002	b1-1	VI. (D)	undefined	yes
	R-006	d3-1	IV. (E)	undefined	yes
	R-007	d2-1	IX. (G)	undefined	yes
		d3-1	IX. (G)	undefined	
	R-008	d2-1	VI. (D)	undefined	
		c1-1	VI. (D)	undefined	
		d1-4	VI. (D)	perpendicular	
		d1-2	VI. (D)	parallel	yes
		d3-1	VI. (D)	oblique	
		d1-3	V. (C)	undefined	
	R-011	d1-1	IV. (E)	undefined	
	R-018	b1-1	V. (C)/VI. (D)	parallel	
		b1-2	V. (C)	parallel	
	R-019	d2-1	II. (B)	undefined	
	R-020	b1-1	II. (B)	undefined	
		b2-1	II. (B)	undefined	
		d2-1	I. (A)	undefined	yes
		d2-2	VIII. (F)	perpendicular	
		d3-1	IX. (G)	undefined	yes
Prądnik scraper	R-010	a2-1	V. (C)	oblique	yes
		d1-1	V. (C)/IV. (E)	undefined	yes
	R-014	a1-1	V. (C)	undefined	
	R-016	b3-1	IX. (G)	undefined	
		d1-1	IX. (G)	undefined	
scraper	R-003	a3-1	V. (C)	undefined	
	R-012	c1-1	V. (C)	undefined	
	R-013	b2-1	IX. (G)	parallel	
		d1-1	IX. (G)	undefined	yes
		d1-2	IX. (G)	undefined	yes
		d3-1	VII. (D2)	undefined	yes
		c3-1	V. (C)/IV. (E)	undefined	
	R-015	a1-1	IX. (G)	undefined	
	R-017	b2-1	V. (C)	undefined	
		b2-2	V. (C)	undefined	
		b3-1	IV. (E)	undefined	
flake	R-009	d2-1	V. (C)	undefined	
		c1-1	V. (C)	undefined	
		c2-2	V. (C)	undefined	

Appendix III.

Results of the qualitative and quantitative use-wear analyses performed on samples from the archaeological sites Buhlen, Balver Höhle and Ramioul.

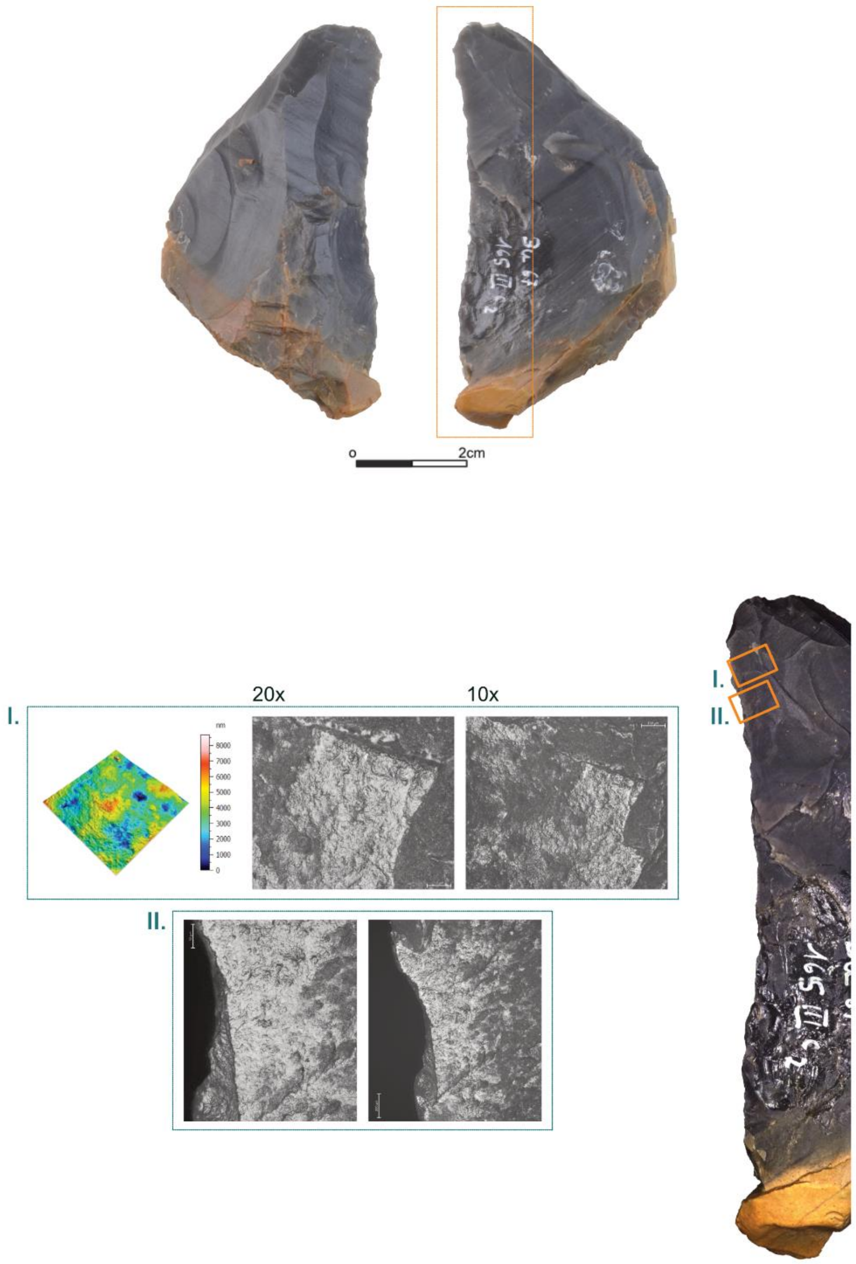


Fig. 1 Buhlen, *Keilmesser* [ID BU-003]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x and 20x (I. type V.; II. type V.). The micro-surface displays the processed result of the confocal data acquisition with the 50x objective.

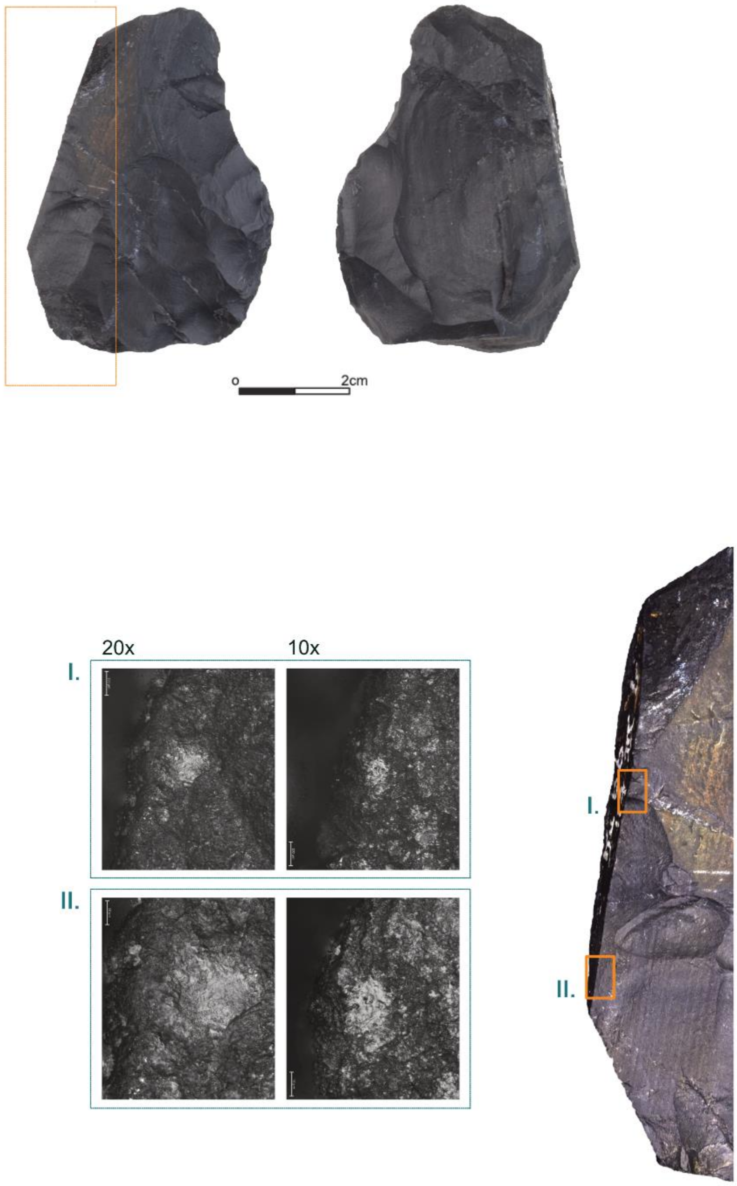


Fig. 2 Buhlen, *Keilmesser* [ID BU-004]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x and 20x (I. type I.; II. type I.).

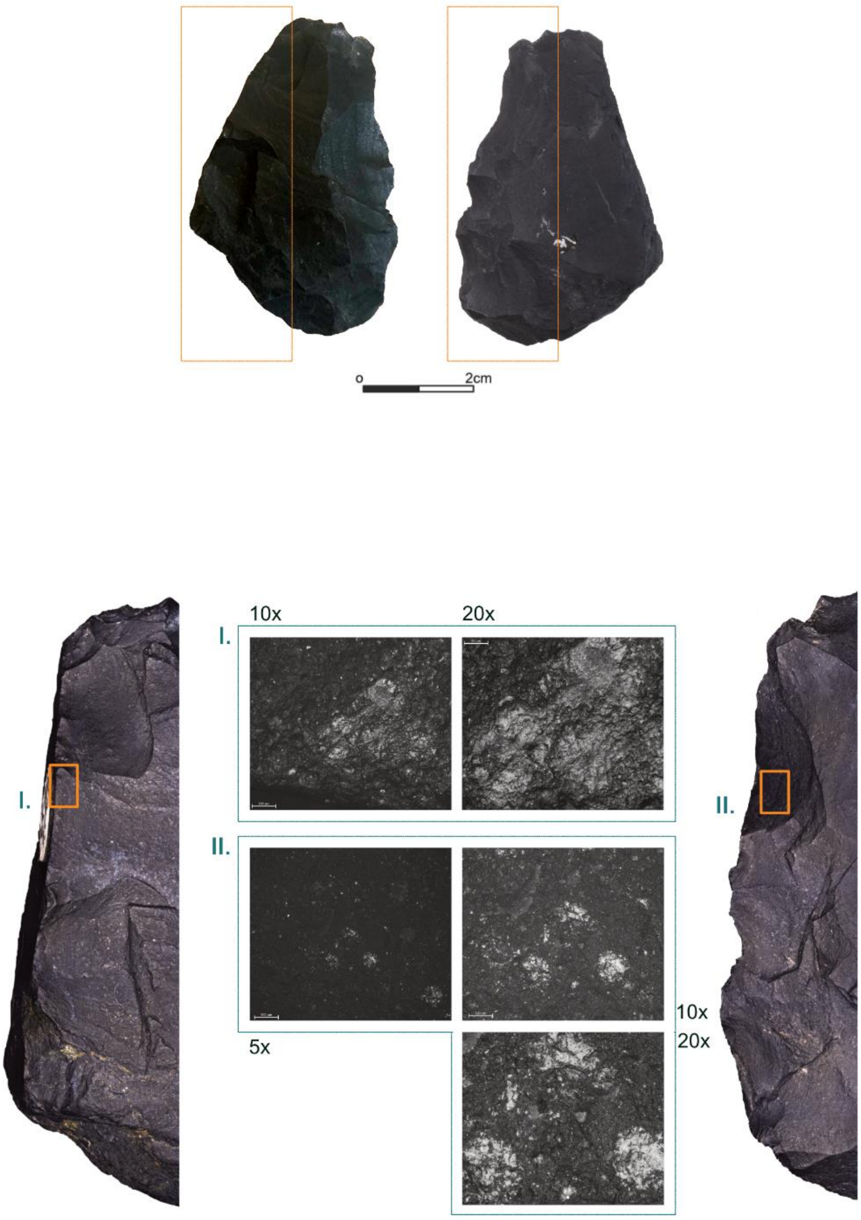


Fig. 3 Buhlen, *Keilmesser* [ID BU-006]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 5x, 10x and 20x (I. type V.; II. type I.).

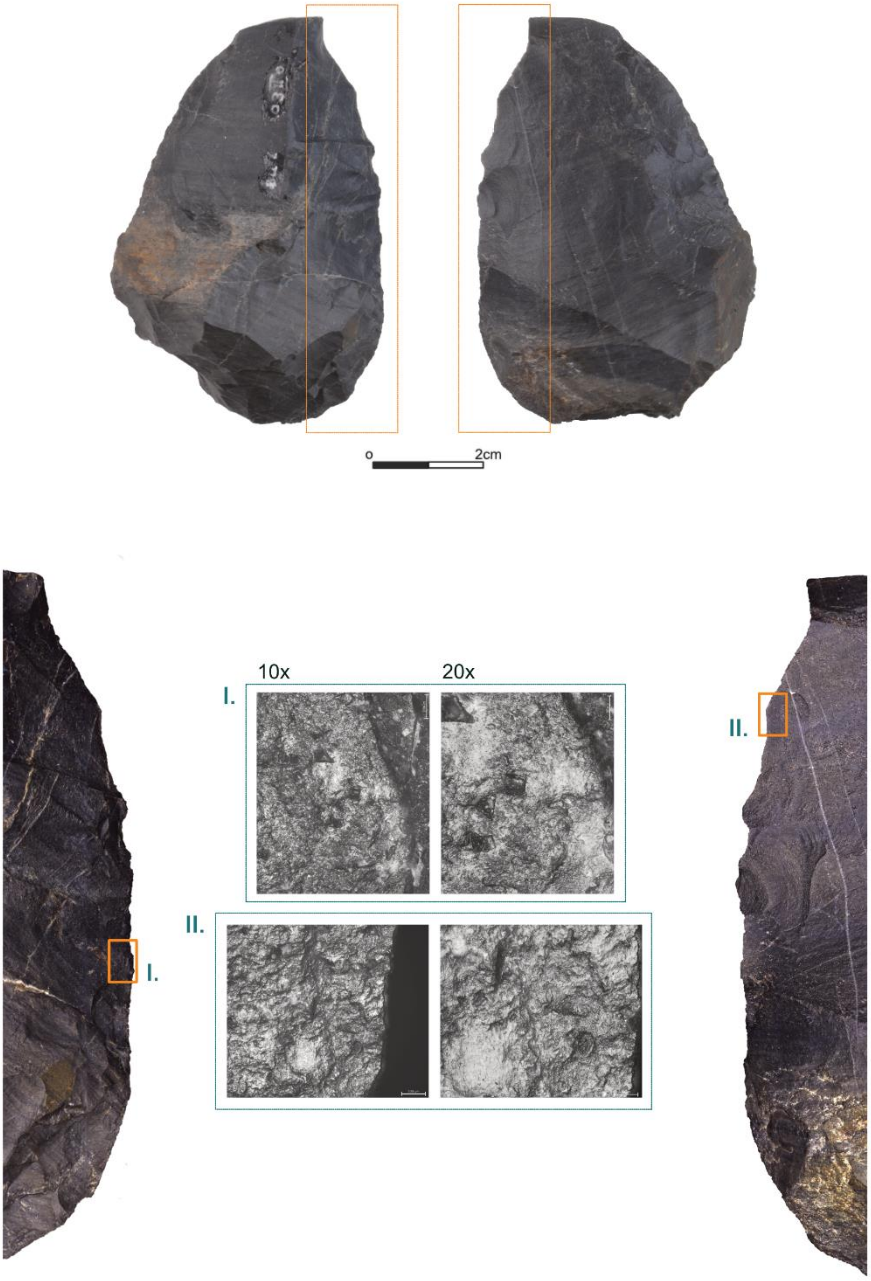


Fig. 4 Buhlen, *Keilmesser* [ID BU-009]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x and 20x (I. type V.; II. type V.).

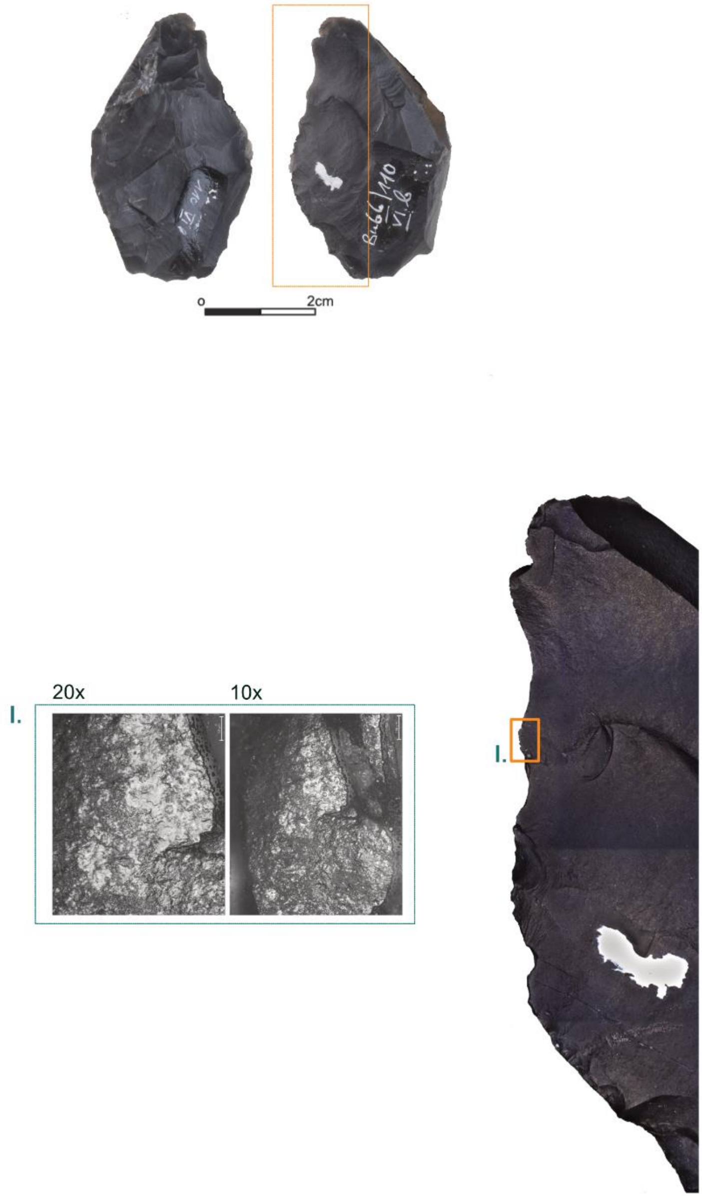


Fig. 5 Buhlen, *Keilmesser* [ID BU-012]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear trace is acquired at magnification of 10x and 20x (I. type V.).

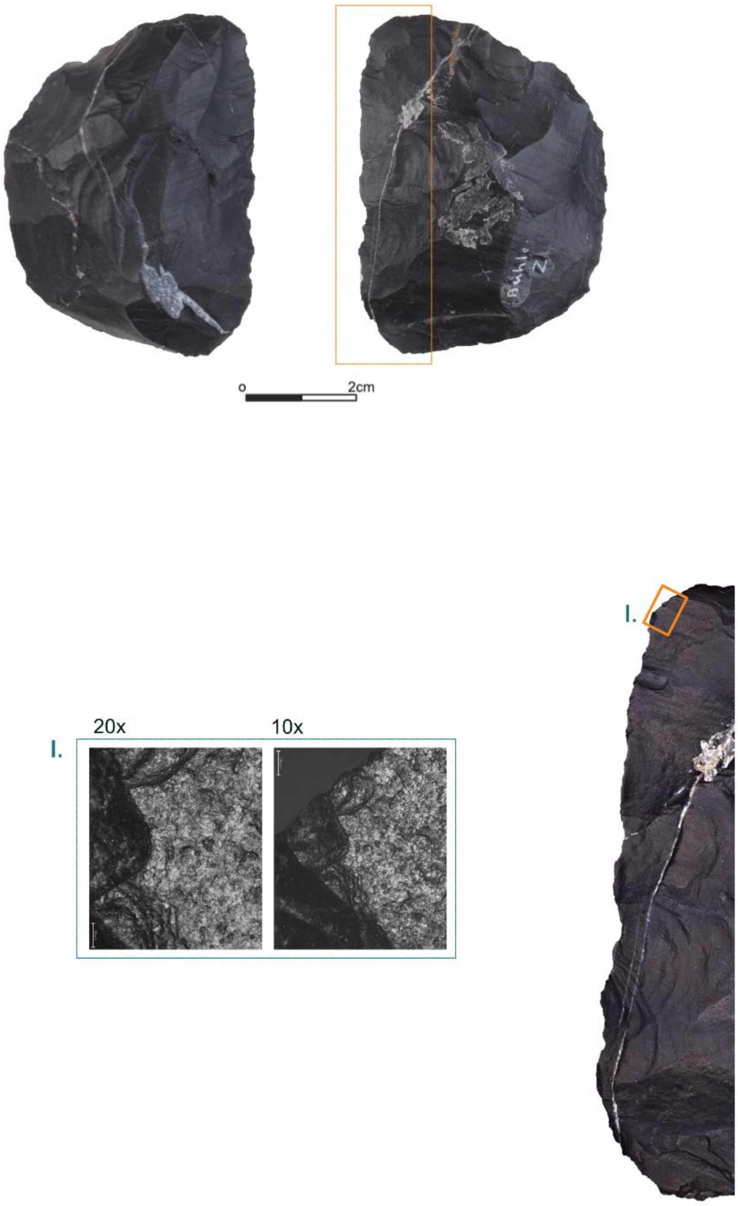


Fig. 6 Buhlen, *Keilmesser* [ID BU-016]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear trace is acquired at magnification of 10x and 20x (I. type V.).

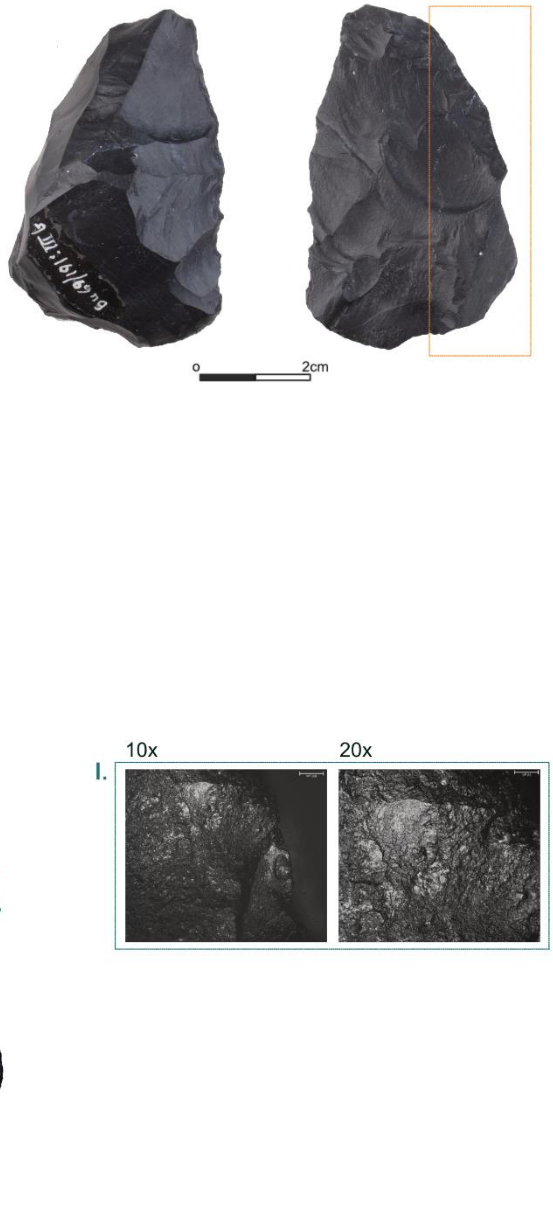


Fig. 7 Buhlen, *Keilmesser* [ID BU-017]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear trace is acquired at magnification of 10x and 20x (I. type V.).

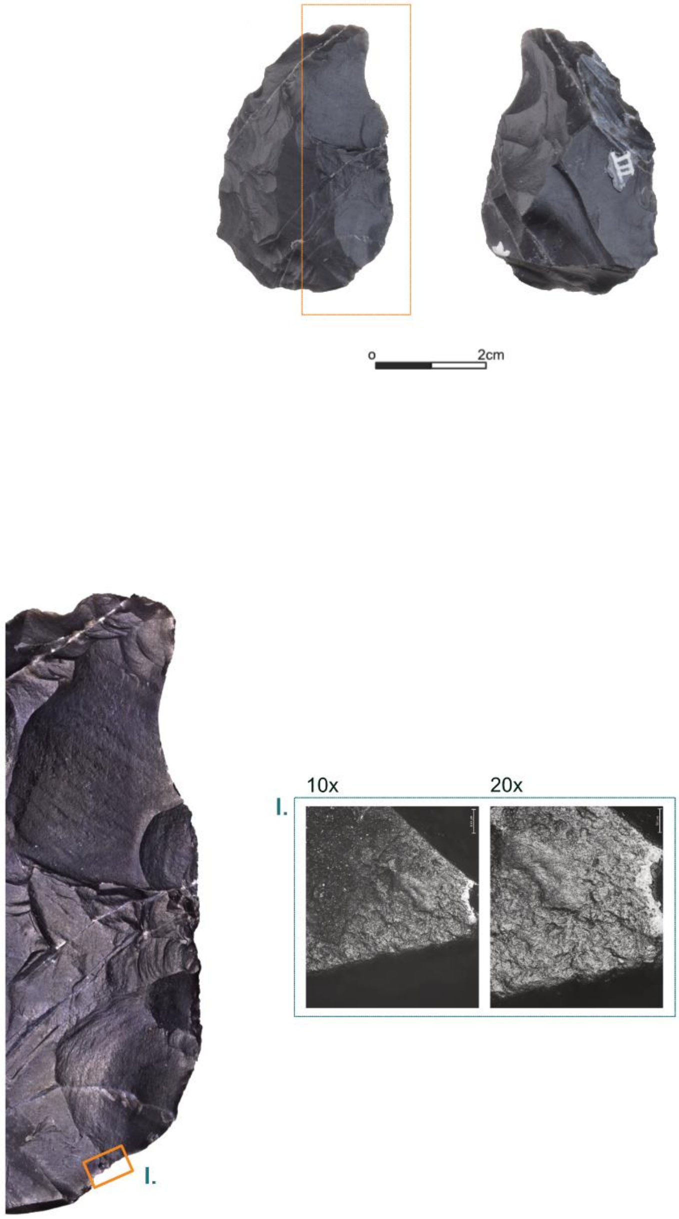


Fig. 8 Buhlen, *Keilmesser* [ID BU-019]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear trace is acquired at magnification of 10x and 20x (I. type IV.).

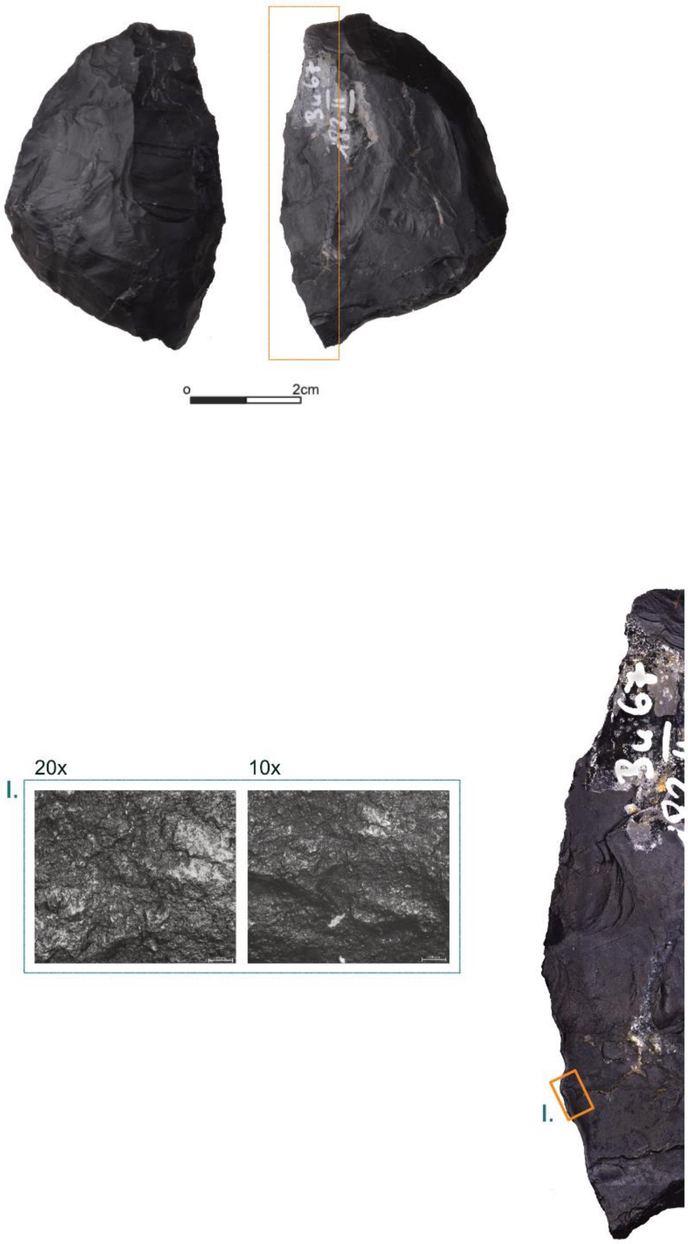


Fig. 9 Buhlen, *Keilmesser* [ID BU-024]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear trace is acquired at magnification of 10x and 20x (I. type I.).

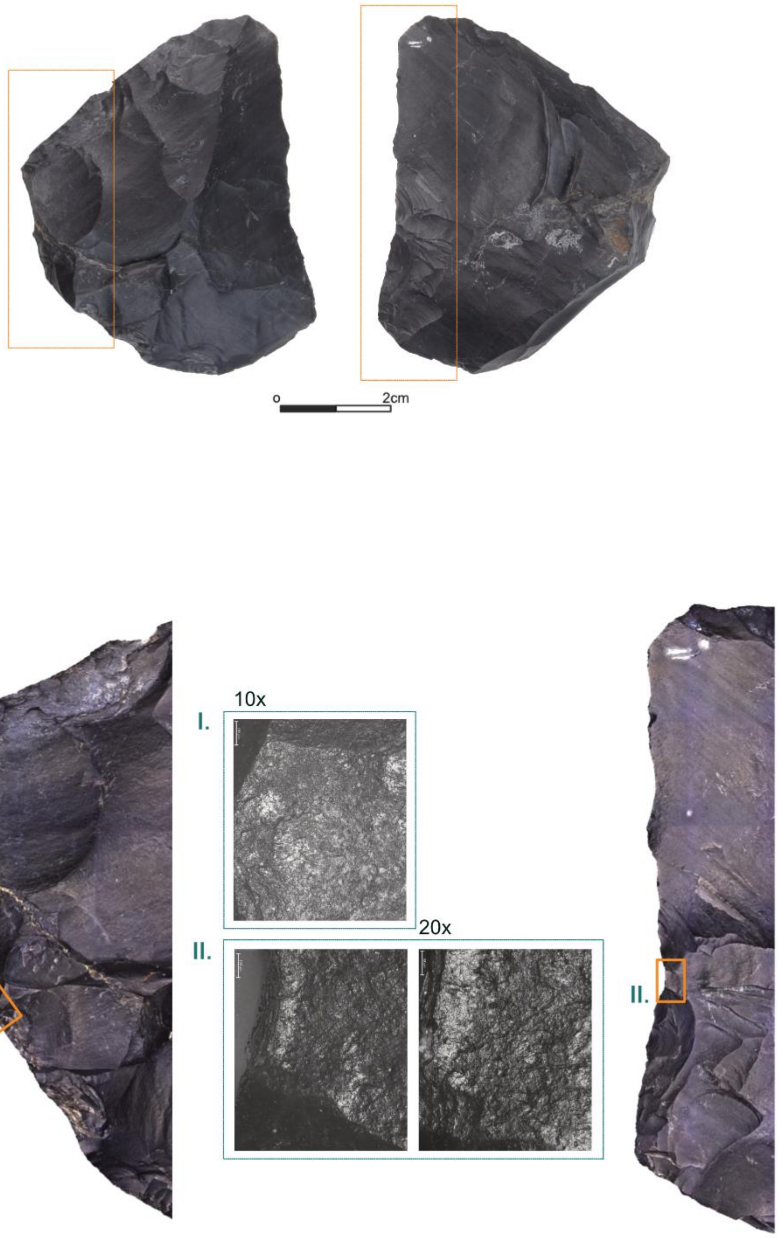
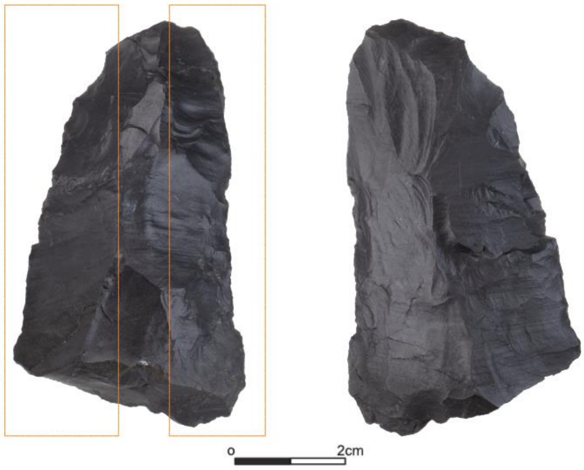


Fig. 10 Buhlen, *Keilmesser* [ID BU-028]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x and 20x (I. type I.; II. type V.).



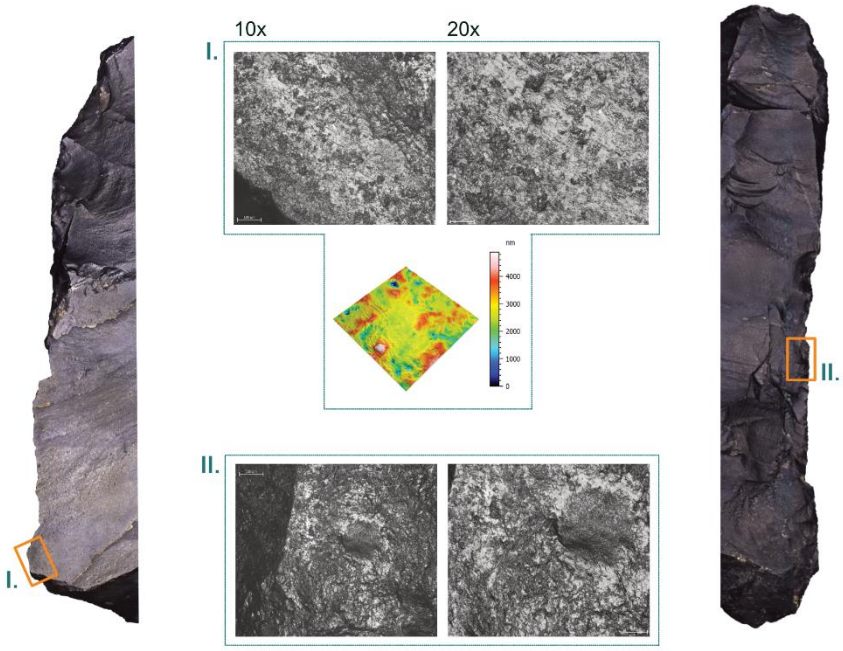


Fig. 11 Buhlen, *Keilmesser* [ID BU-032]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x and 20x (I. type VII.; II. type V.). The micro-surface displays the processed result of the confocal data acquisition with the 50x objective.

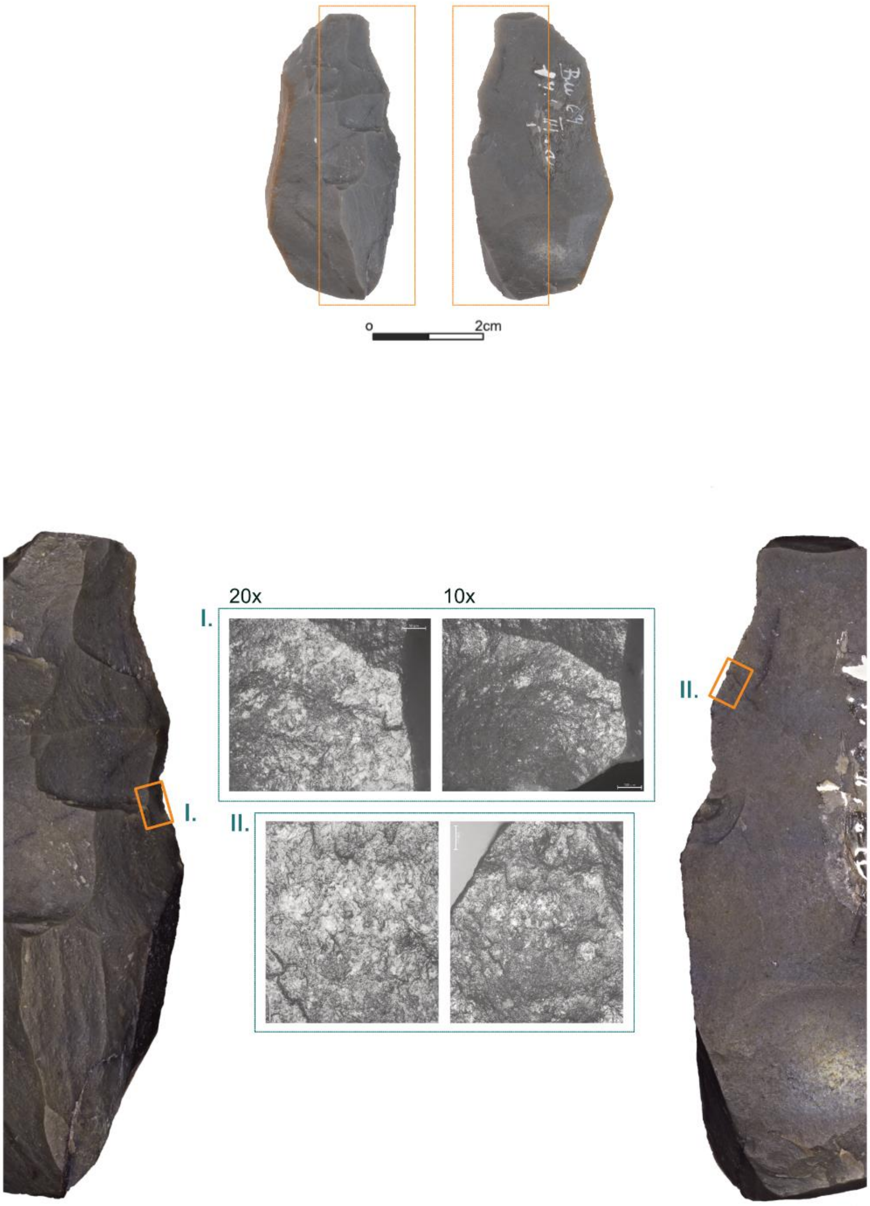


Fig. 12 Buhlen, *Keilmesser* [ID BU-036]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x and 20x (I. type V.; II. type V.).

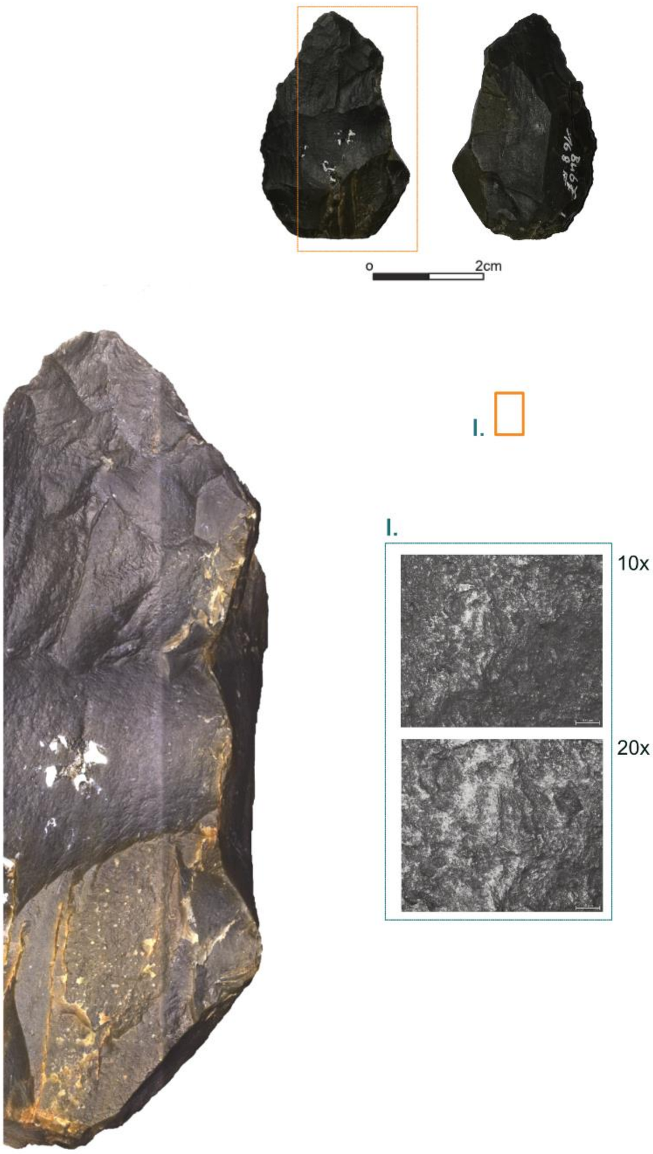


Fig. 13 Buhlen, *Keilmesser* [ID BU-039]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear trace is acquired at magnification of 10x and 20x (I. type V.).

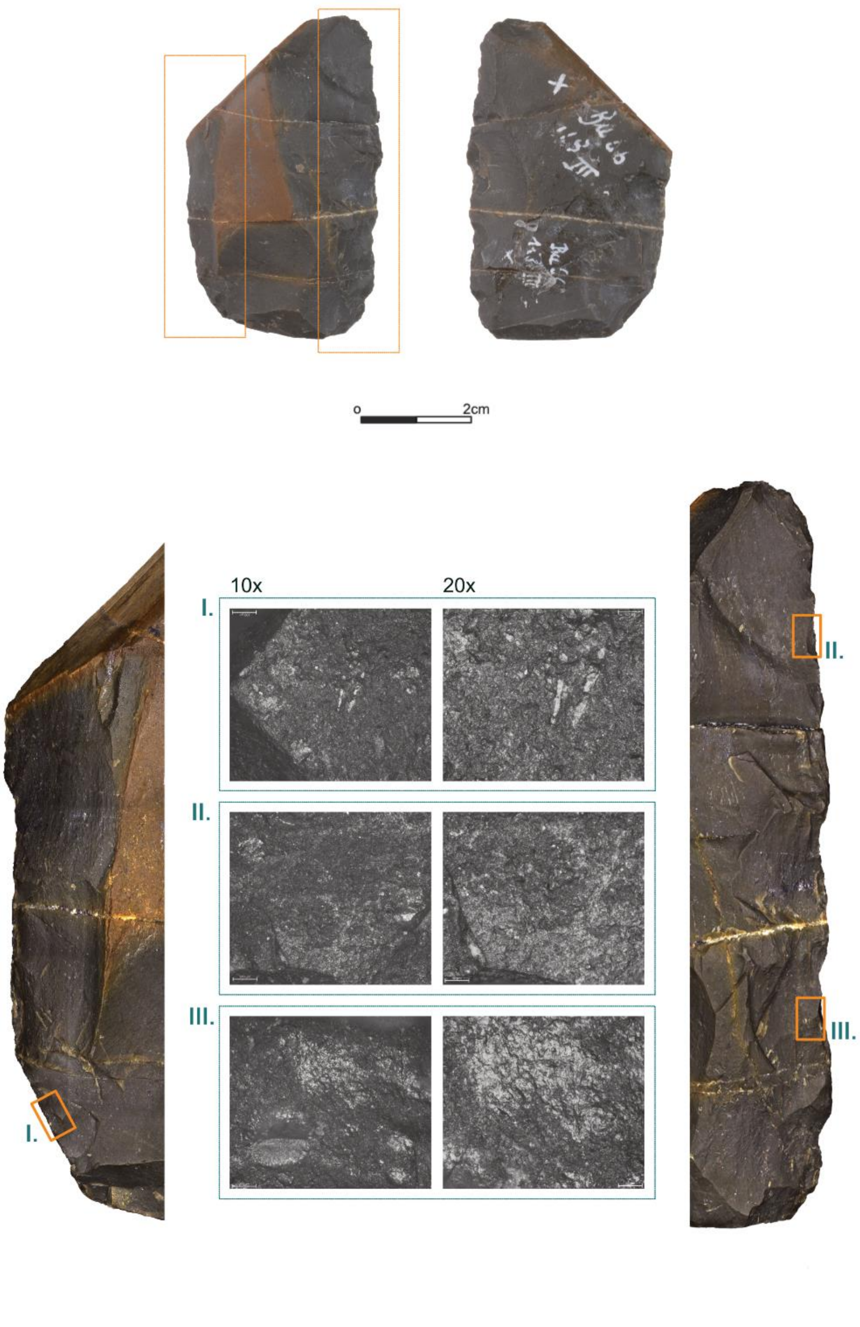


Fig. 14 Buhlen, *Keilmesser* [ID BU-040]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x and 20x (I. type I.; II. type V.; III. type V.).

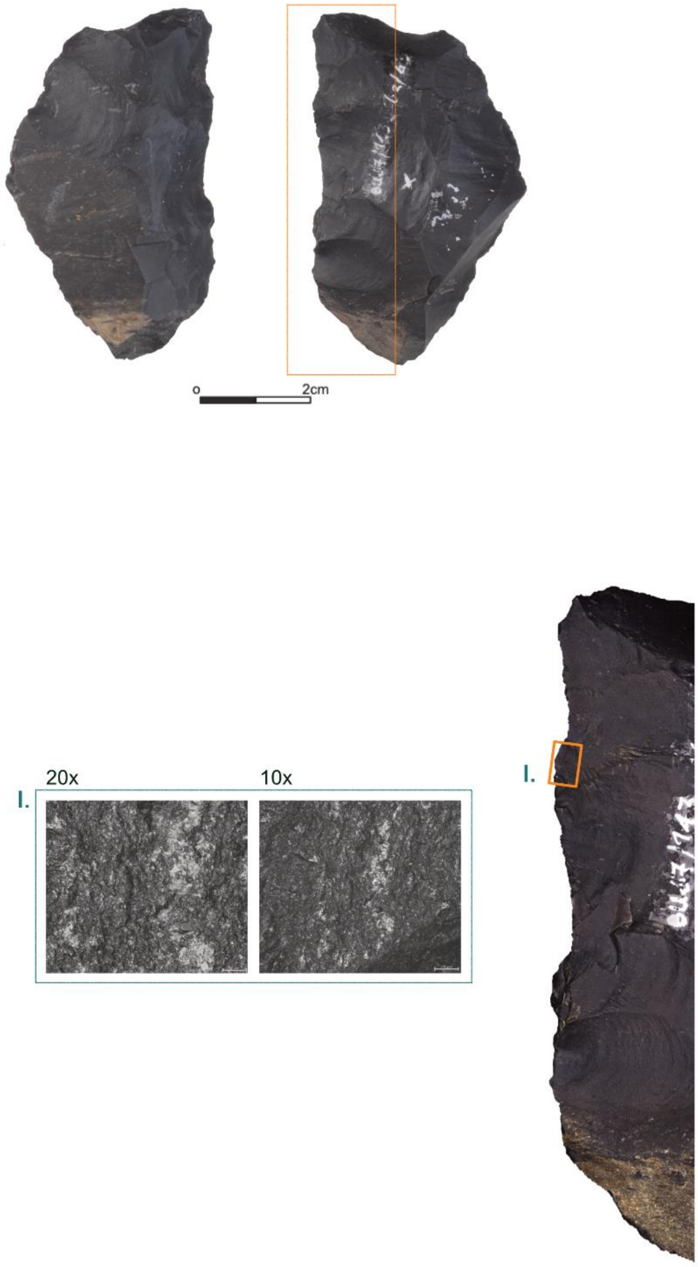


Fig. 15 Buhlen, *Keilmesser* [ID BU-046]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear trace is acquired at magnification of 10x and 20x (I. type V.).

Fig. 16 Buhlen, *Keilmesser* [ID BU-048]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear trace is acquired at magnification of 10x and 20x (I. type V.).

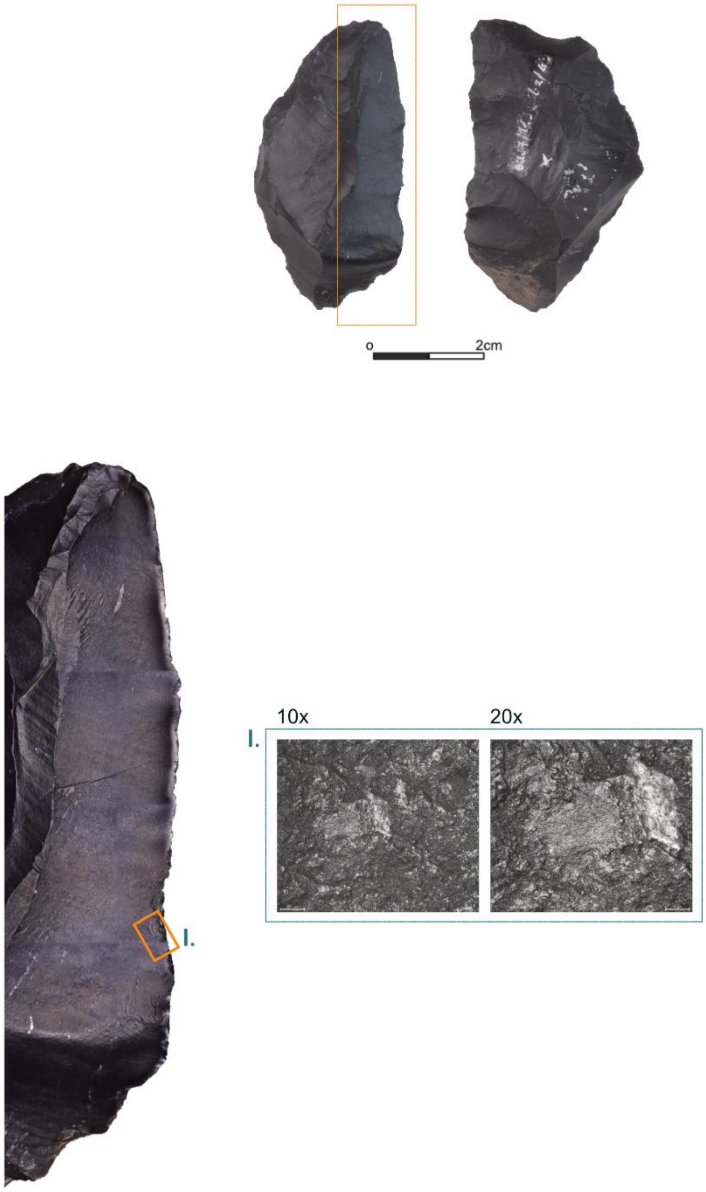


Fig. 17 Buhlen, *Keilmesser* [ID BU-051]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear trace is acquired at magnification of 10x and 20x (I. type I.).

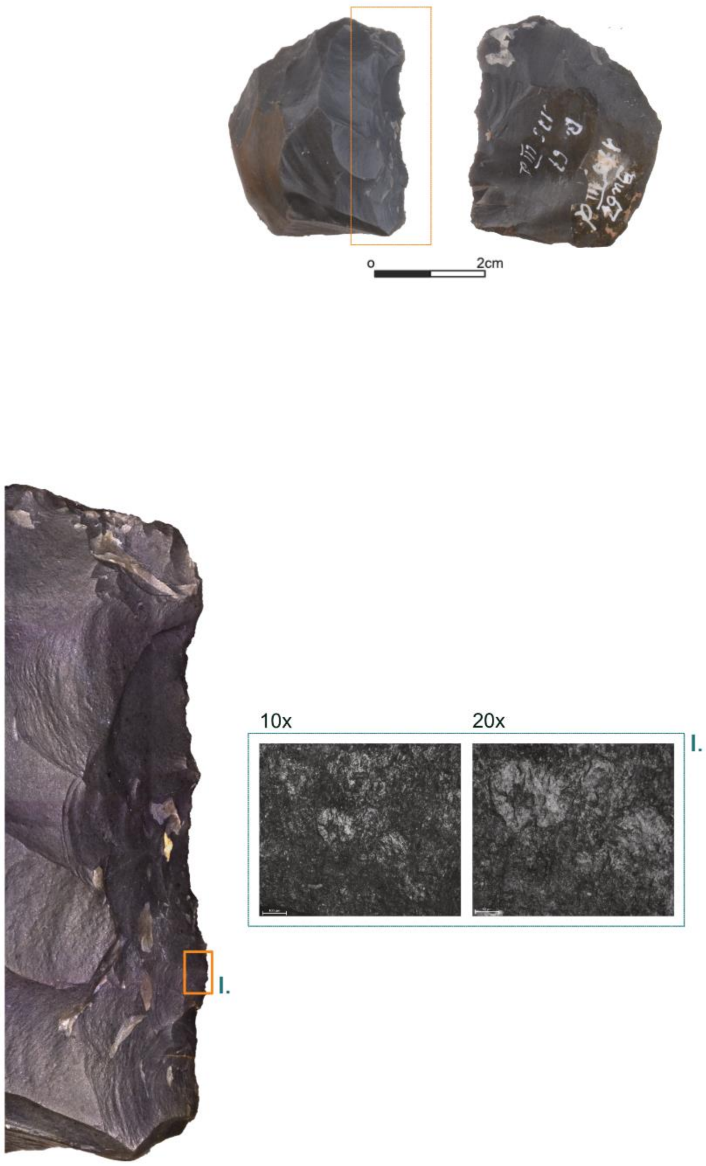


Fig. 18 Buhlen, *Keilmesser* [ID BU-054]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear trace is acquired at magnification of 10x and 20x (I. type I.).

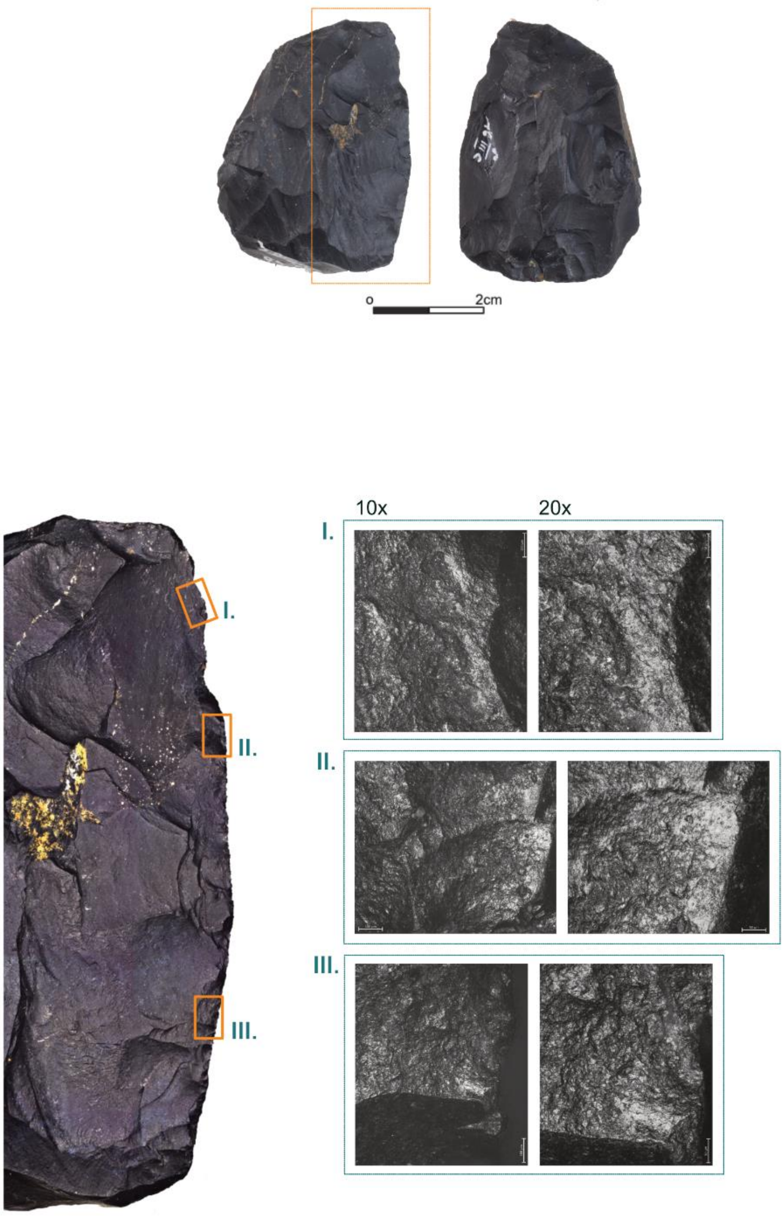


Fig. 19 Buhlen, *Keilmesser* [ID BU-056]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x and 20x (I. type V.; II. type V.; III. type V.).

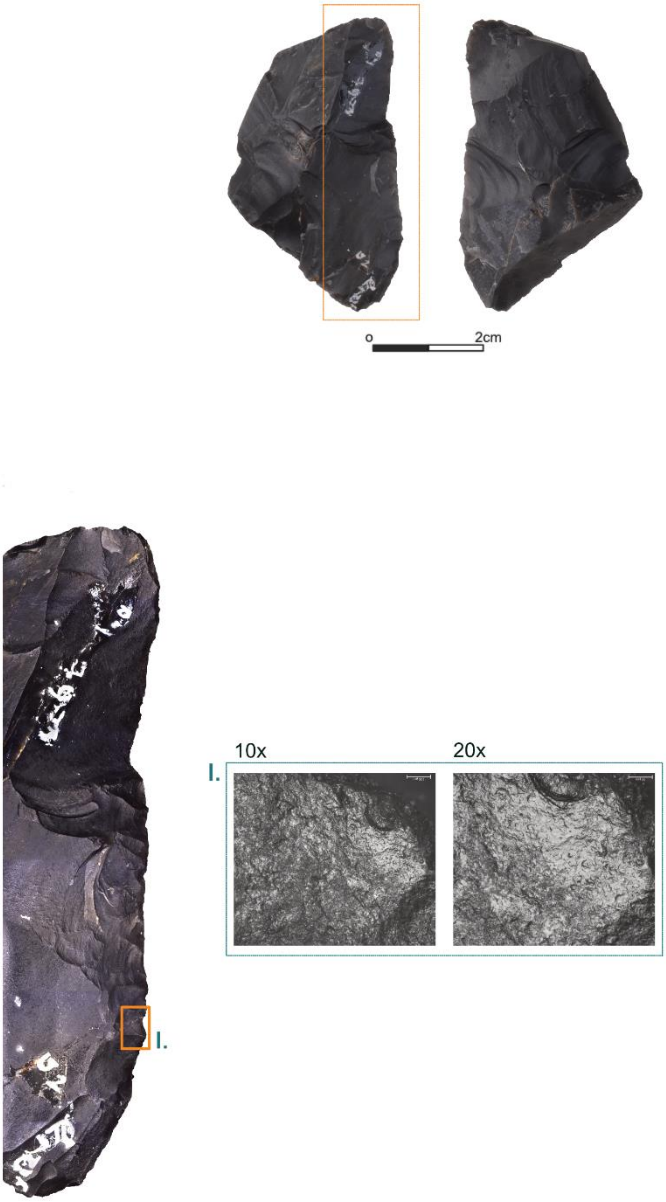


Fig. 20 Buhlen, *Keilmesser* [ID BU-057]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear trace is acquired at magnification of 10x and 20x (I. type V.).

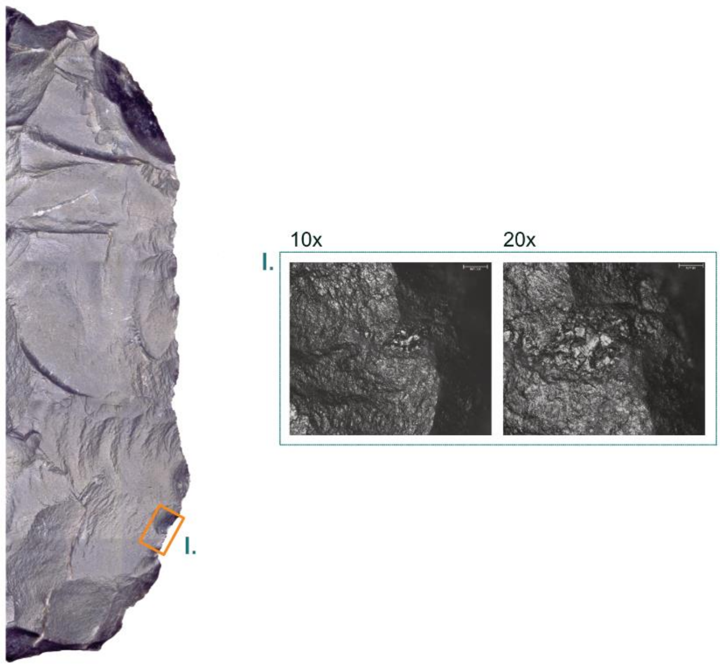


Fig. 21 Buhlen, *Keilmesser* [ID BU-058]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear trace is acquired at magnification of 10x and 20x (I. type I.).

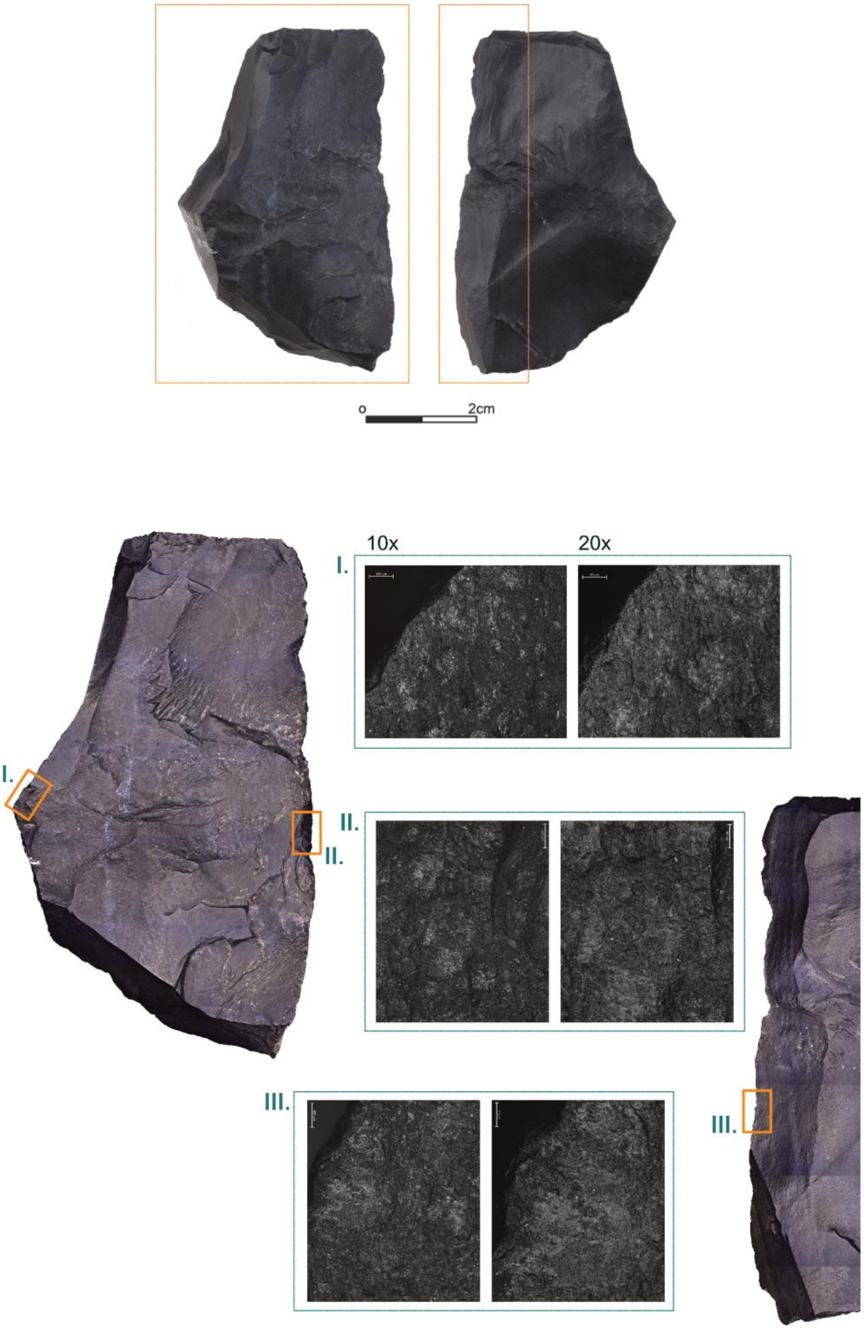


Fig. 22 Buhlen, *Keilmesser* [ID BU-060]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x and 20x (I. type V.; II. type V.; III. type V.).

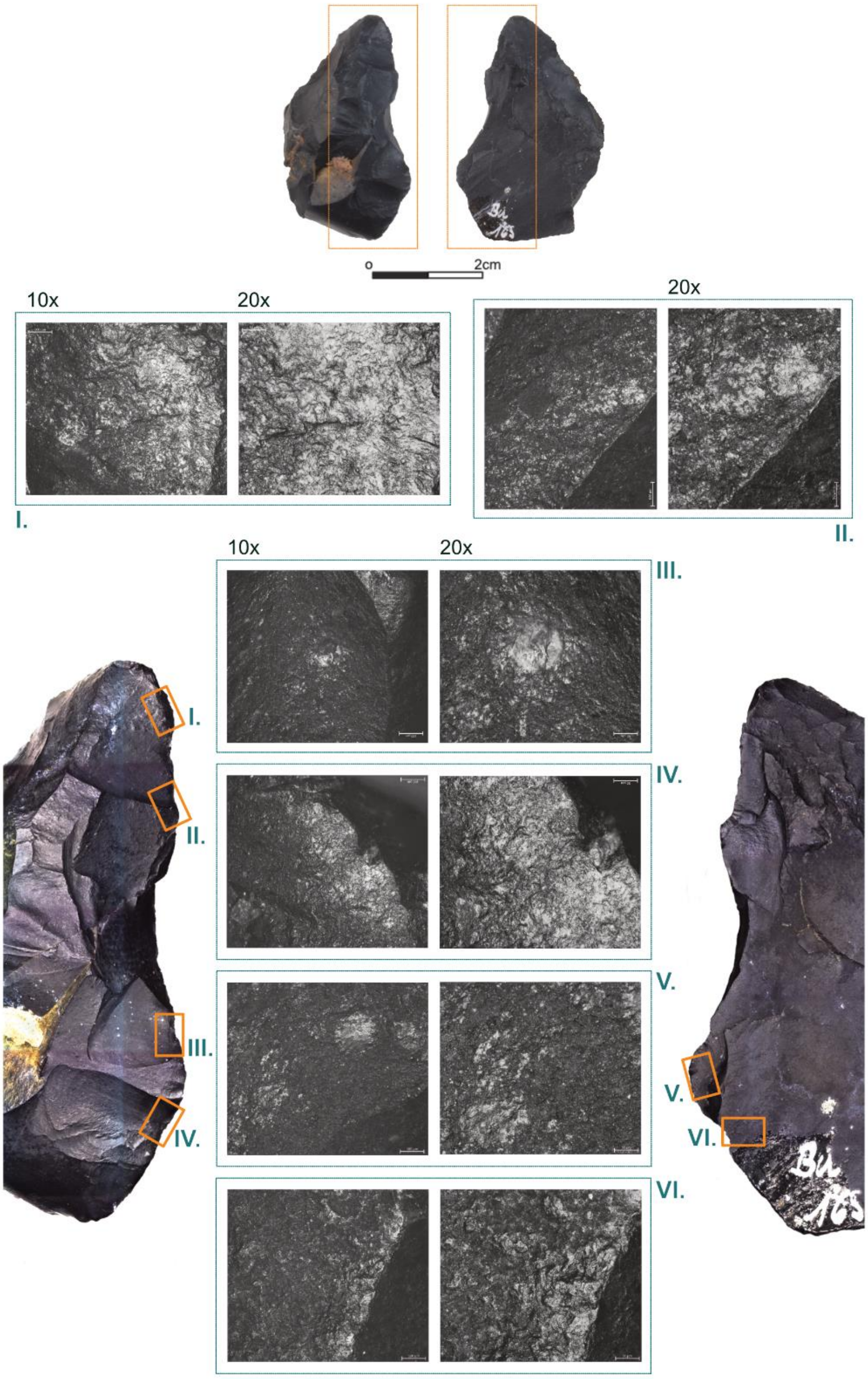


Fig. 23 Buhlen, *Keilmesser* [ID BU-066]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x and 20x (I. type V.; II. type V.; III. type I.; IV. type I.; V. type I.; VI. type V.).

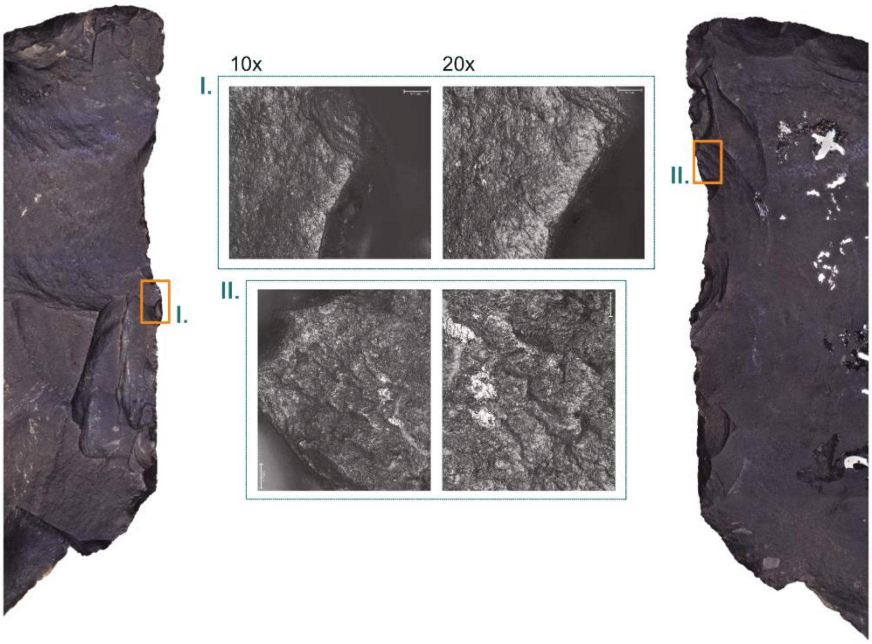


Fig. 24 Buhlen, *Keilmesser* [ID BU-069]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x and 20x (I. type V.; II. type V.).

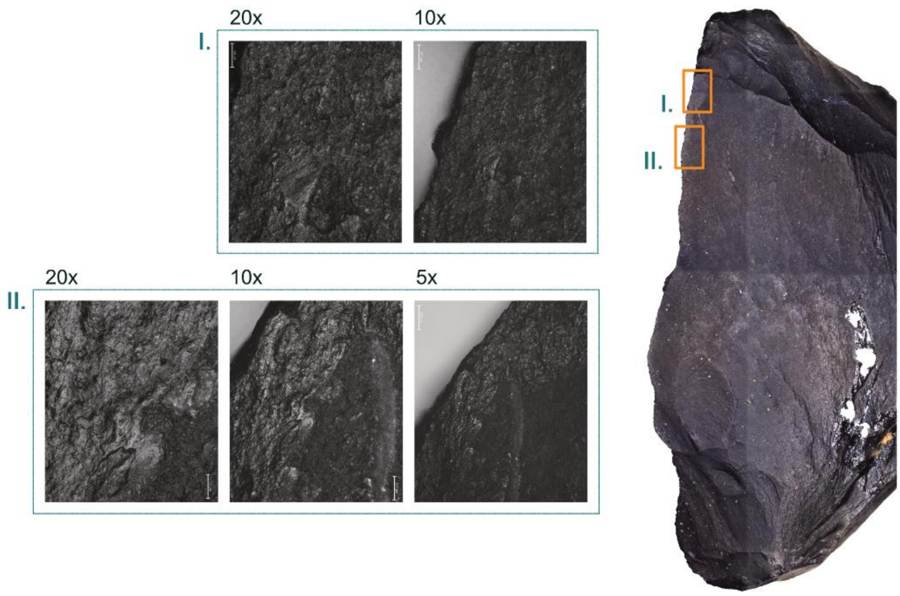


Fig. 25 Buhlen, *Keilmesser* [ID BU-074]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 5x, 10x and 20x (I. type V.; II. type V.).

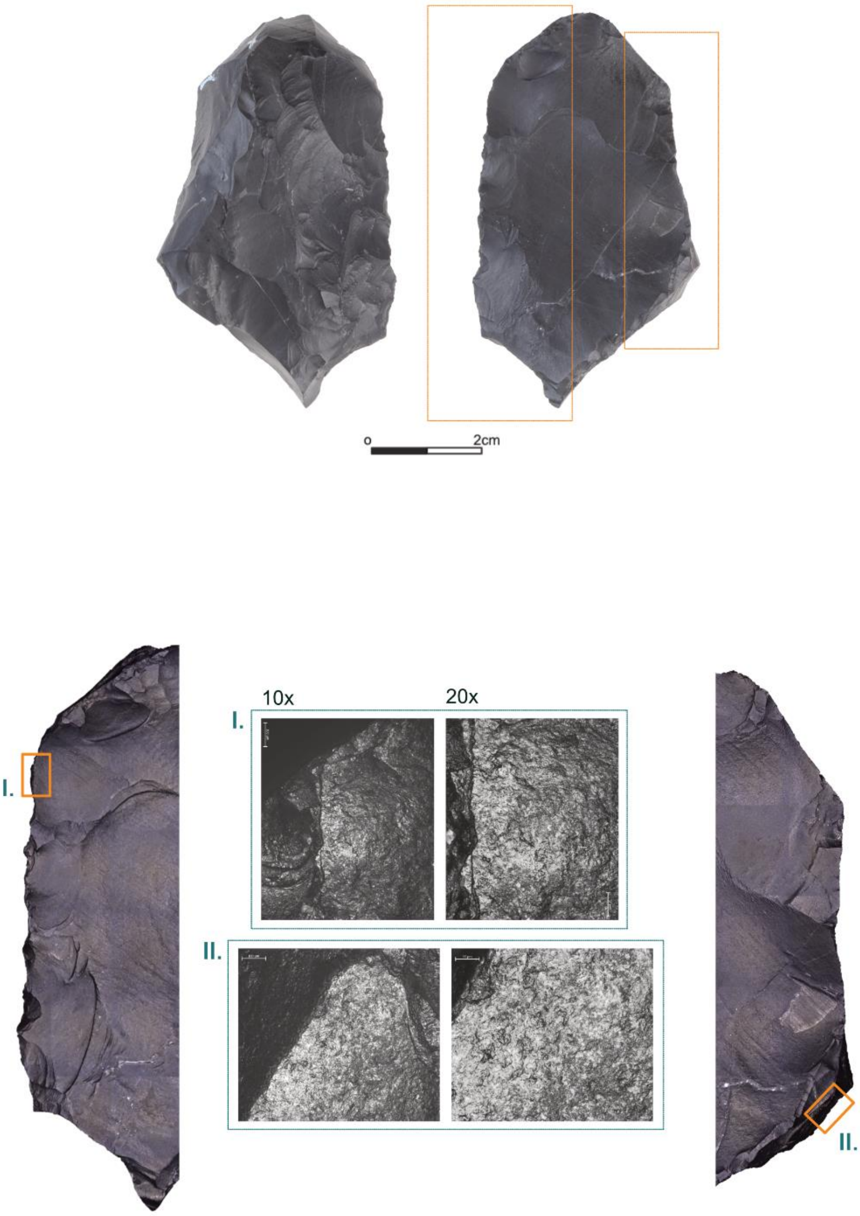


Fig. 26 Buhlen, *Keilmesser* [ID BU-076; dorsal]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x and 20x (I. type V.; II. type V.).

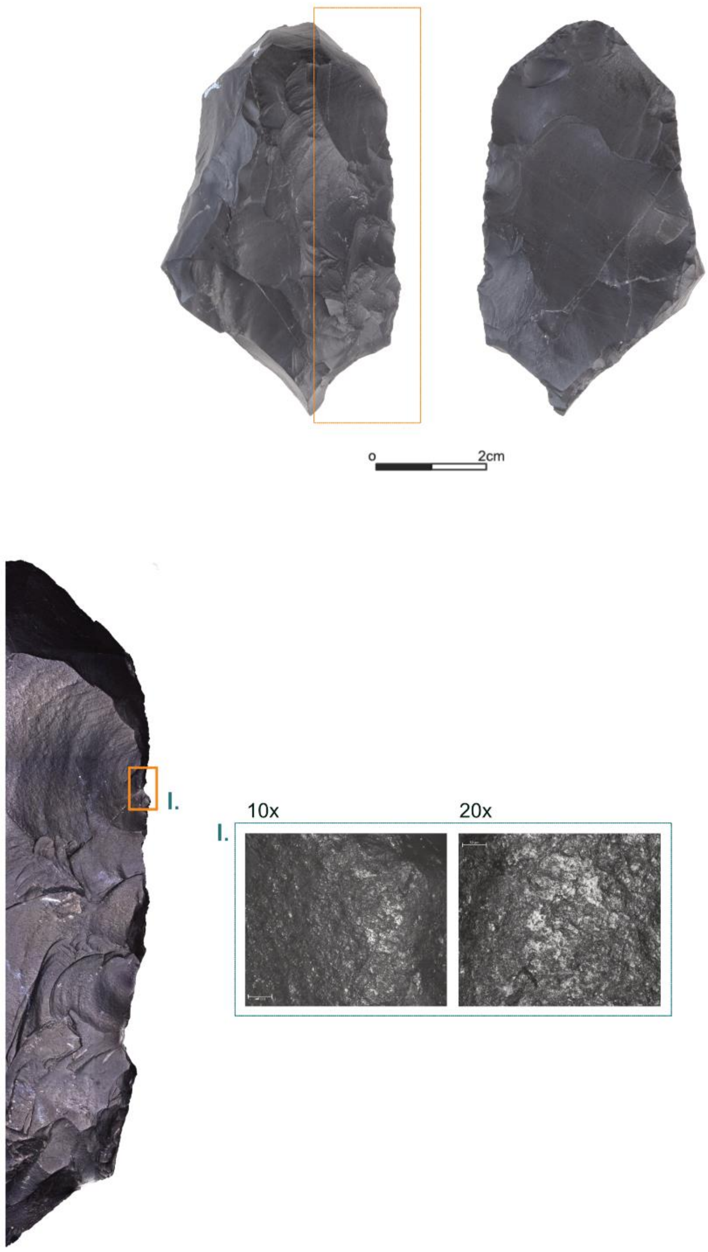


Fig. 27 Buhlen, *Keilmesser* [ID BU-076; ventral]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear trace is acquired at magnification of 10x and 20x (I. type V.).

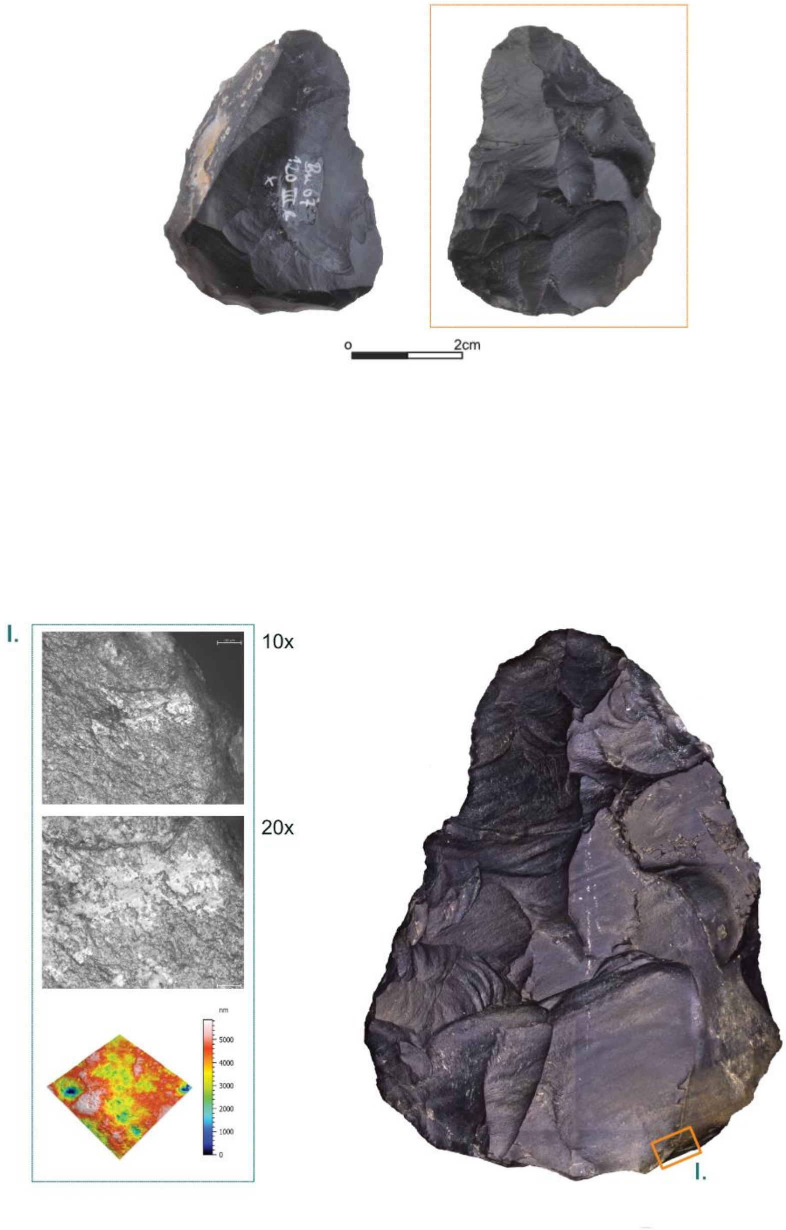


Fig. 28 Buhlen, *Keilmesser* [ID BU-077]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear trace is acquired at magnification of 10x and 20x (I. type V. / IV.). The micro-surface displays the processed result of the confocal data acquisition with the 50x objective.

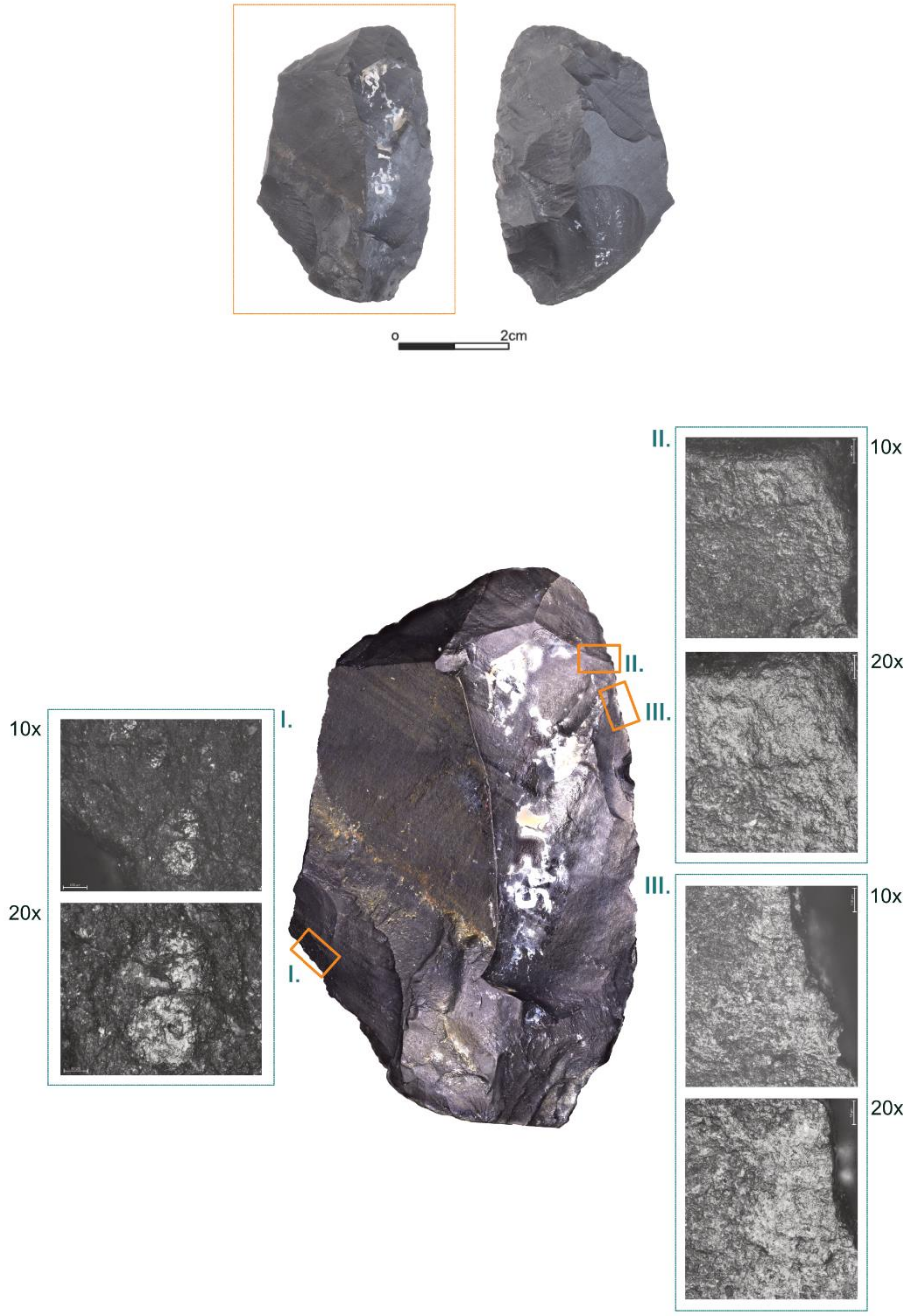


Fig. 29 Buhlen, *Keilmesser* [ID BU-078; dorsal]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x and 20x (I. type I.; II. type V.; III. type V.).

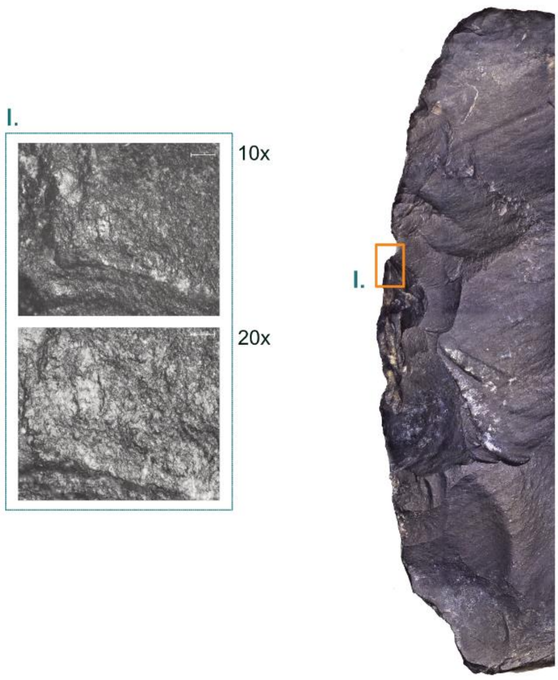


Fig. 30 Buhlen, *Keilmesser* [ID BU-078; ventral]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear trace is acquired at magnification of 10x and 20x (I. type V.).

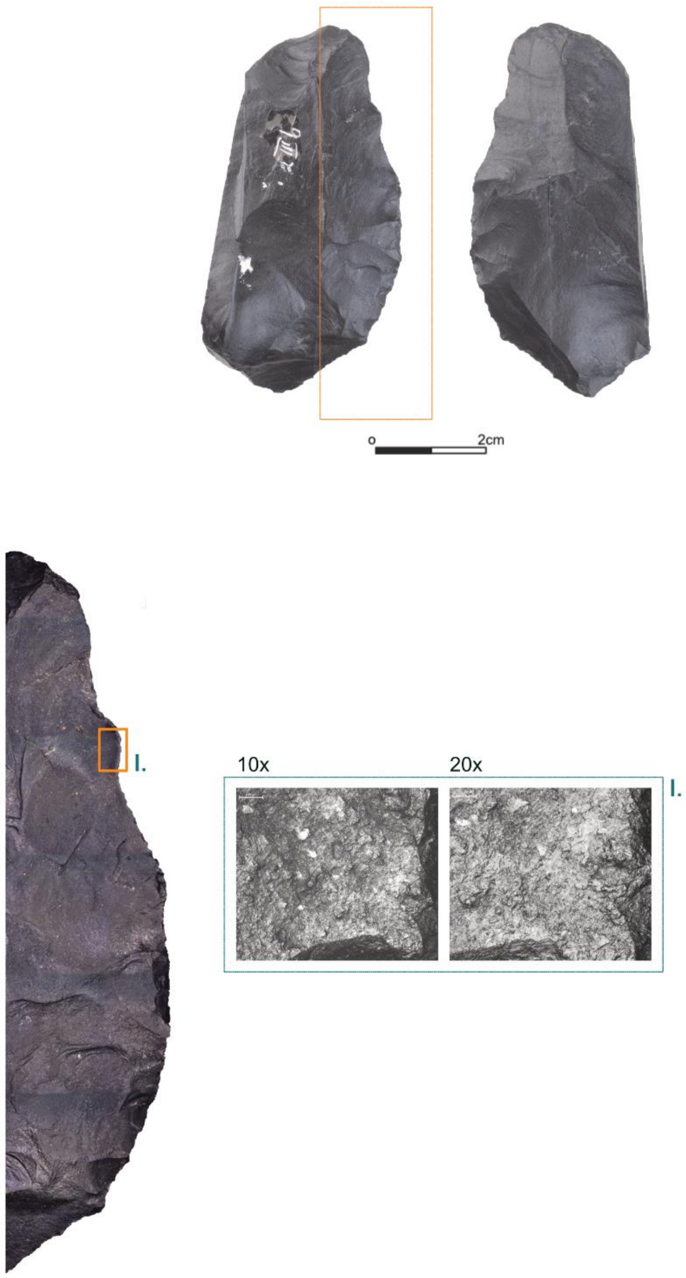


Fig. 31 Buhlen, *Keilmesser* [ID BU-079]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear trace is acquired at magnification of 10x and 20x (I. type V.).

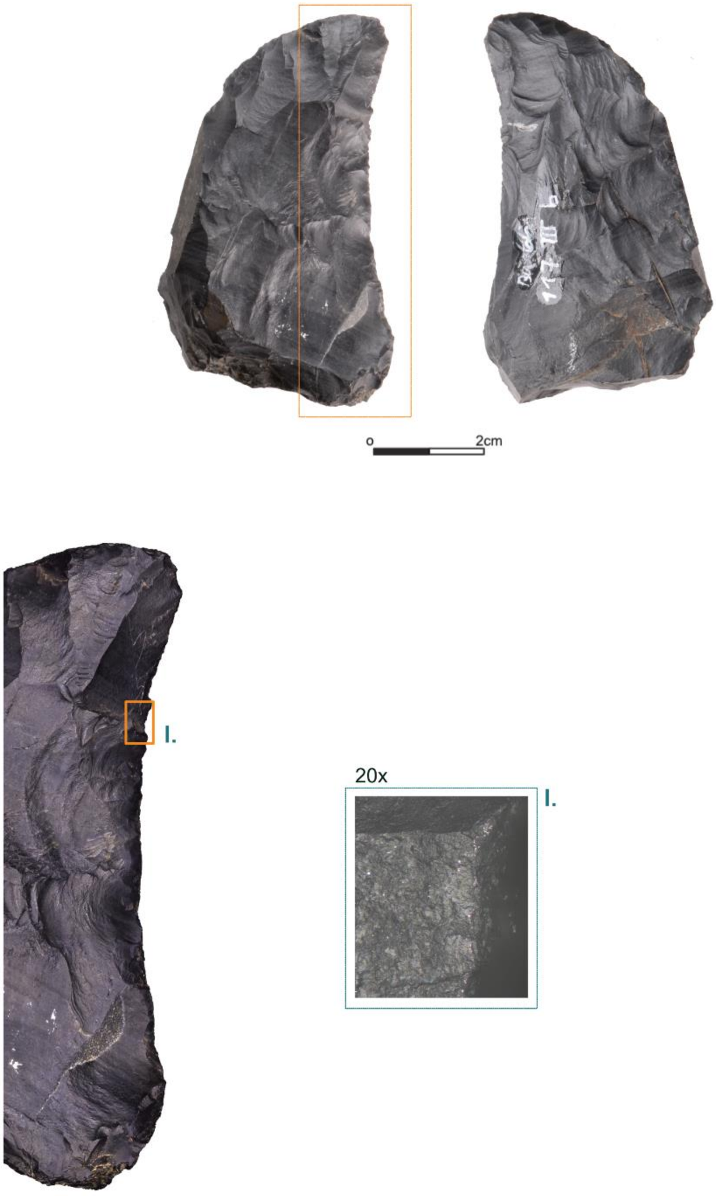


Fig. 32 Buhlen, *Keilmesser* [ID BU-160]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear trace is acquired at magnification of 20x (I. type V.).

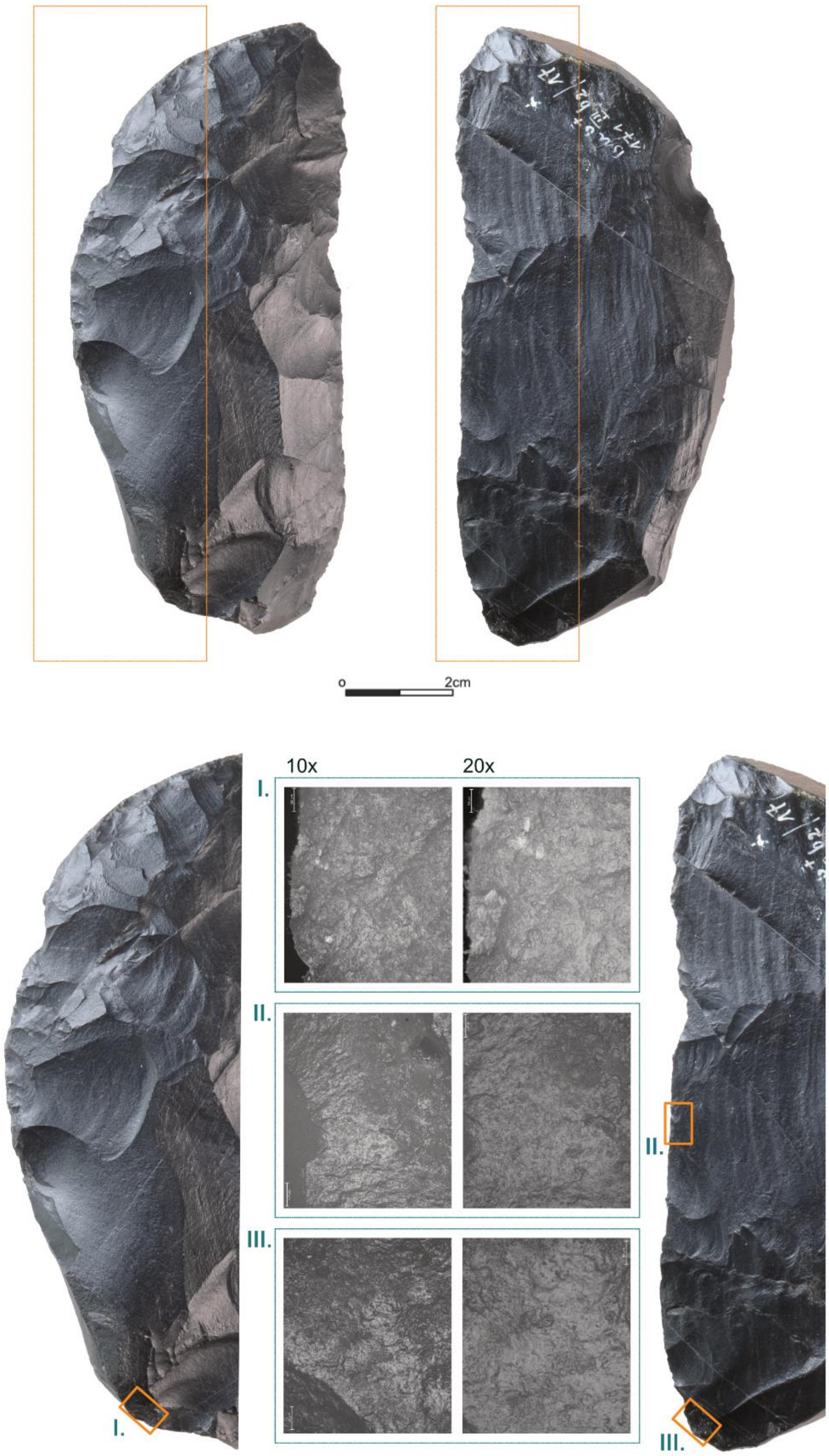


Fig. 33 Buhlen, *Keilmesser* [ID BU-163]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x and 20x (I. type V.; II. type I.).

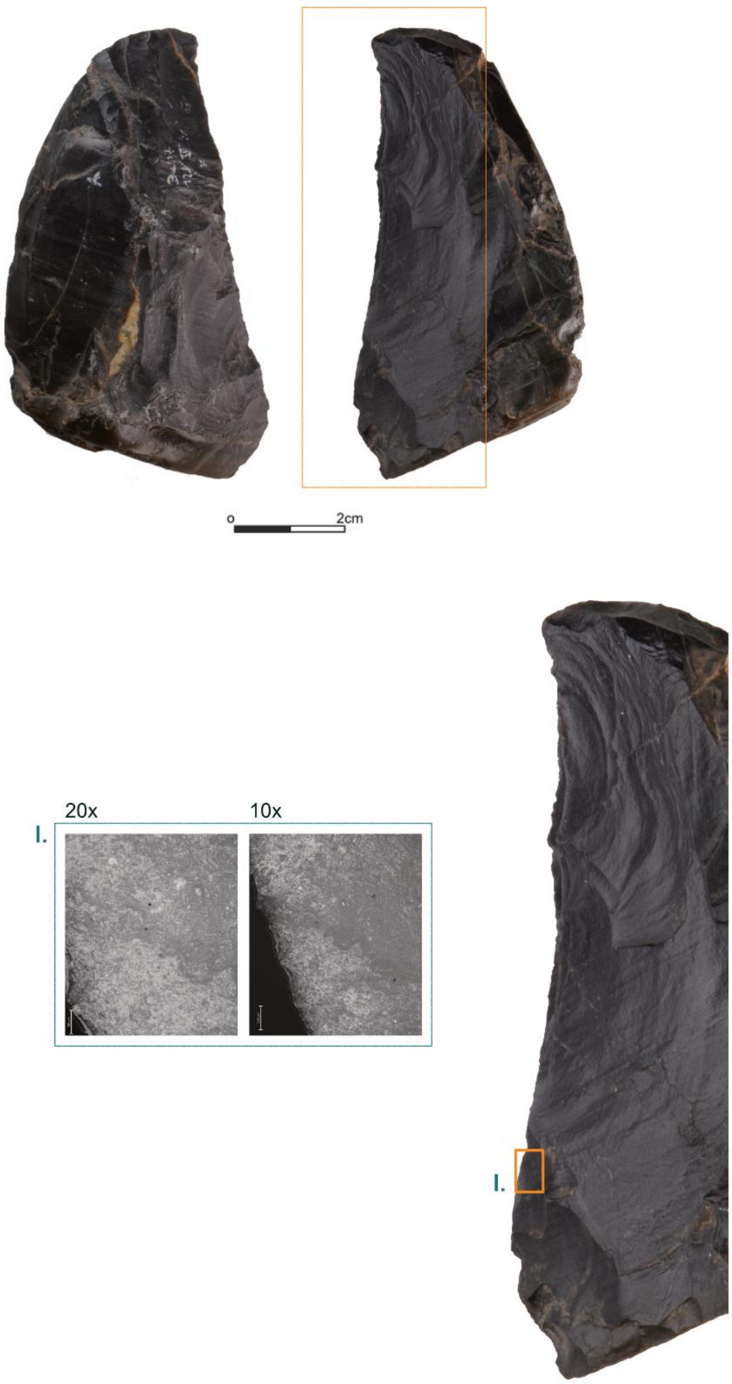


Fig. 34 Buhlen, *Keilmesser* [ID BU-158]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear trace is acquired at magnification of 10x and 20x (I. type V.).

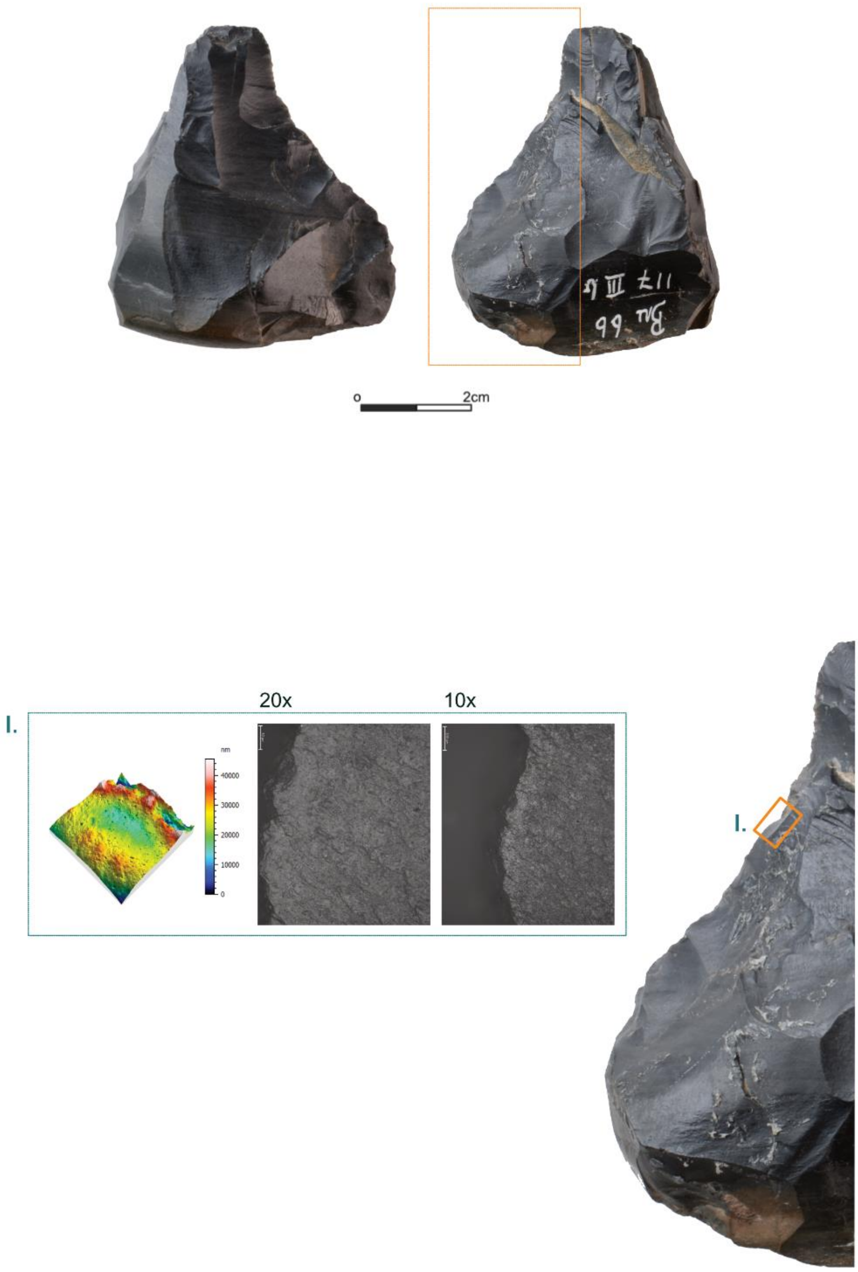


Fig. 35 Buhlen, *Keilmesser* [ID BU-173]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear trace is acquired at magnification of 10x and 20x (I. type V.). The micro-surface displays the processed result of the confocal data acquisition with the 50x objective.

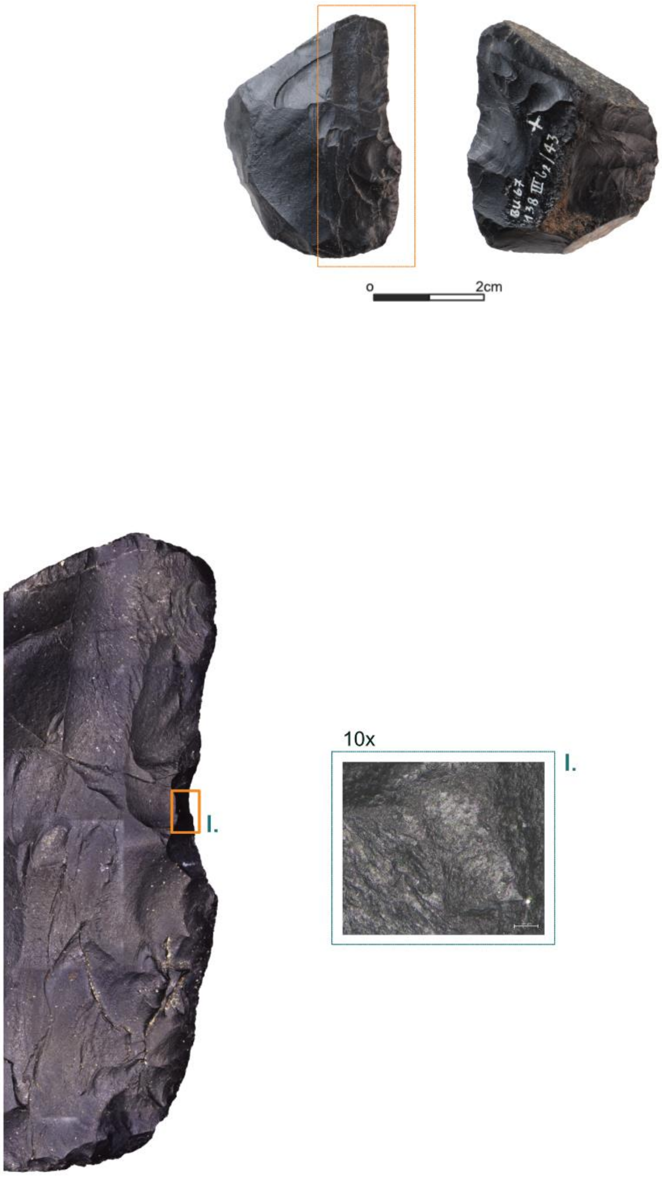


Fig. 36 Buhlen, *Keilmesser* [ID BU-174]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear trace is acquired at magnification of 10x (I. type V.).

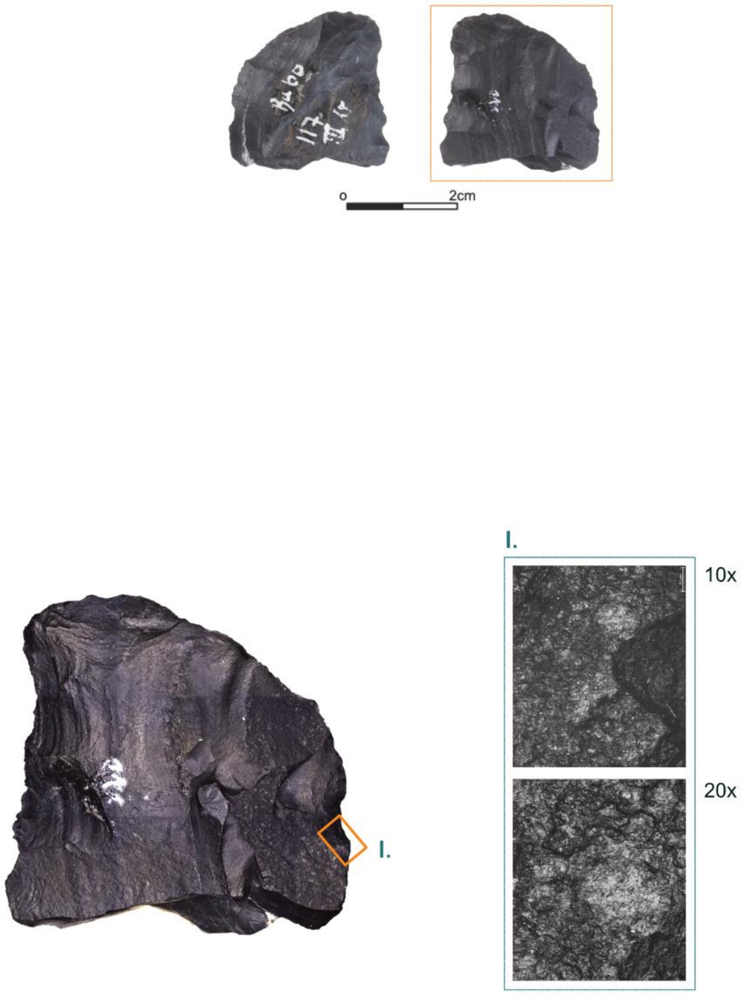


Fig. 37 Buhlen, *Keilmesser* tip [ID BU-085]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear trace is acquired at magnification of 10x and 20x (I. type V.).

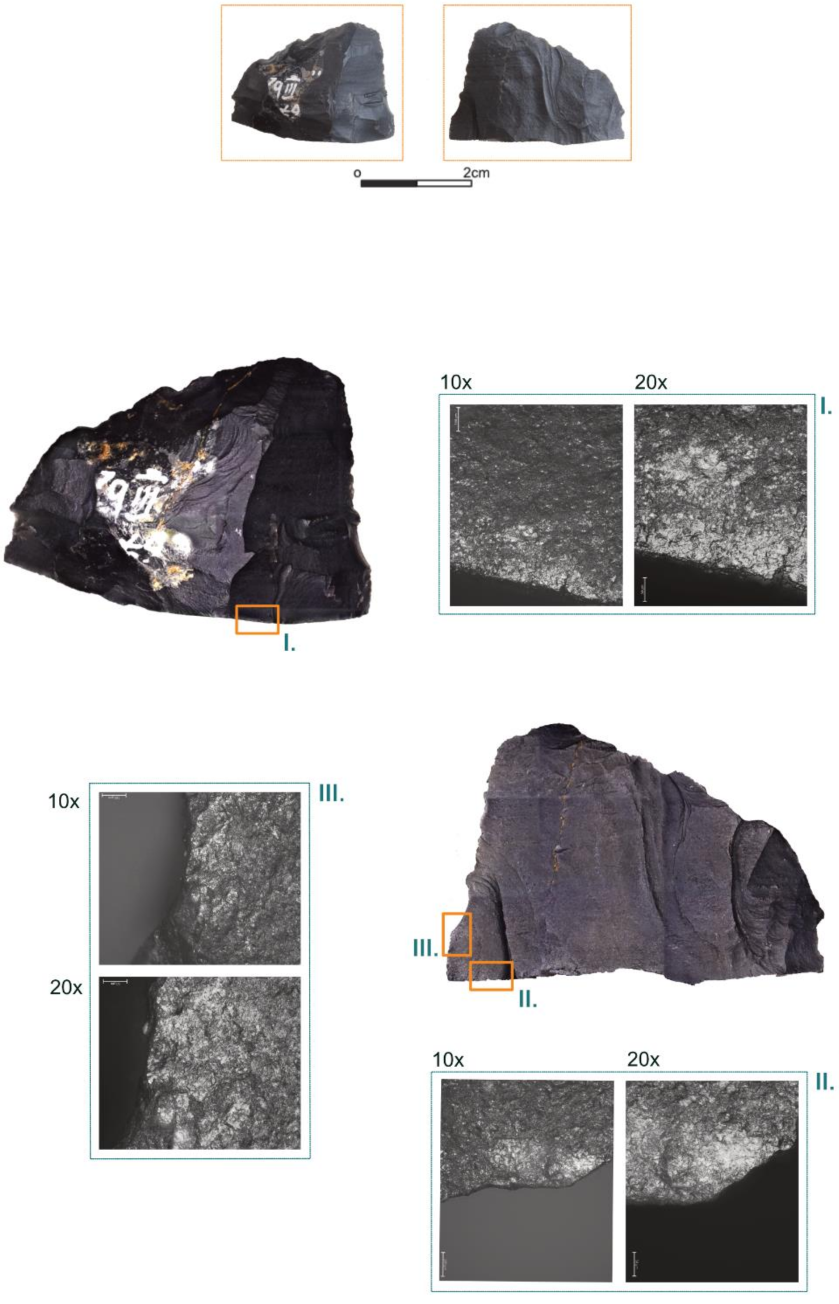


Fig. 38 Buhlen, *Keilmesser* tip [ID BU-086]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x and 20x (I. type V.; II. type V.; III. type V.).

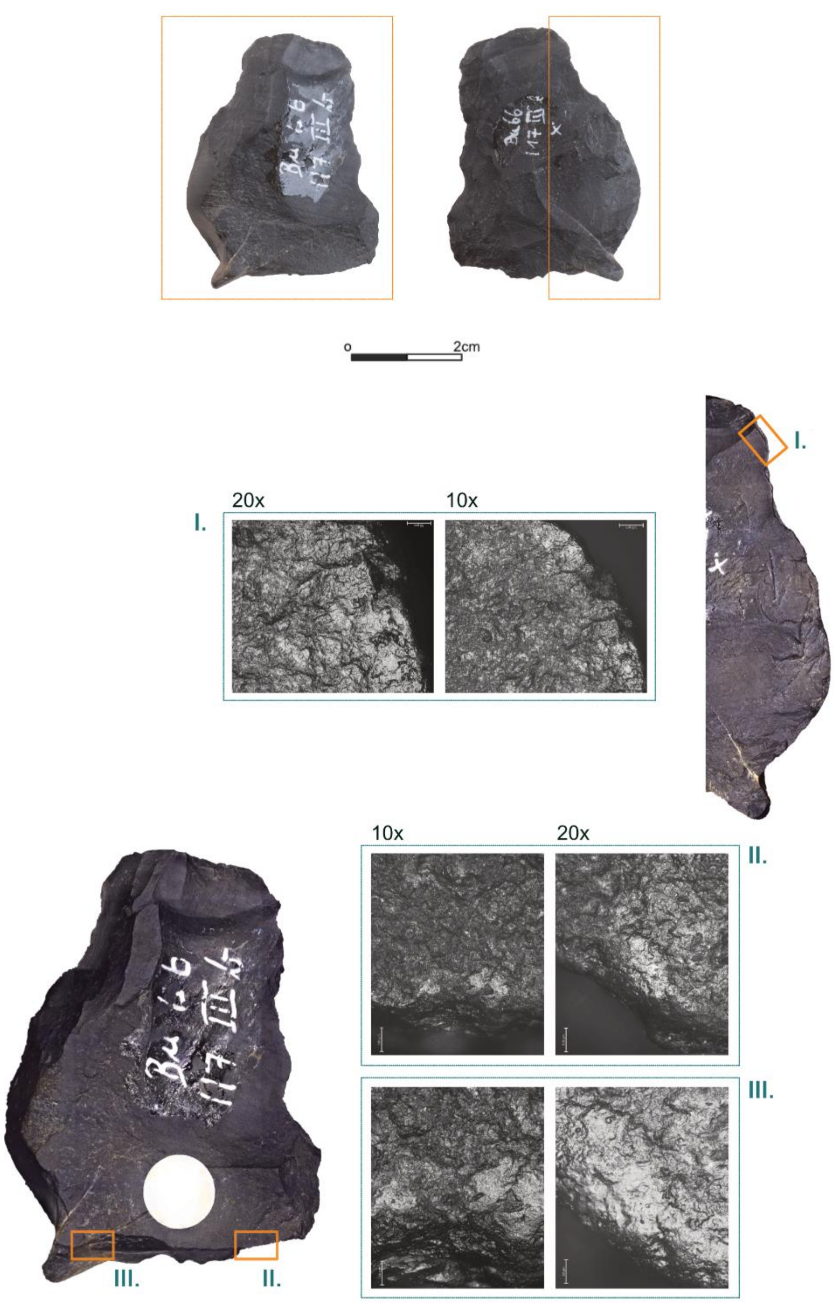


Fig. 39 Buhlen, *Keilmesser* tip [ID BU-087]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x and 20x (I. type V.; II. type V.; III. type V.).

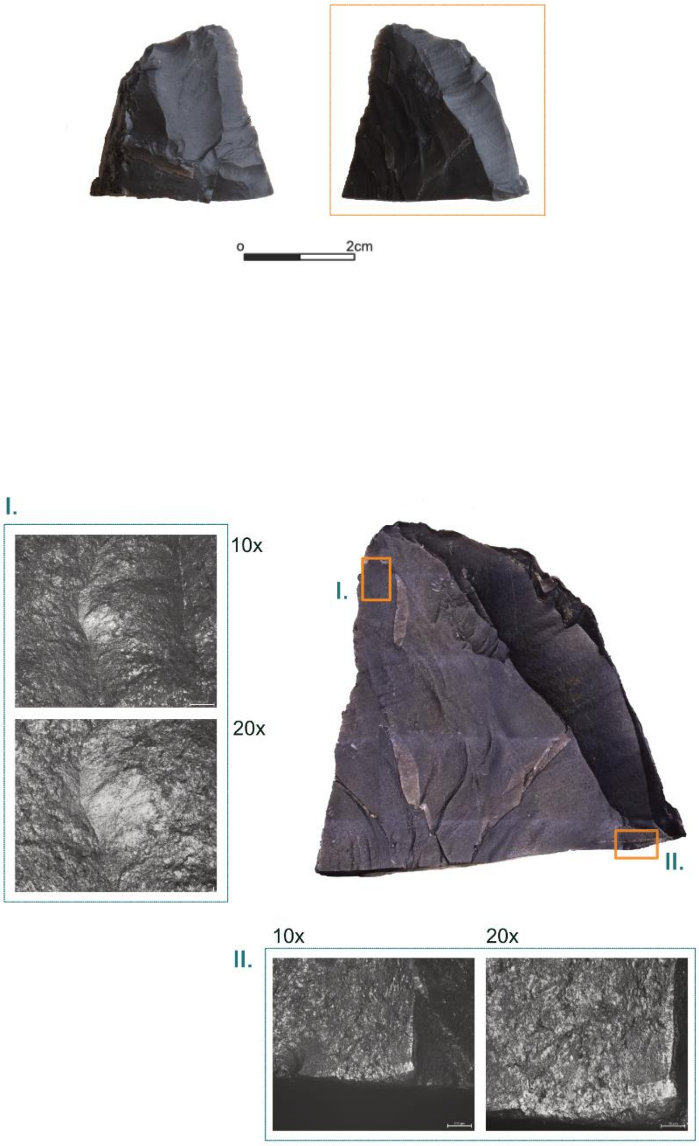
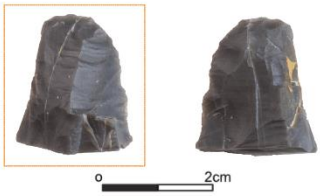


Fig. 40 Buhlen, *Keilmesser* tip [ID BU-088]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x and 20x (I. type V.; II. type IV.).



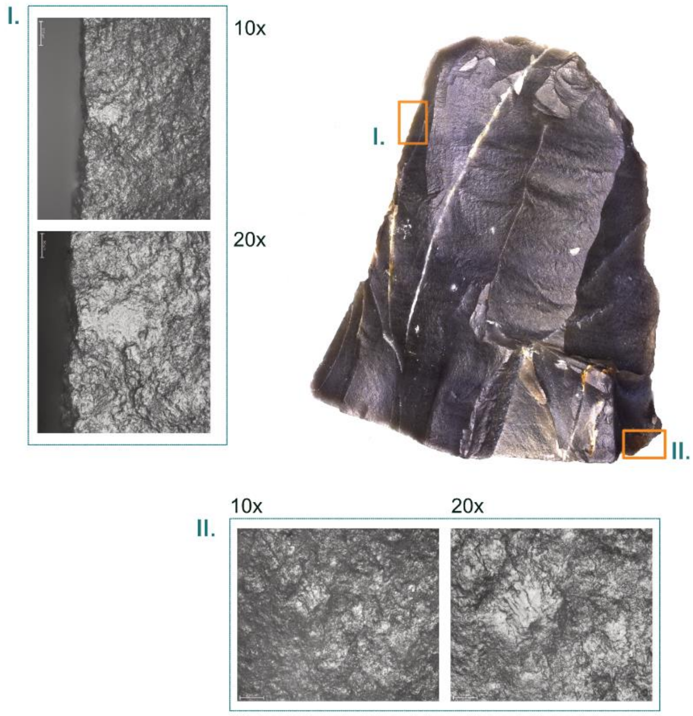


Fig. 41 Buhlen, *Keilmesser* tip [ID BU-090]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x and 20x (I. type I.; II. type V.).

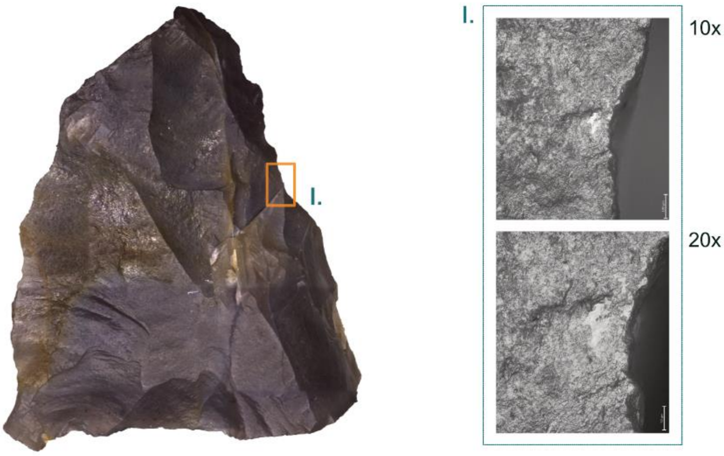
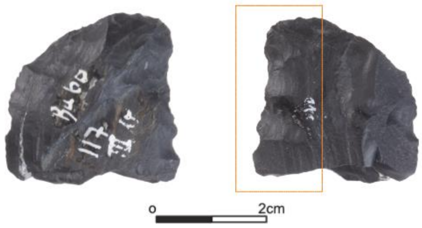


Fig. 42 Buhlen, *Keilmesser* tip [ID BU-093]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear trace is acquired at magnification of 10x and 20x (I. type I.).



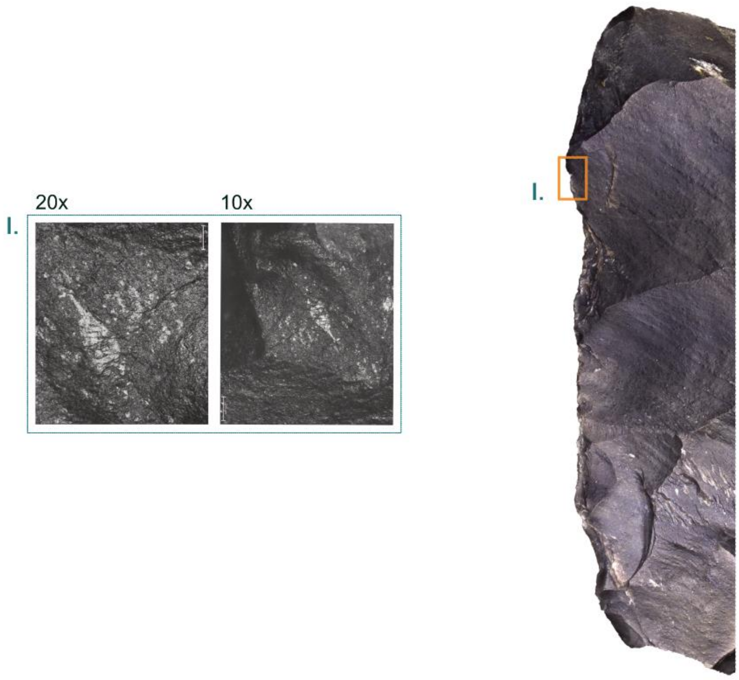


Fig. 43 Buhlen, *Keilmesser* tip [ID BU-097]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear trace is acquired at magnification of 10x and 20x (I. type I.).

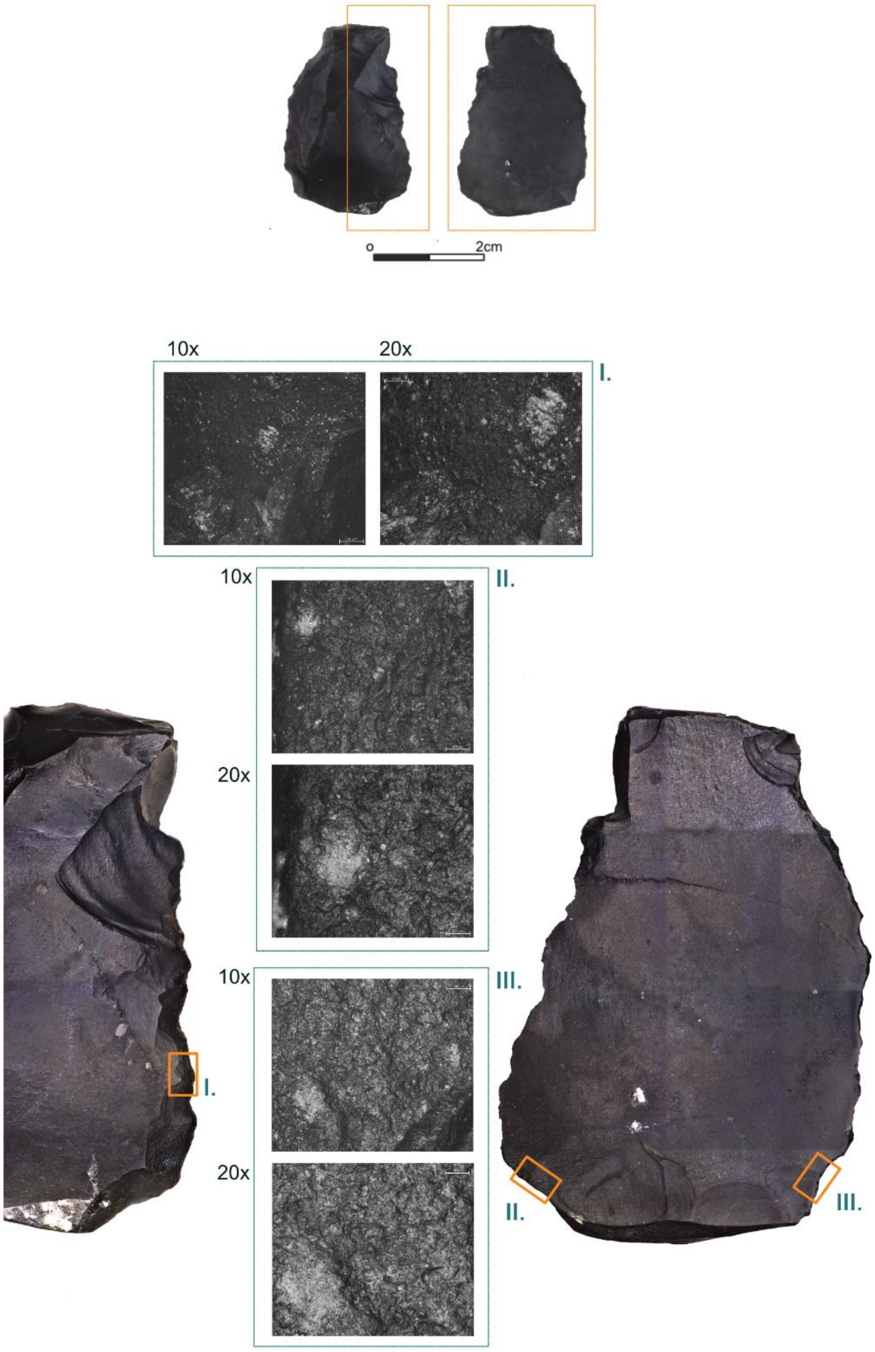


Fig. 44 Buhlen, *Prądnik scraper* [ID BU-099]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x and 20x (I. type I.; II. type I. III. type I.).

Fig. 45 Buhlen, *Prądnik scraper* [ID BU-100]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear trace is acquired at magnification of 10x and 20x (I. type I.).

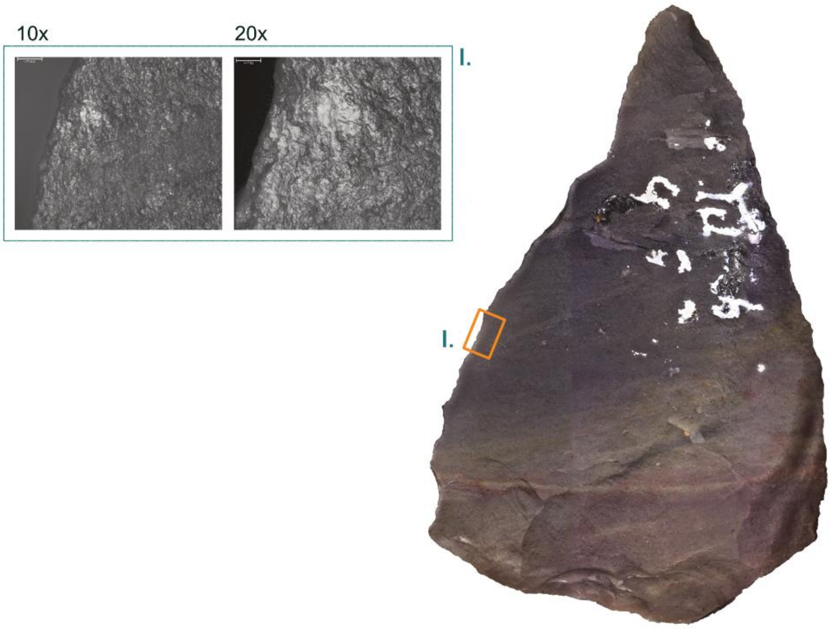


Fig. 46 Buhlen, *Prądnik scraper* [ID BU-101]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear trace is acquired at magnification of 10x and 20x (I. type V.).

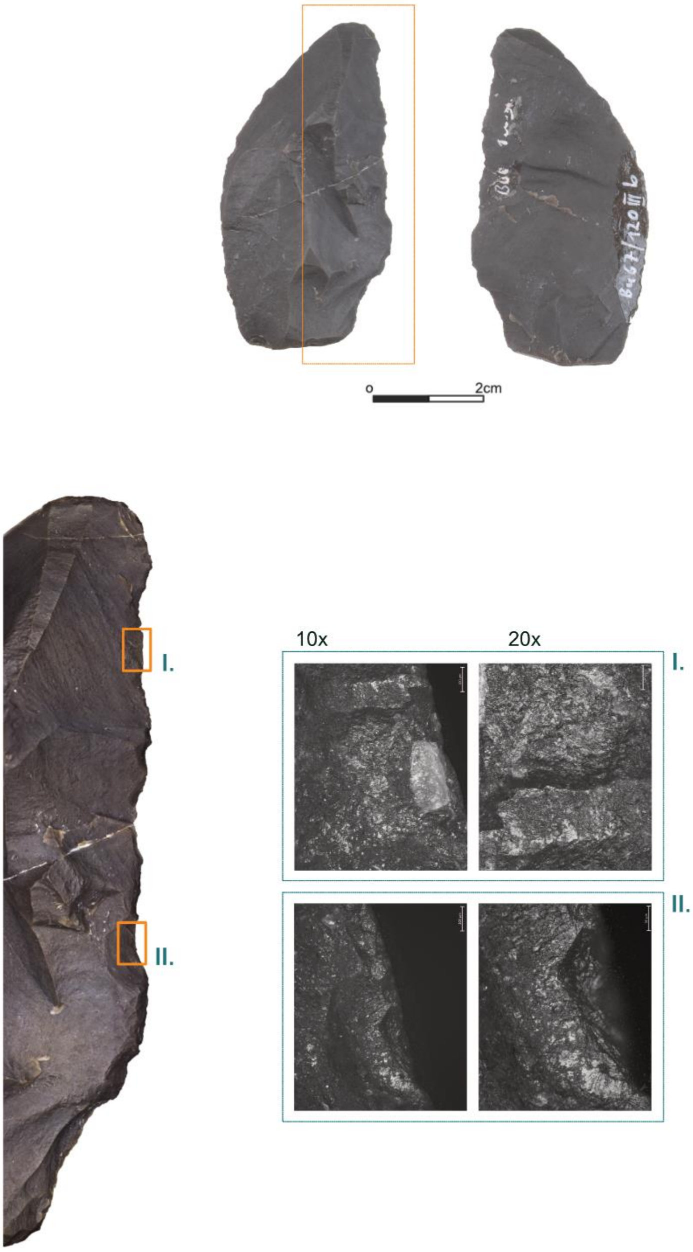


Fig. 47 Buhlen, *Prądnik scraper* [ID BU-103]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x and 20x (I. type V.; II. type V.).

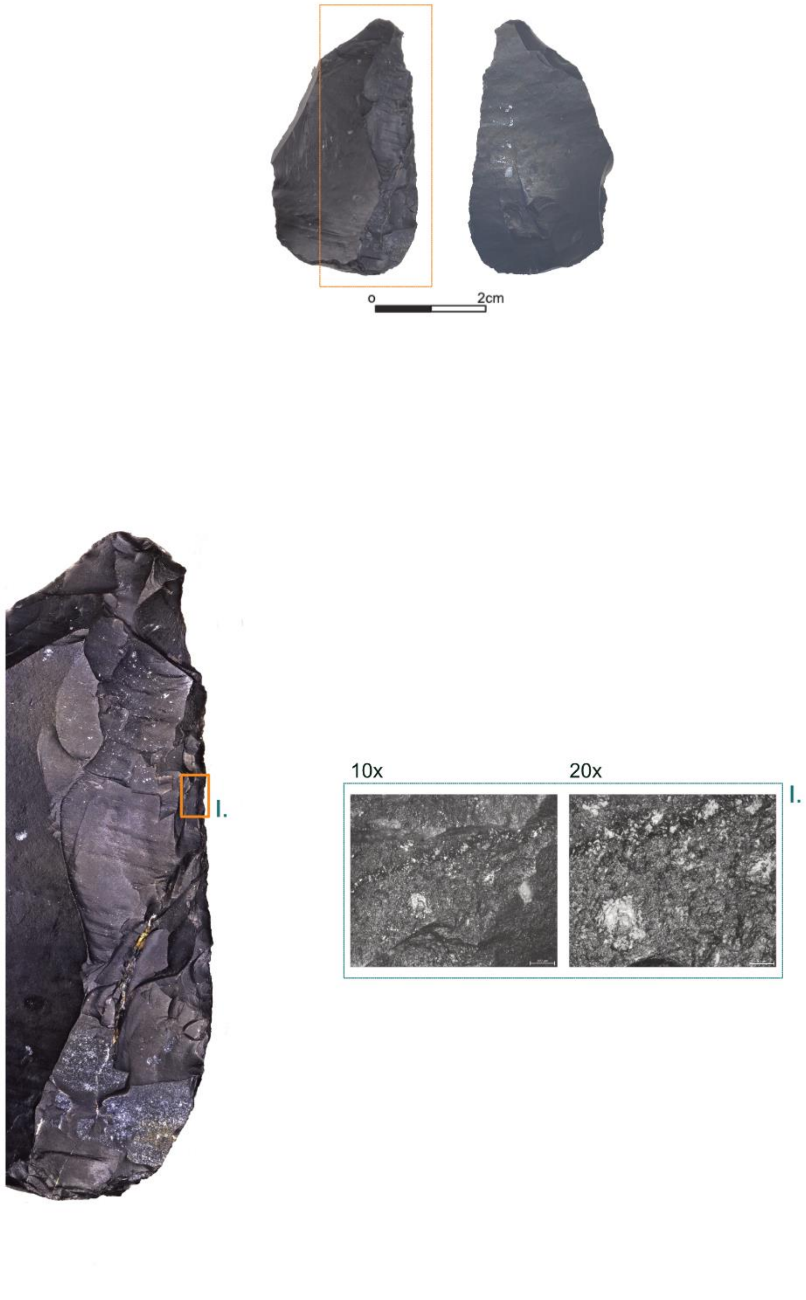


Fig. 48 Buhlen, *Prądnik scraper* [ID BU-104]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear trace is acquired at magnification of 10x and 20x (I. type I.).

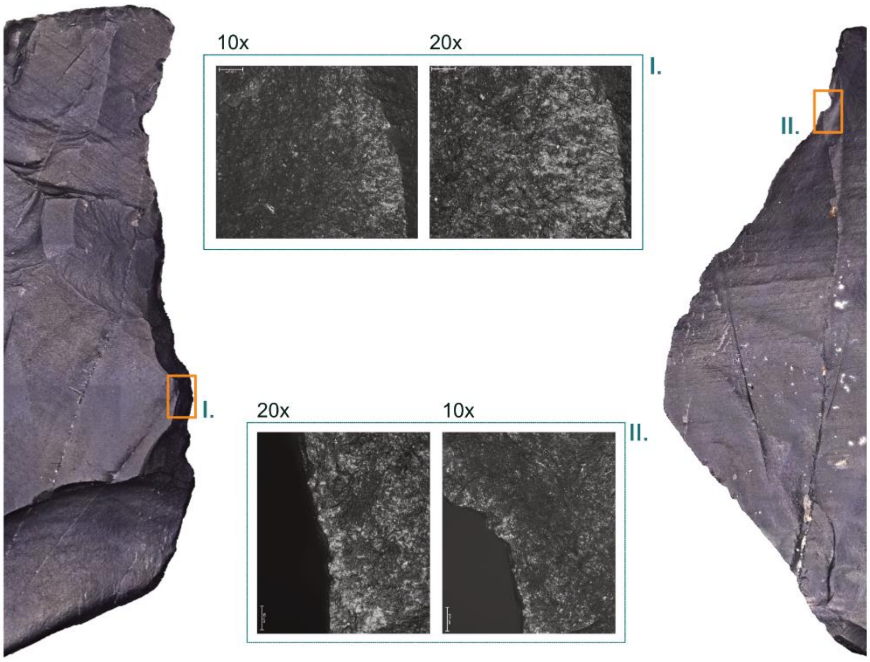


Fig. 49 Buhlen, *Prądnik scraper* [ID BU-105]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x and 20x (I. type V.; II. type V.).

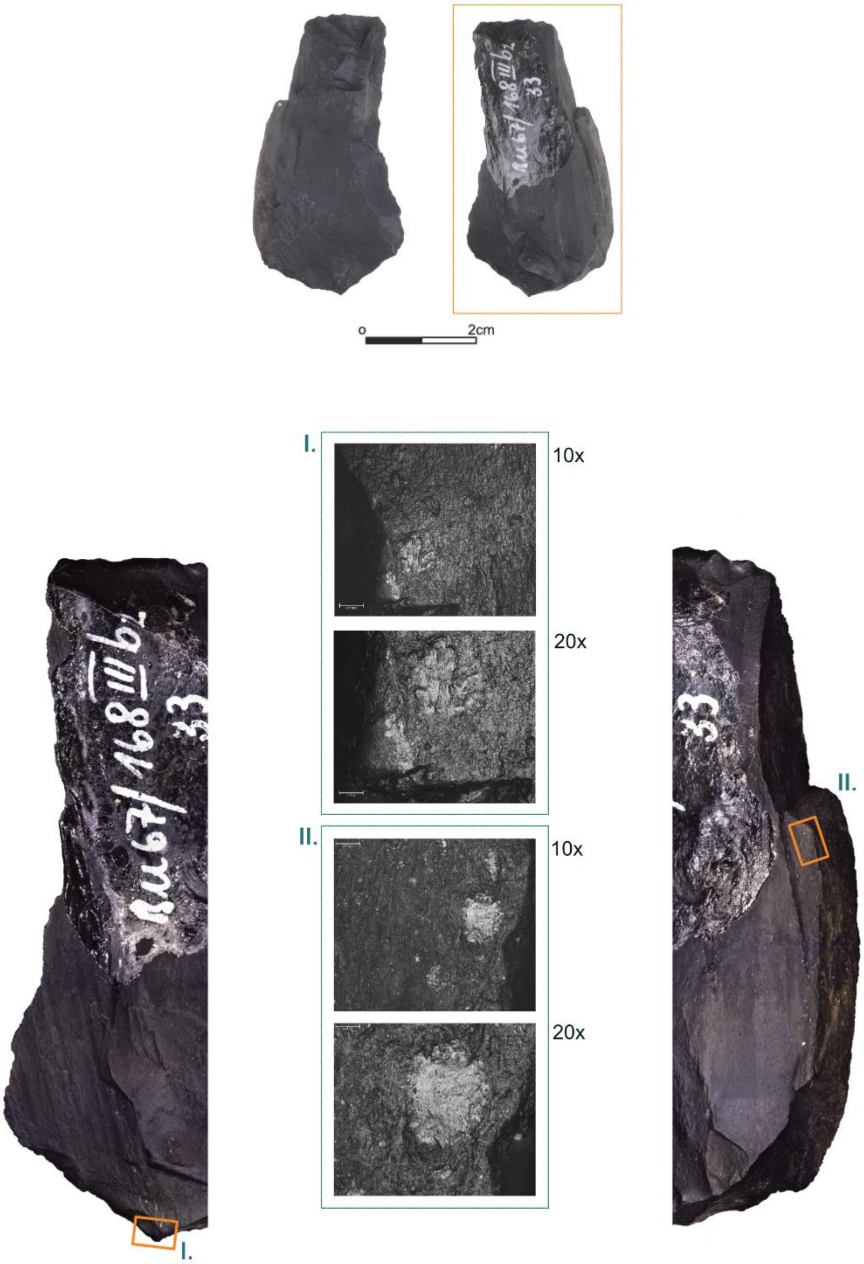


Fig. 50 Buhlen, *Prądnik scraper* [ID BU-106]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x and 20x (I. type I.; II. type V.).

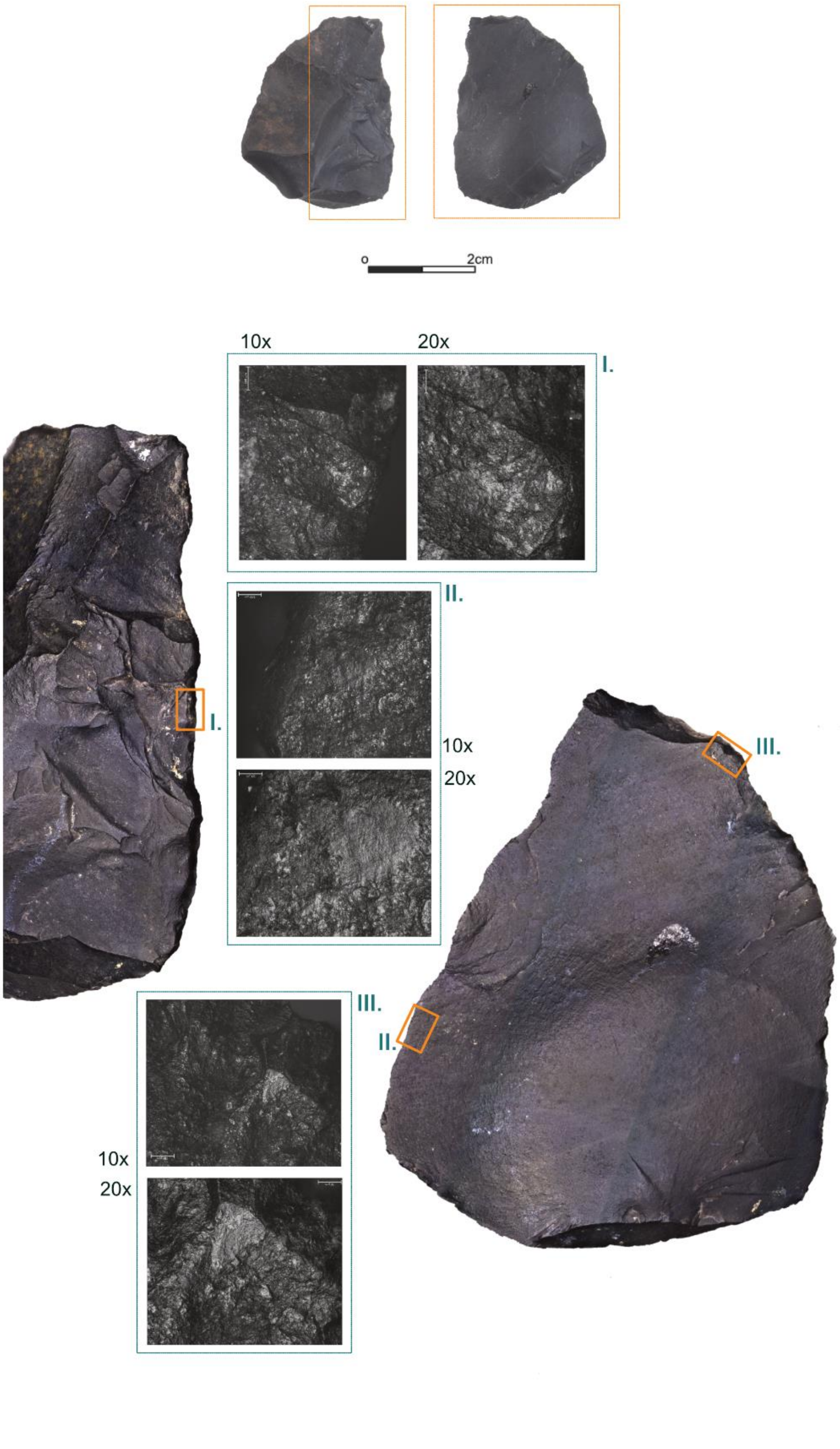


Fig. 51 Buhlen, *Prądnik scraper* [ID BU-107]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x and 20x (I. type V.; II. type IX.; III. type V.).

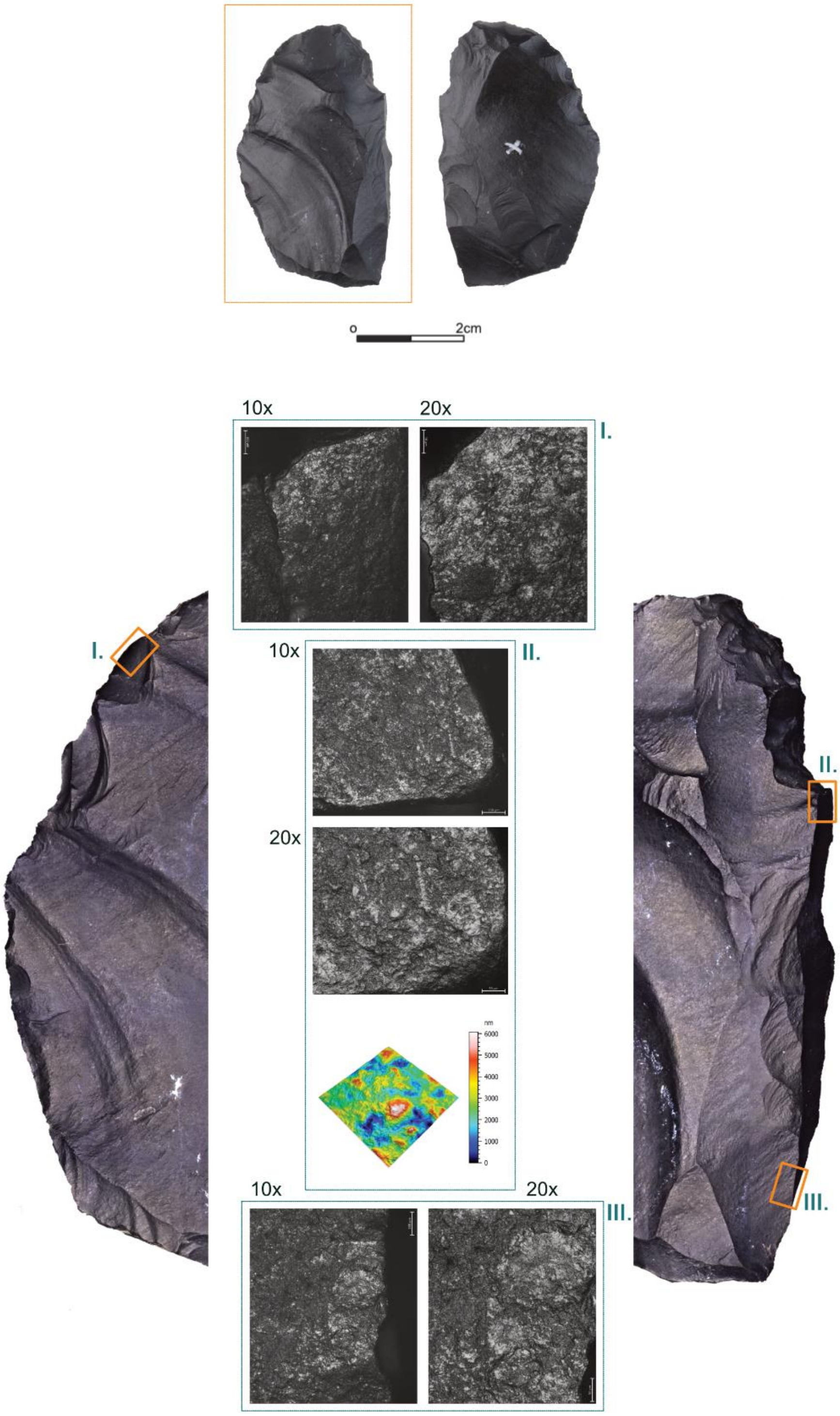


Fig. 52 Buhlen, *Prądnik scraper* [ID BU-115; dorsal]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x and 20x (I. type V.; II. type V.; III. type V.).

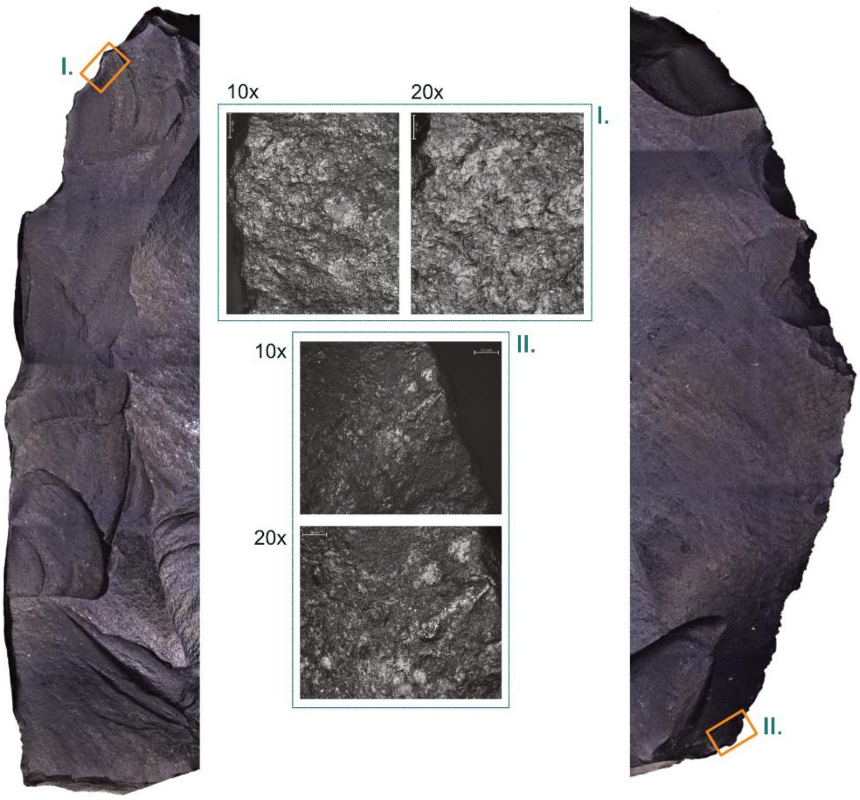


Fig. 53 Buhlen, *Prądnik scraper* [ID BU-115; ventral]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x and 20x (I. type V.; II. type V.).

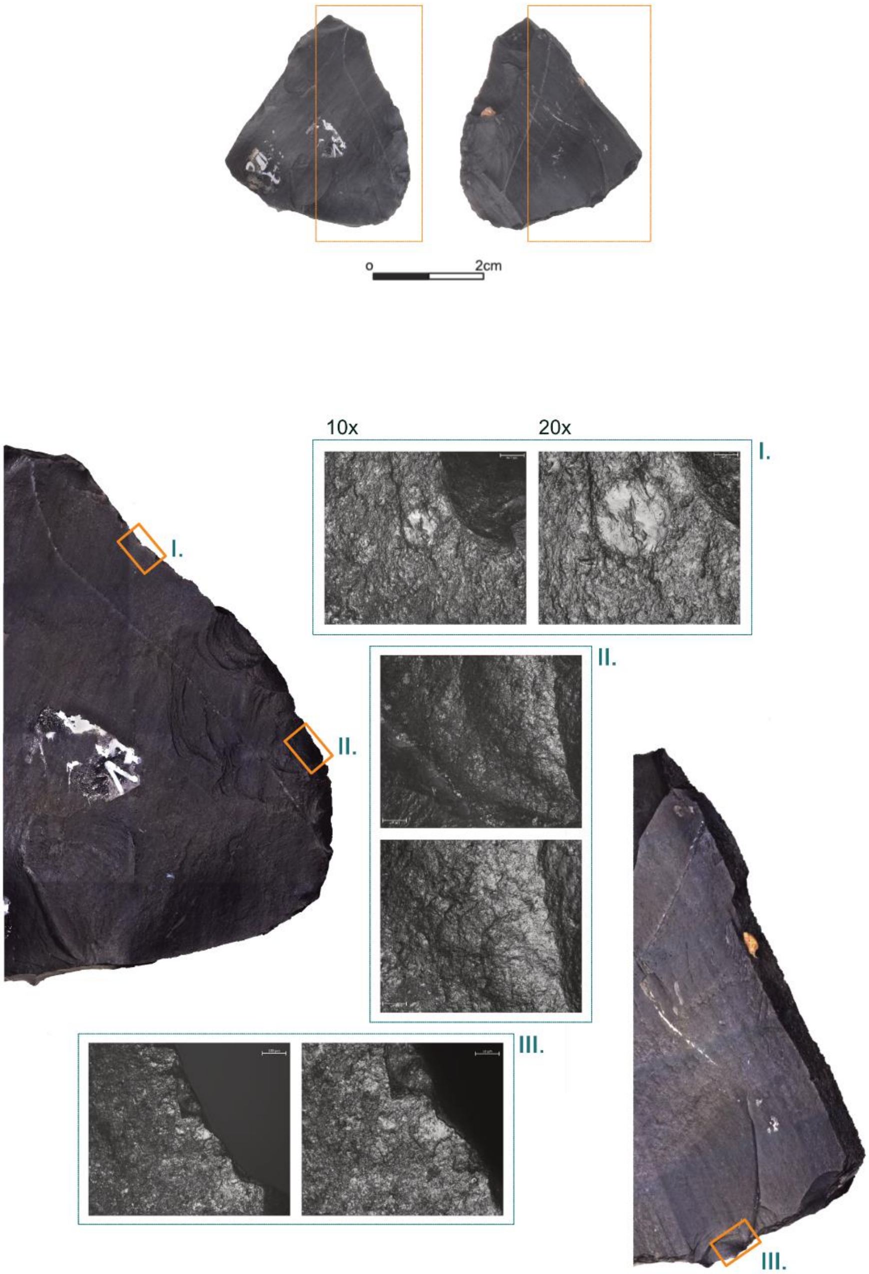


Fig. 54 Buhlen, *Prądnik scraper* [ID BU-117]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x and 20x (I. type I.; II. type V.; III. type V.).

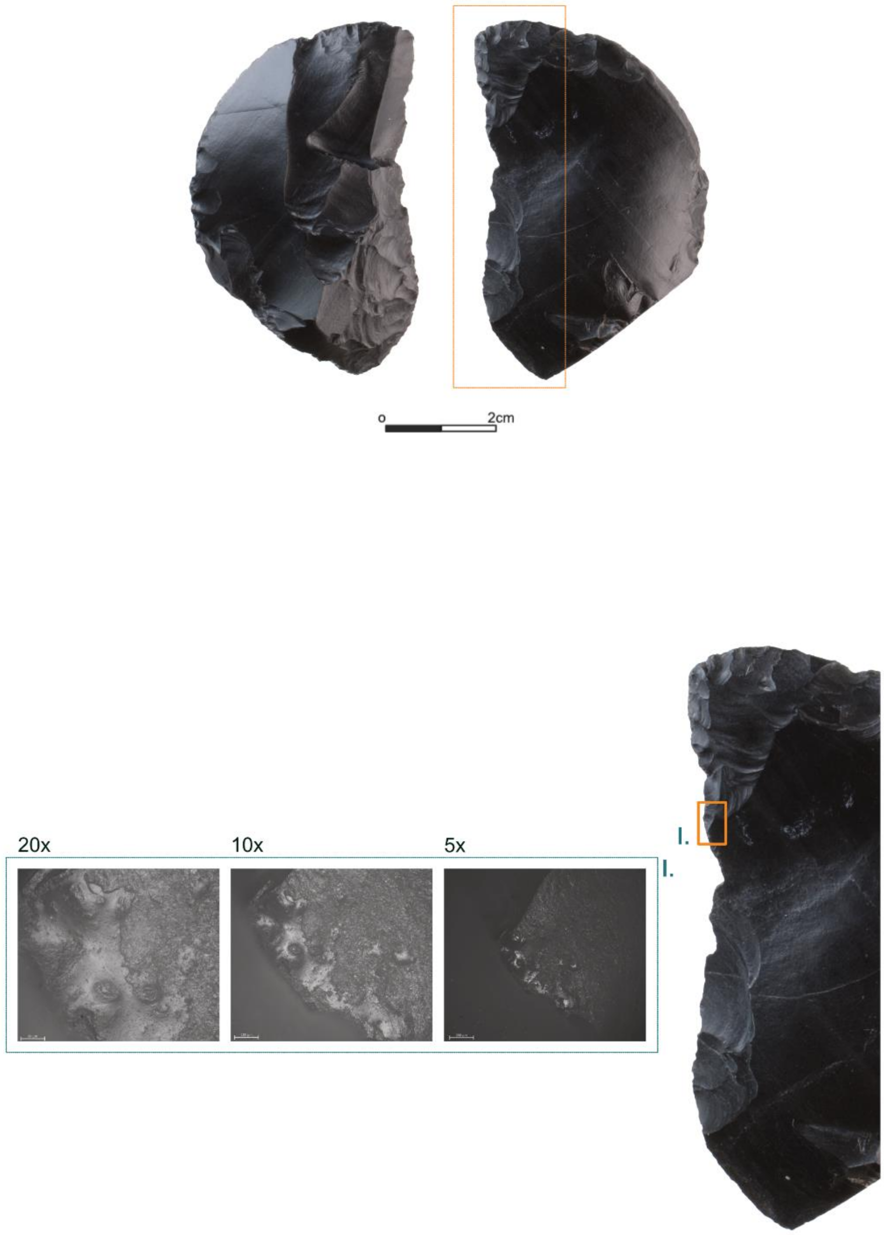


Fig. 55 Buhlen, *Prądnik scraper* [ID BU-194]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear trace is acquired at magnification of 5x, 10x and 20x (I. type VI.).

Fig. 56 Buhlen, *Prądnik spall* [ID BU-121]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 5x, 10x and 20x (I. type V.; II. type V.; III. type V.).

Fig. 57 Buhlen, *Prądnik spall* [ID BU-124]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x and 20x (I. type V.; II. type V.).

Fig. 58 Buhlen, *Prądnik spall* [ID BU-127]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x and 20x (I. type V.; II. type V.; III. type V.).

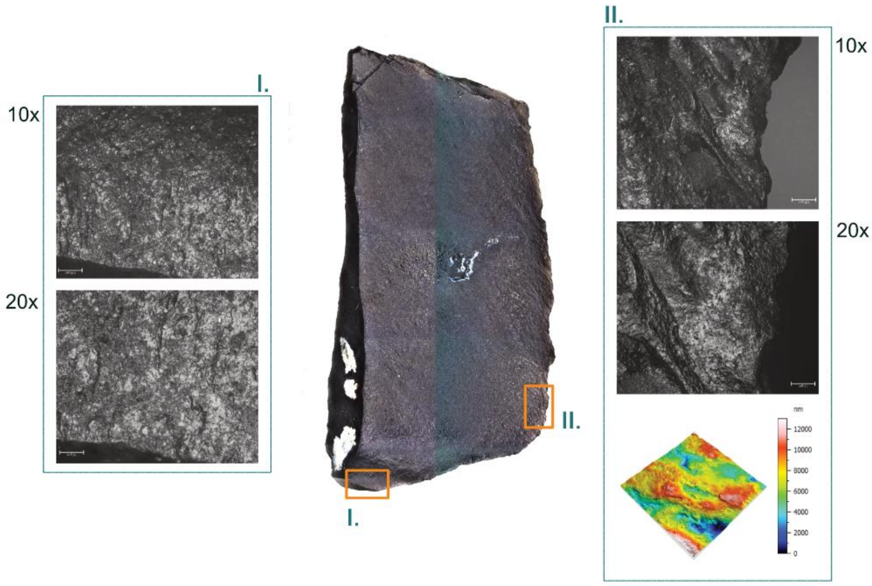


Fig. 59 Buhlen, *Prądnik spall* [ID BU-128]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x and 20x (I. type V.; II. type V.).

Fig. 60 Buhlen, *Prądnik spall* [ID BU-129]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x and 20x (I. type I.; II. type I.).

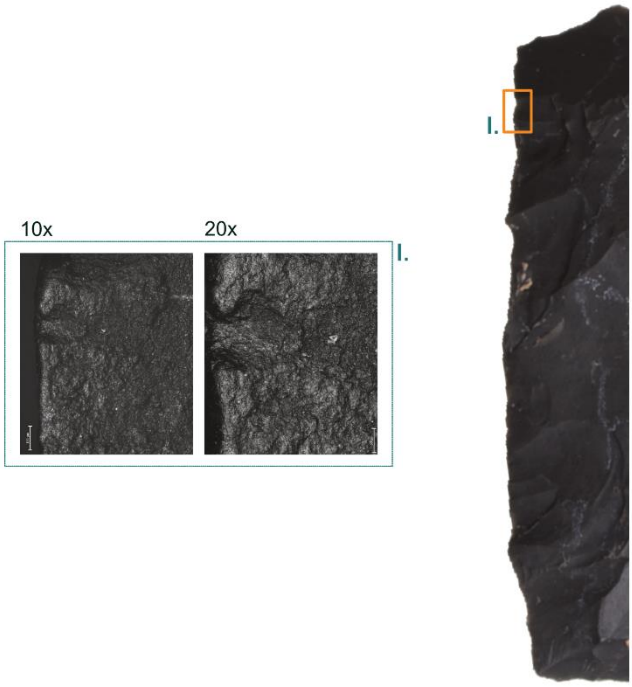


Fig. 61 Buhlen, *Prądnik spall* [ID BU-131]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear trace is acquired at magnification of 10x and 20x (I. type V.).

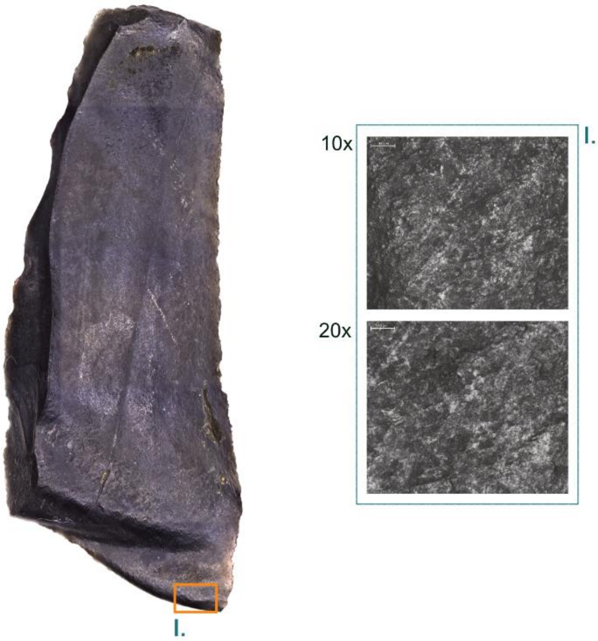


Fig. 62 Buhlen, *Prądnik spall* [ID BU-132]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear trace is acquired at magnification of 10x and 20x (I. type V.).

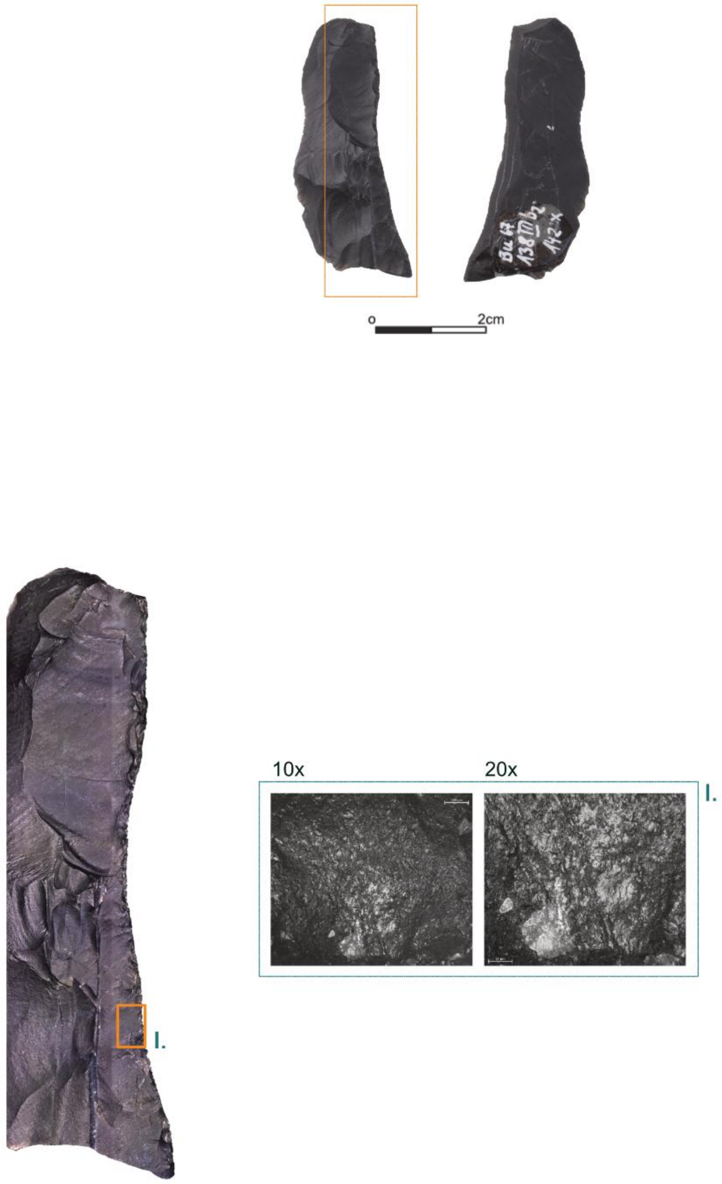


Fig. 63 Buhlen, *Prądnik spall* [ID BU-136]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear trace is acquired at magnification of 10x and 20x (I. type V.).

Fig. 64 Buhlen, *Prądnik spall* [ID BU-139]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear trace is acquired at magnification of 10x (I. type V.).

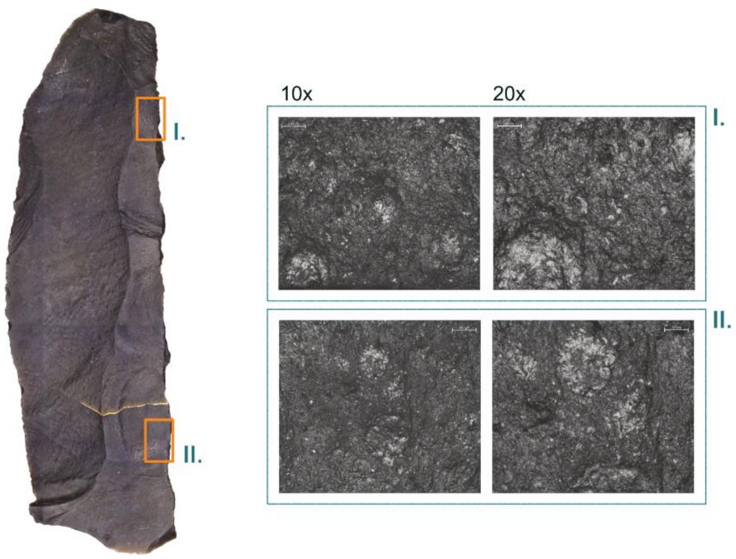


Fig. 65 Buhlen, *Prądnik spall* [ID BU-157]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x and 20x (I. type I.; II. type I.).

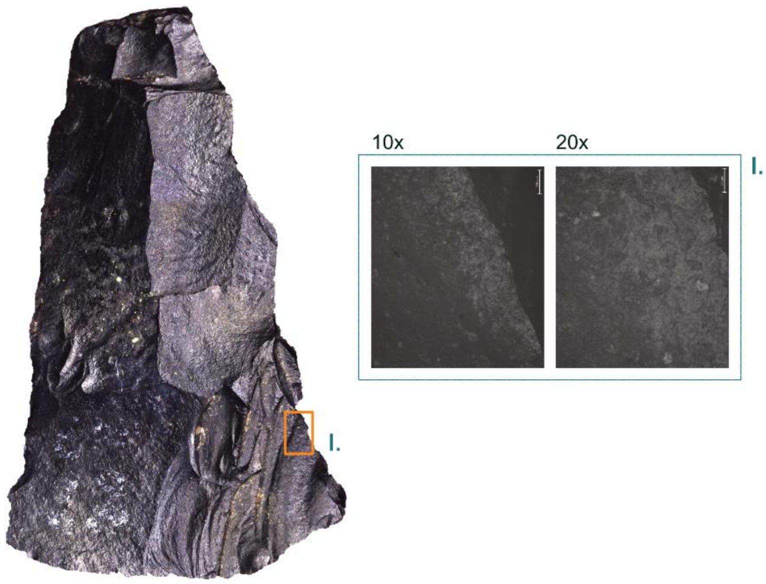


Fig. 66 Buhlen, *Prądnik spall* [ID BU-169]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear trace is acquired at magnification of 10x and 20x (I. type V.).

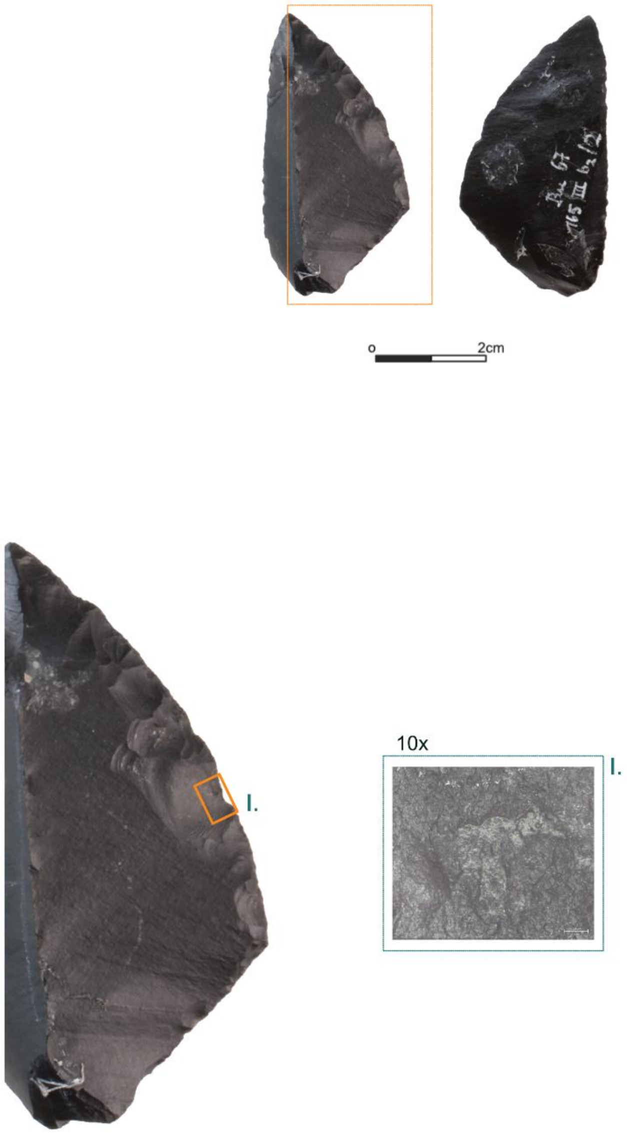


Fig. 67 Buhlen, scraper [ID BU-189]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear trace is acquired at magnification of 10x (I. type V.).

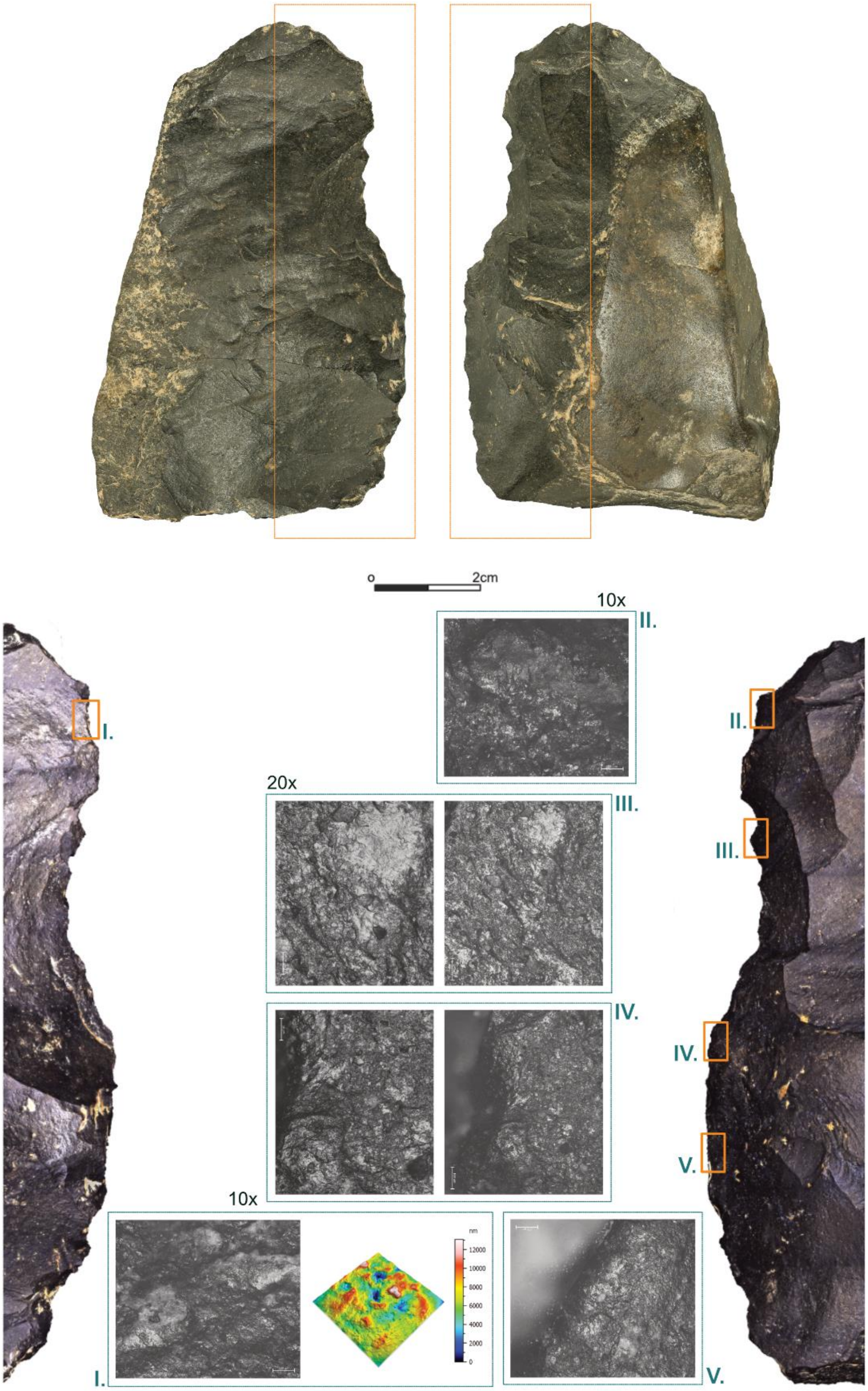


Fig. 68 Balver Höhle, *Keilmesser* [ID MU-003]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x and 20x (I. type II.; II. type I.; III. type I.; IV. type I.; V. type I.). The micro-surface displays the processed result of the confocal data acquisition with the 50x objective.

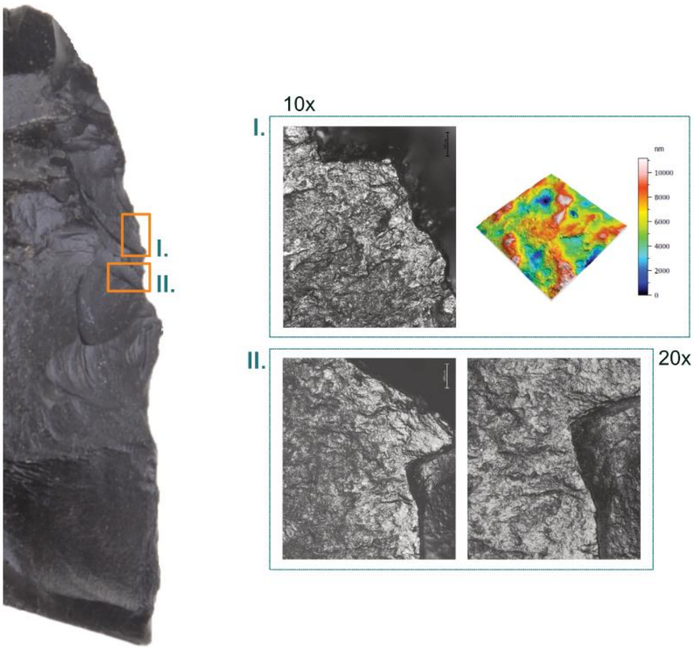


Fig. 69 Balver Höhle, *Keilmesser* [ID MU-008]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x and 20x (I. type V.; II. type V.). The micro-surface displays the processed result of the confocal data acquisition with the 50x objective.

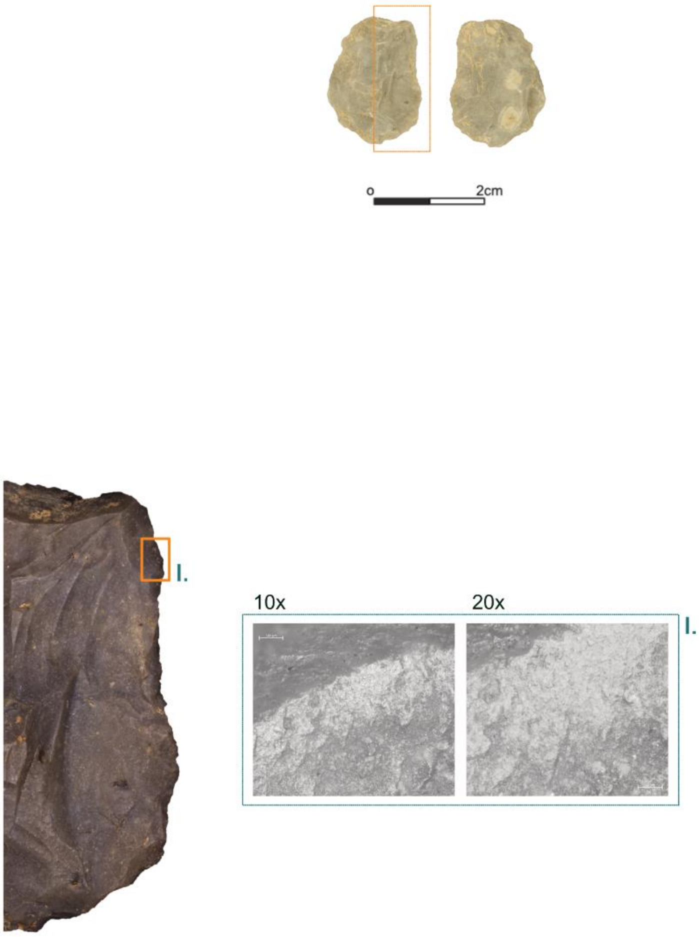


Fig. 70 Balver Höhle, *Keilmesser* [ID MU-011]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear trace is acquired at magnification of 10x and 20x (I. type V.).

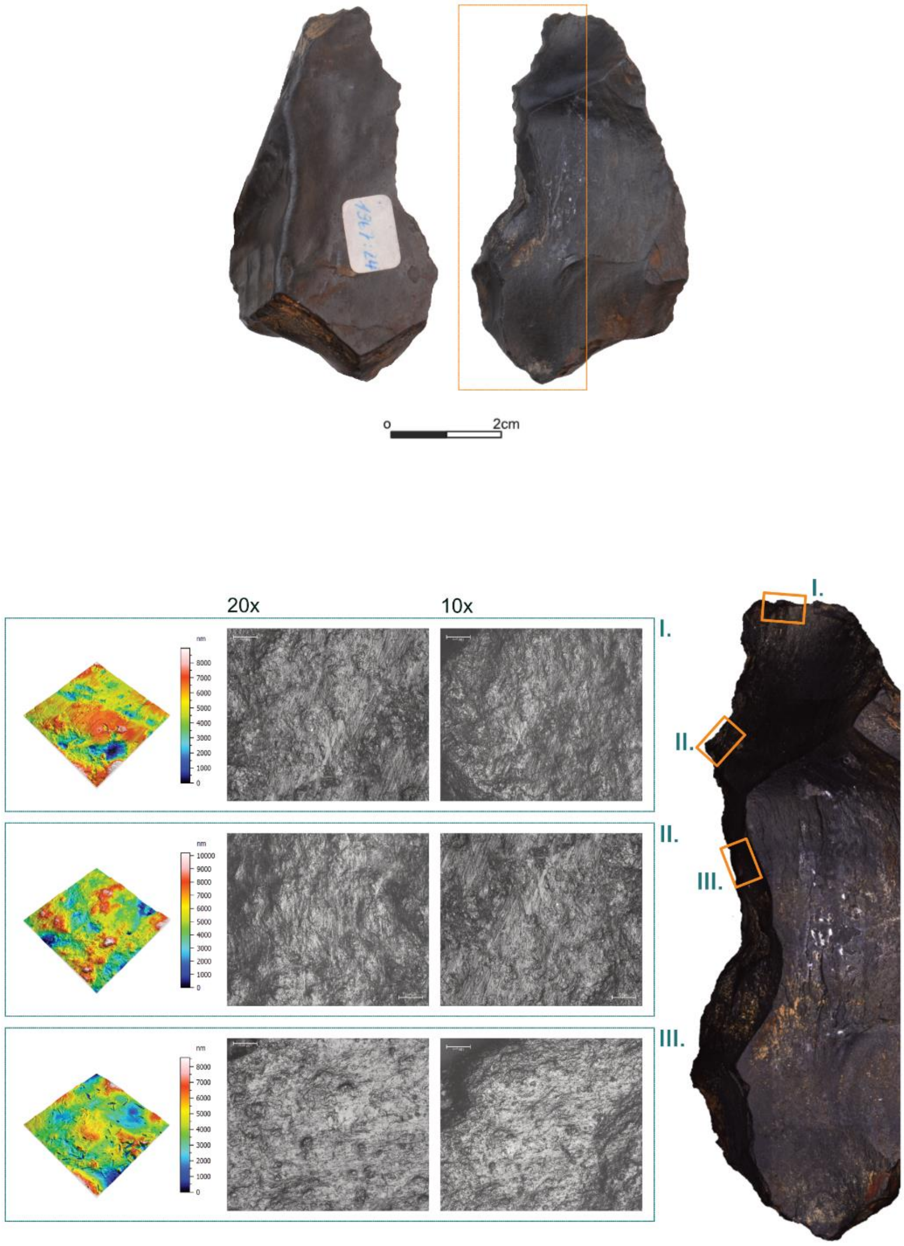


Fig. 71 Balver Höhle, *Keilmesser* [ID MU-020]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x and 20x (I. type VI.; II. type VI.; III. type VII.). The micro-surface displays the processed result of the confocal data acquisition with the 50x objective.

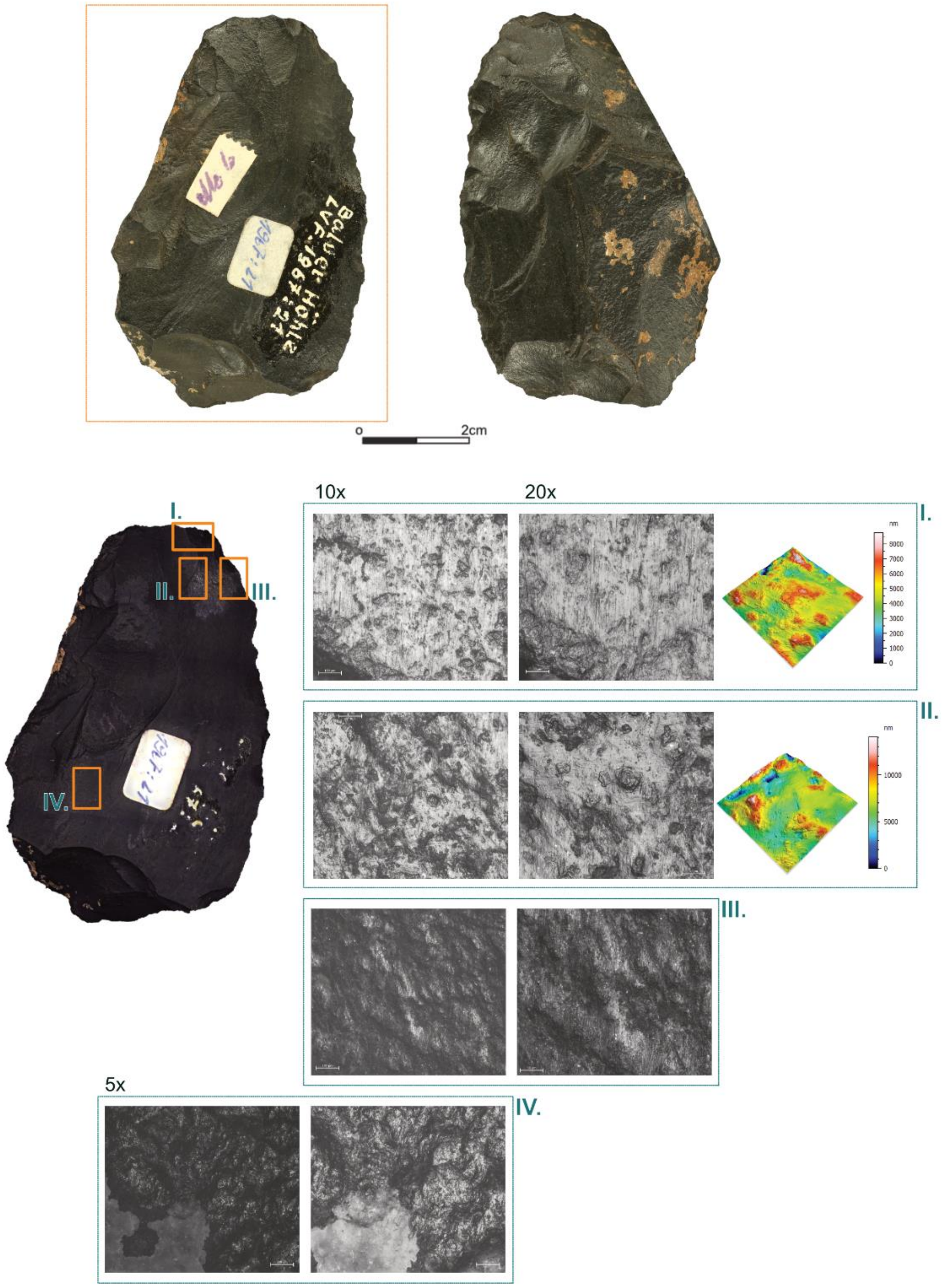


Fig. 72 Balver Höhle, *Keilmesser* [ID MU-021]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 5x, 10x and 20x (I. type VII.; II. type VII.; III. type VII.; IV. type II.). The micro-surface displays the processed result of the confocal data acquisition with the 50x objective.

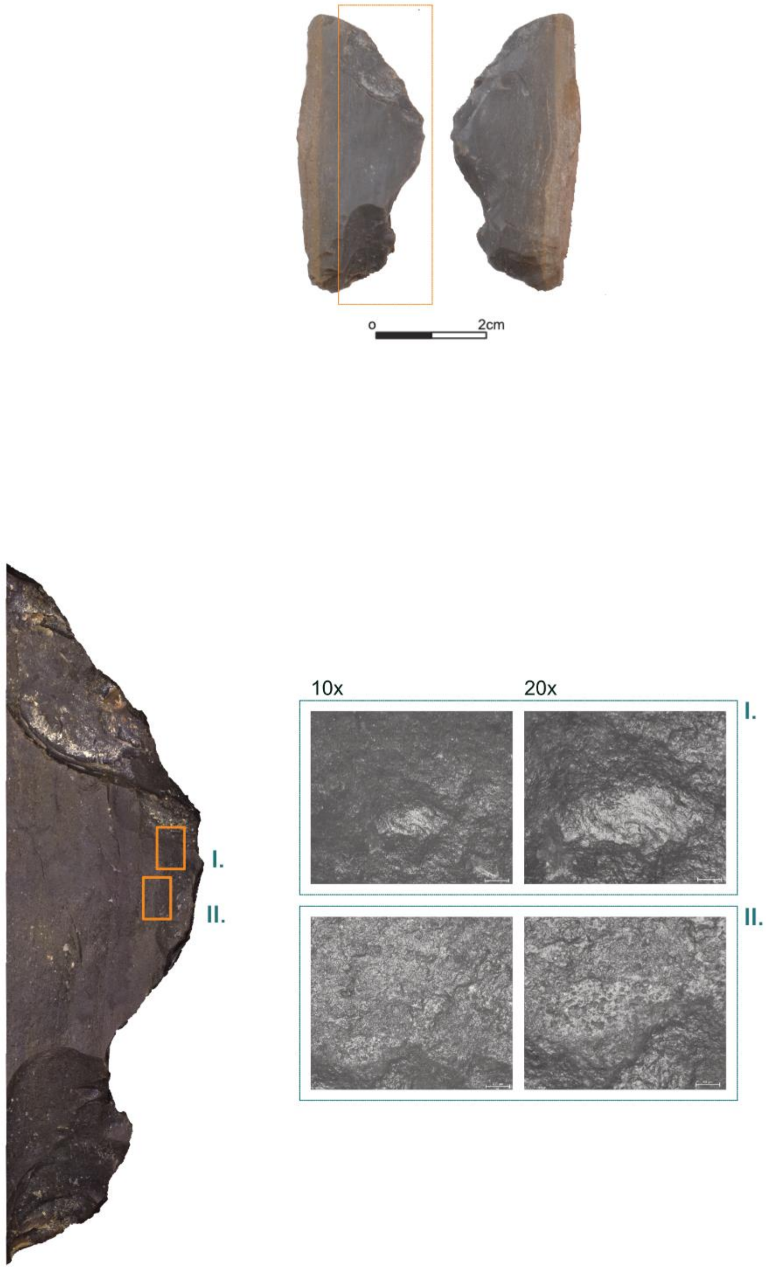


Fig. 73 Balver Höhle, *Keilmesser* [ID MU-023]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x and 20x (I. type I.; II. type II.).

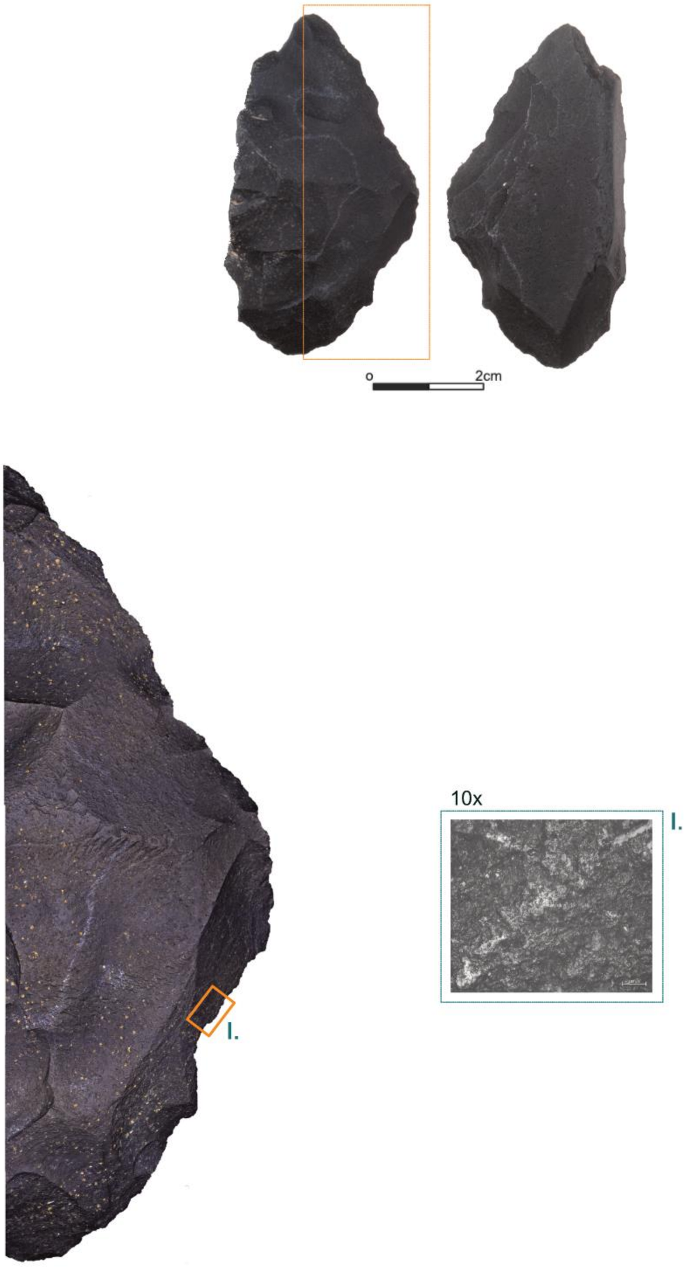


Fig. 74 Balver Höhle, *Keilmesser* [ID MU-044]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear trace is acquired at magnification of 10x (I. type II.).

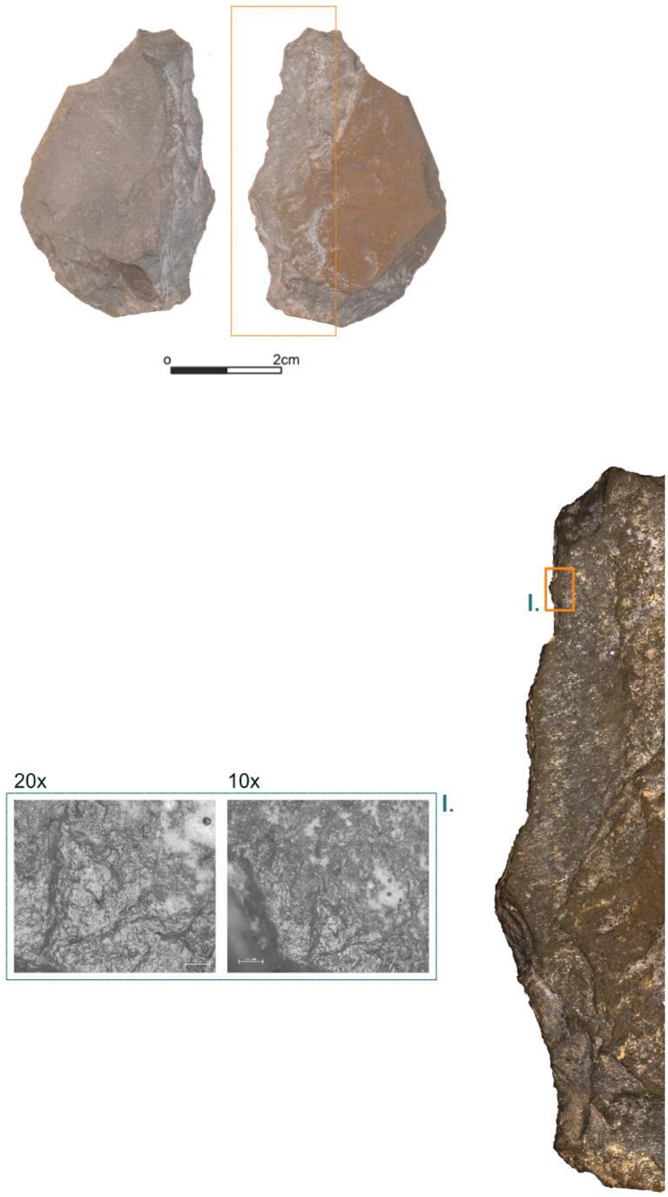


Fig. 75 Balver Höhle, *Keilmesser* [ID MU-061]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear trace is acquired at magnification of 10x and 20x (I. type V.).

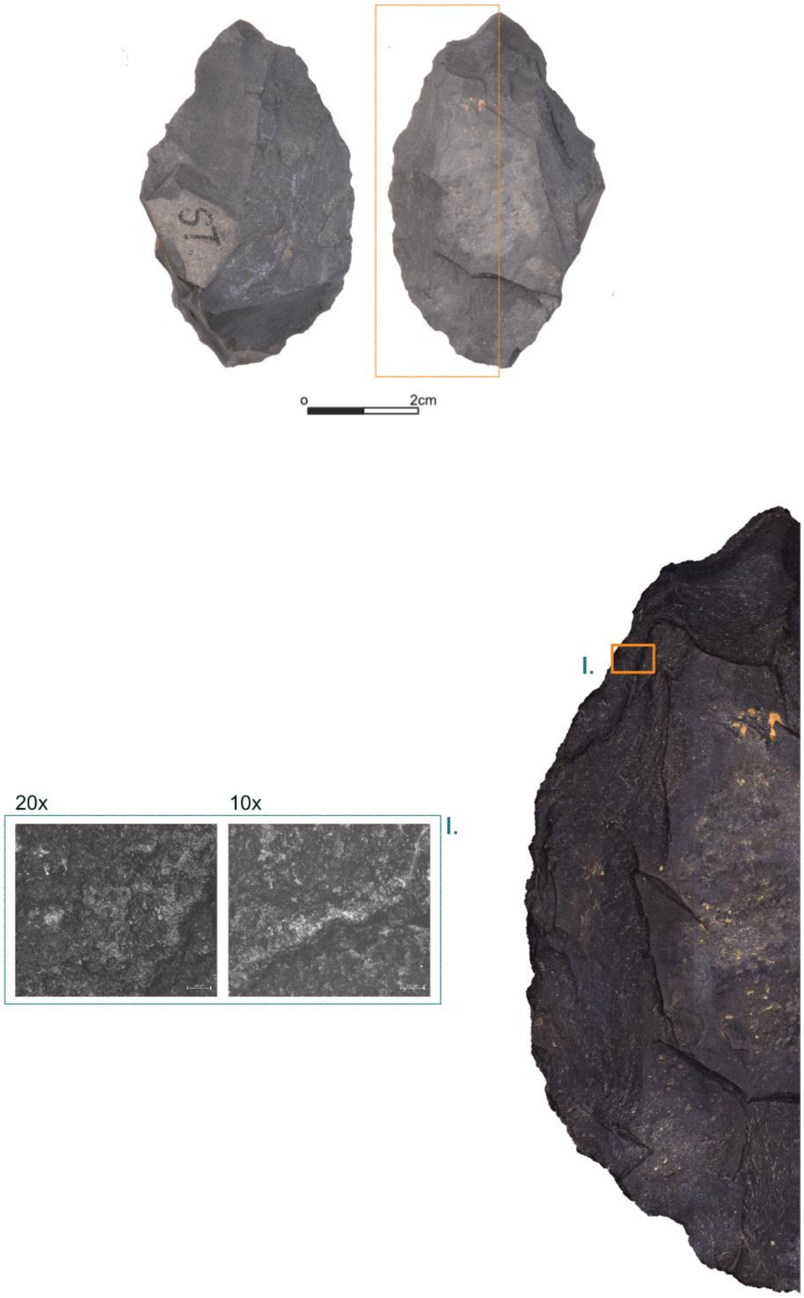


Fig. 76 Balver Höhle, *Keilmesser* [ID MU-063]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear trace is acquired at magnification of 10x and 20x (I. type II.).

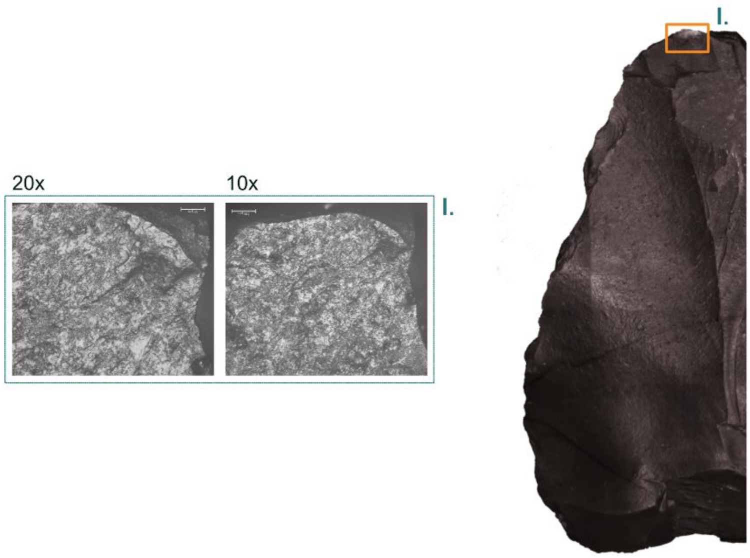


Fig. 77 Balver Höhle, *Keilmesser* [ID MU-073]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear trace is acquired at magnification of 10x and 20x (I. type II.).

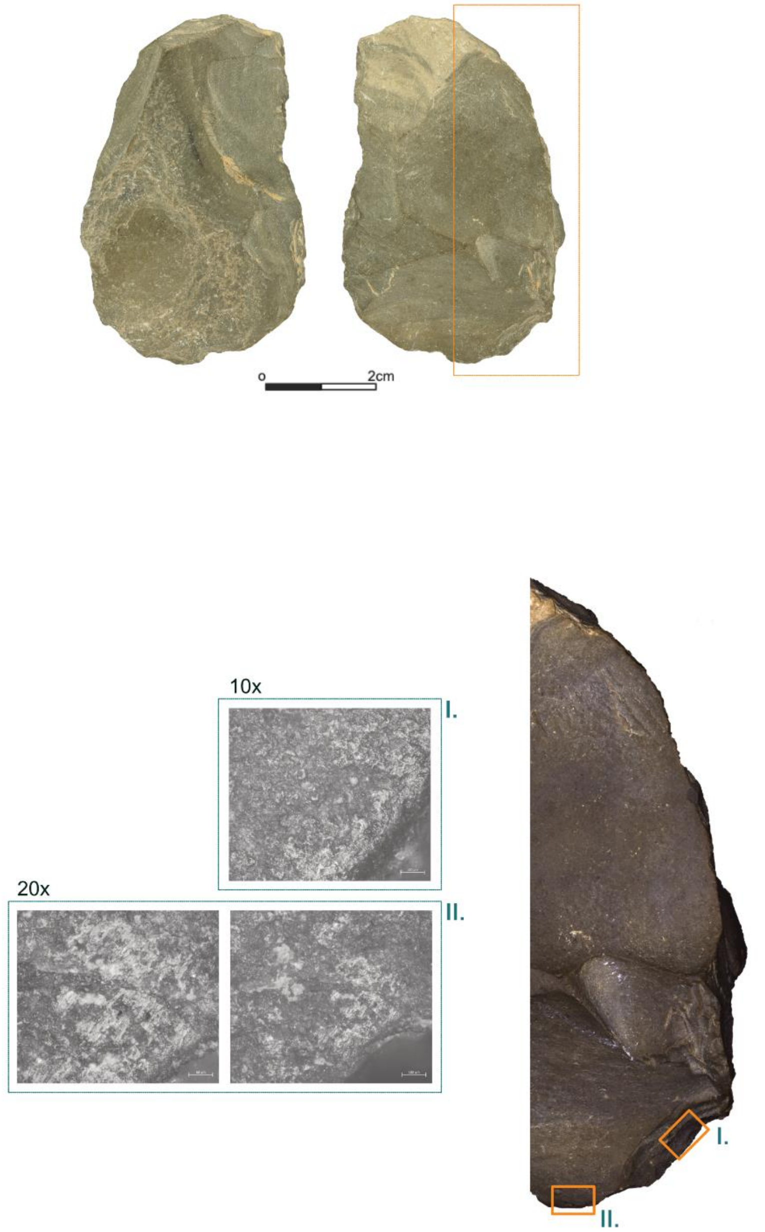


Fig. 78 Balver Höhle, *Keilmesser* [ID MU-093]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x and 20x (I. type V.; II. type VII.).

Fig. 79 Balver Höhle, *Keilmesser* [ID MU-100]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x and 20x (I. type I.; II. type I.).

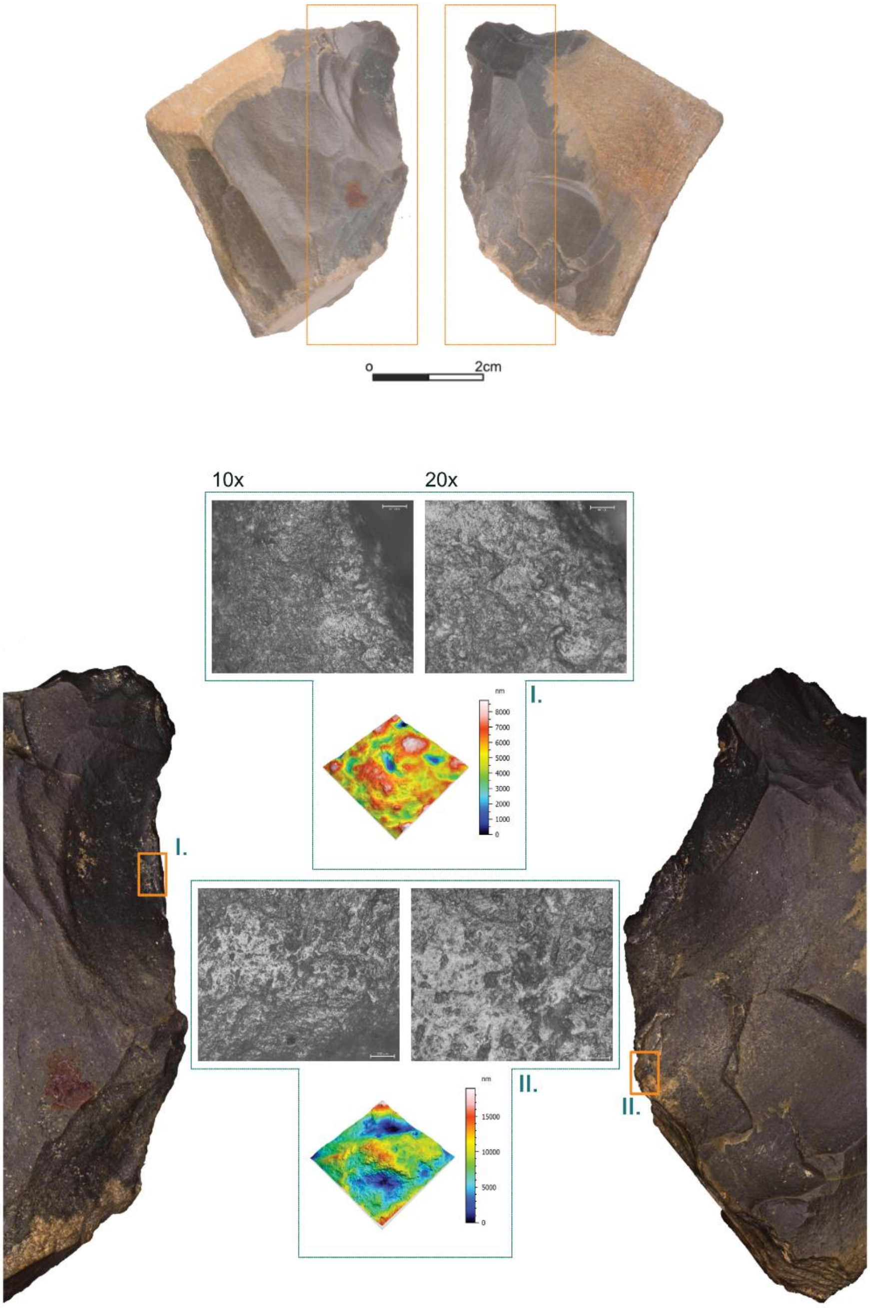


Fig. 80 Balver Höhle, *Keilmesser* [ID MU-107]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x and 20x (I. type V.; II. type V.). The micro-surface displays the processed result of the confocal data acquisition with the 50x objective.

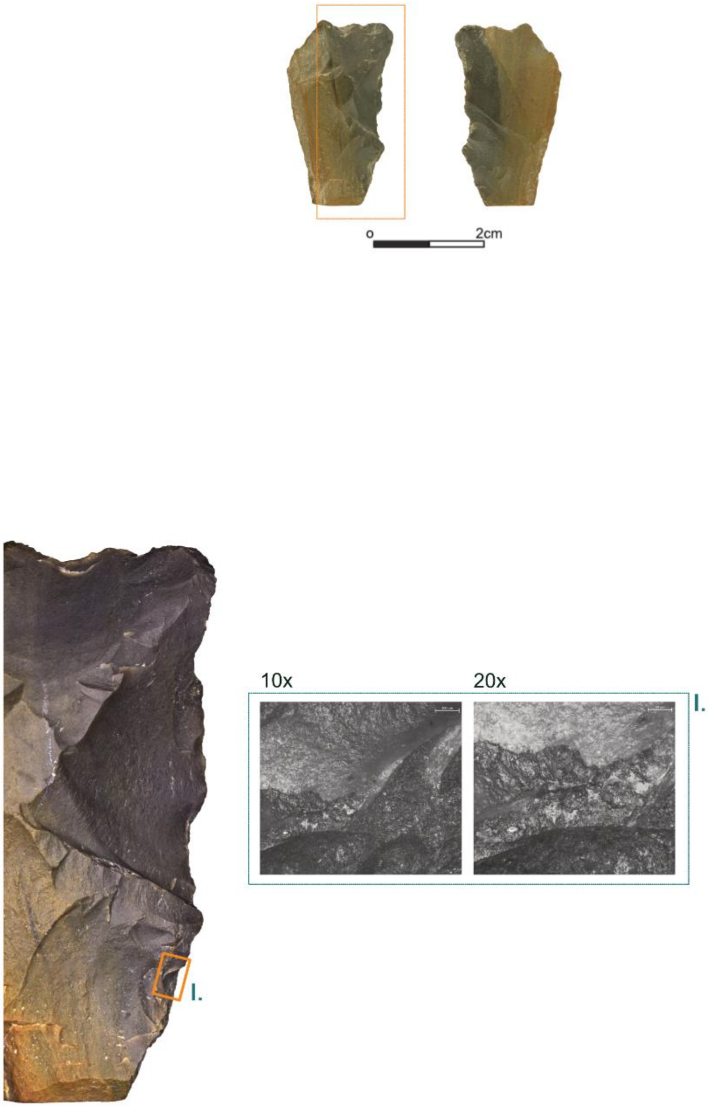


Fig. 81 Balver Höhle, *Keilmesser* [ID MU-109]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear trace is acquired at magnification of 10x and 20x (I. type I.).

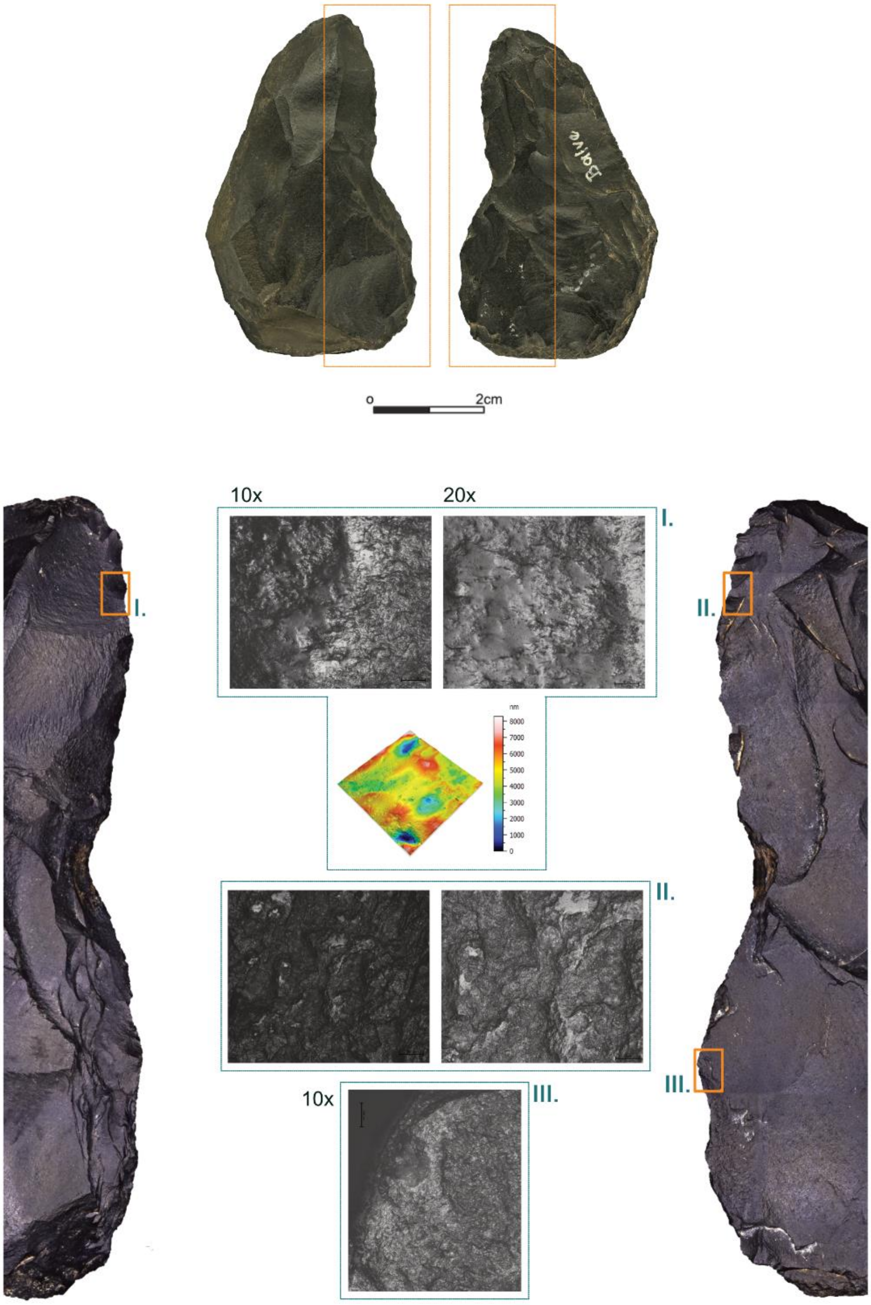


Fig. 82 Balver Höhle, *Keilmesser* [ID MU-111]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x and 20x (I. type IV.; II. type IV.; III. type III.). The micro-surface displays the processed result of the confocal data acquisition with the 50x objective.

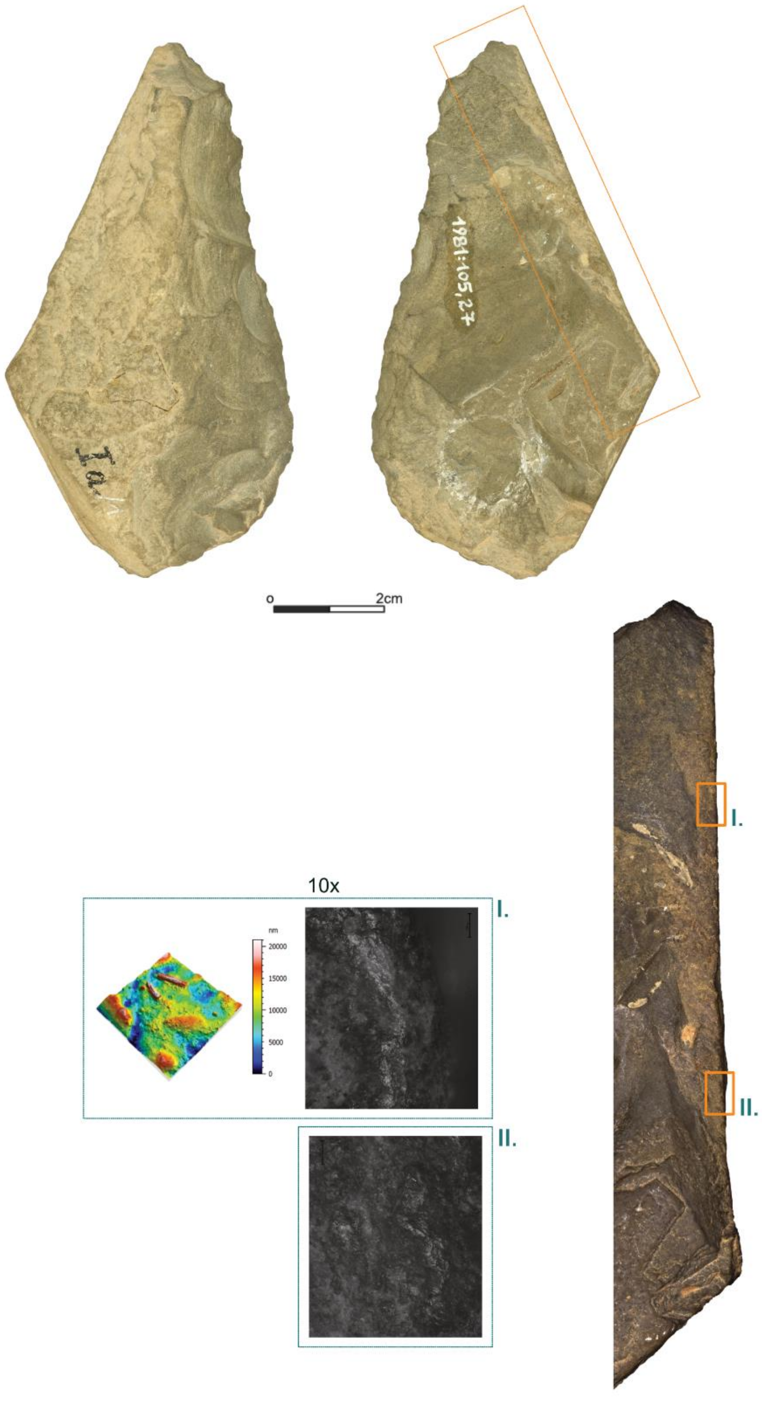


Fig. 83 Balver Höhle, *Keilmesser* [ID MU-112]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x (I. type IV.; II. type IV.). The micro-surface displays the processed result of the confocal data acquisition with the 50x objective.

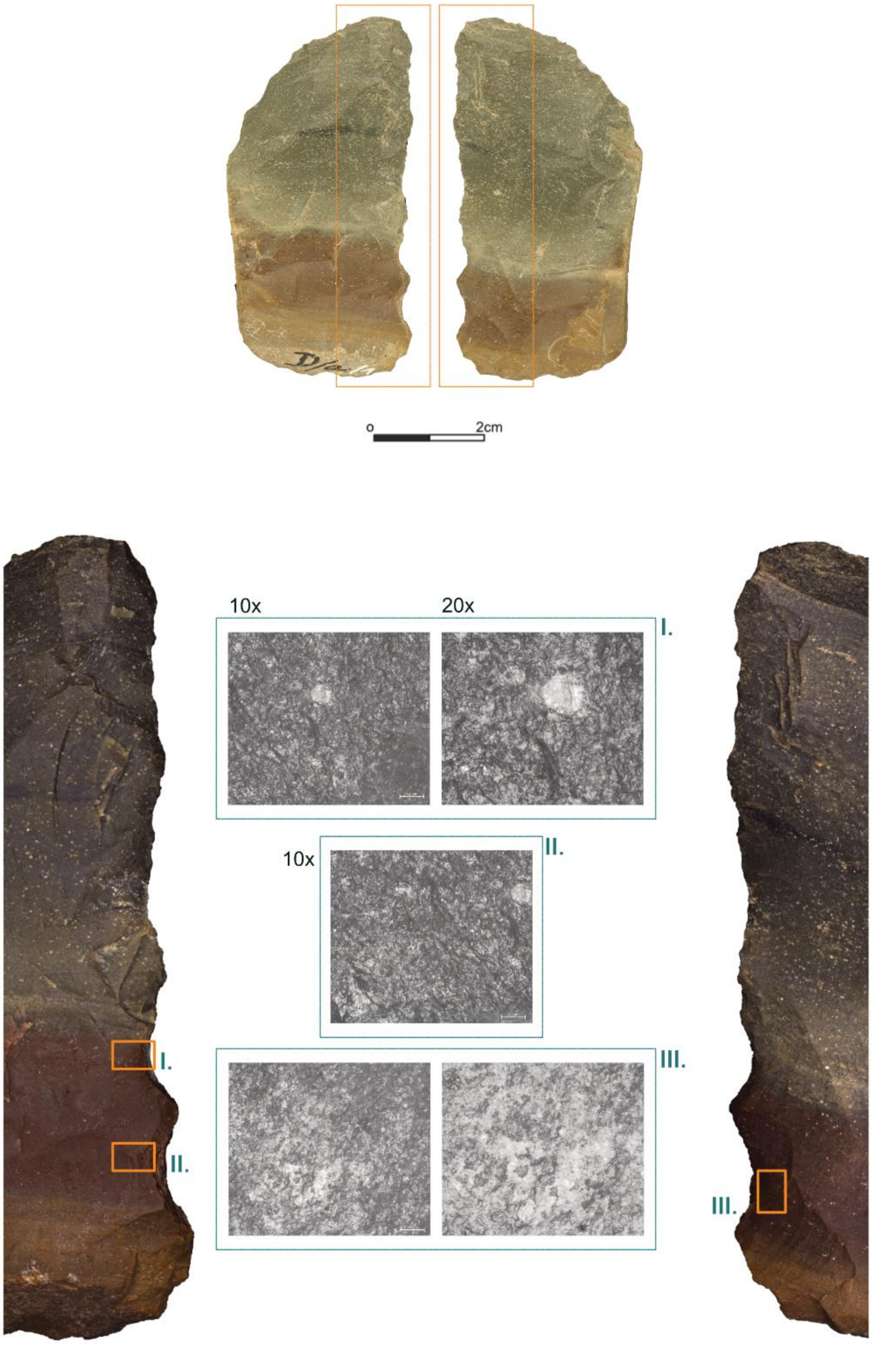


Fig. 84 Balver Höhle, *Keilmesser* [ID MU-114]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x and 20x (I. type II.; II. type II.; III. type III.).

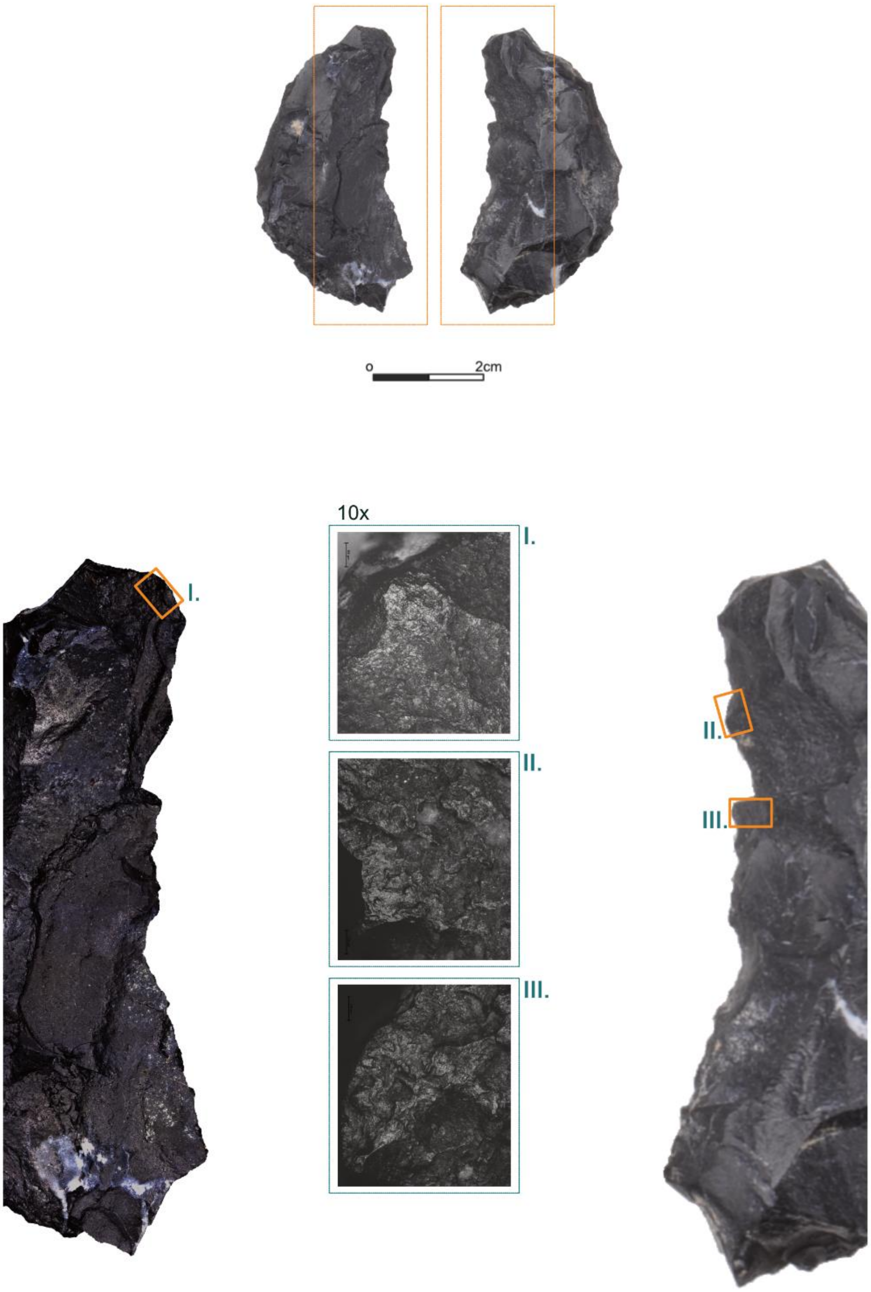


Fig. 85 Balver Höhle, *Keilmesser* [ID MU-196]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x (I. type V.; II. type V.; III. type V.).

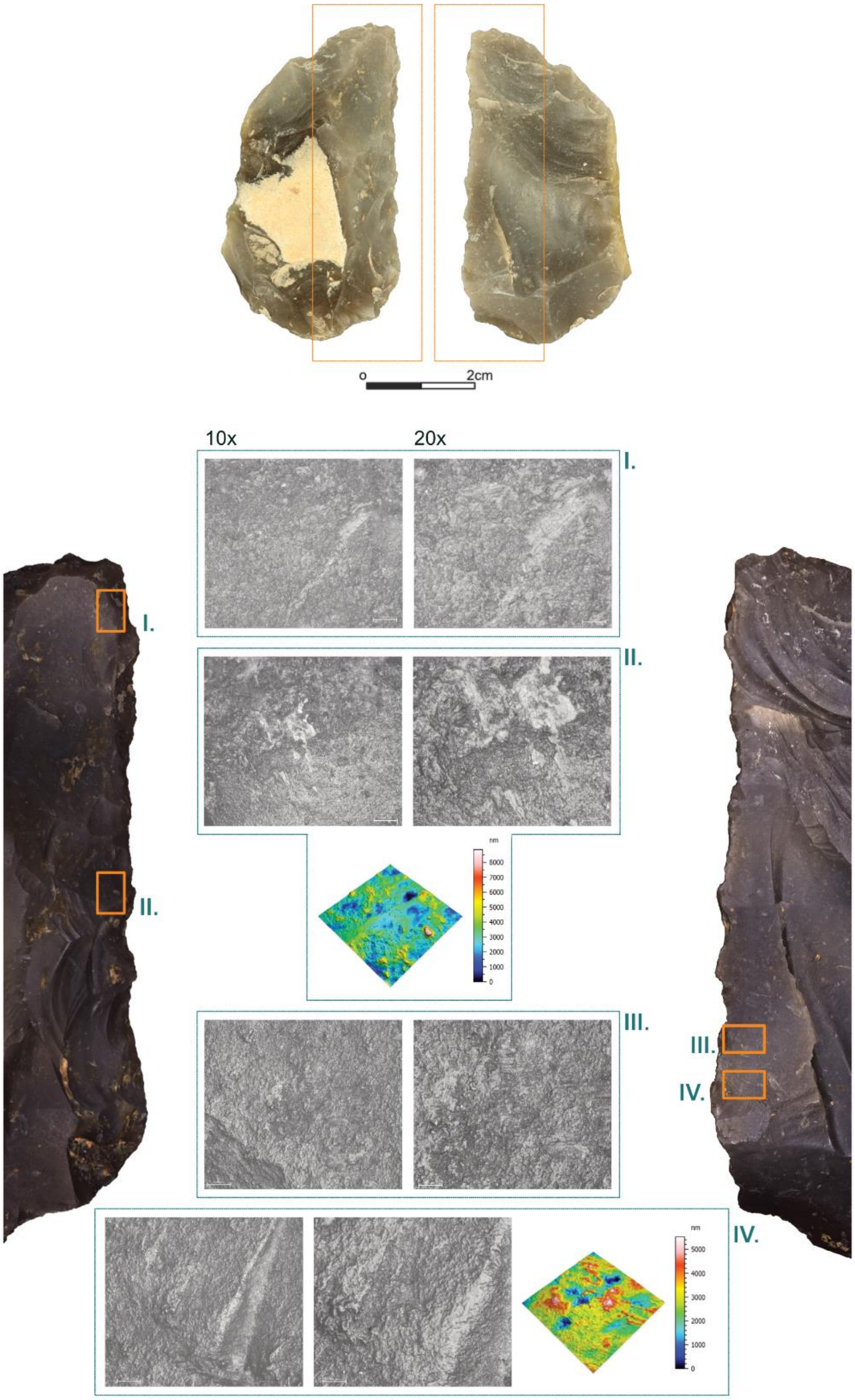


Fig. 86 Balver Höhle, *Keilmesser* [ID MU-197]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x and 20x (I. type VIII.; II. type VIII.; III. type V.; IV. type VIII.). The micro-surface displays the processed result of the confocal data acquisition with the 50x objective.

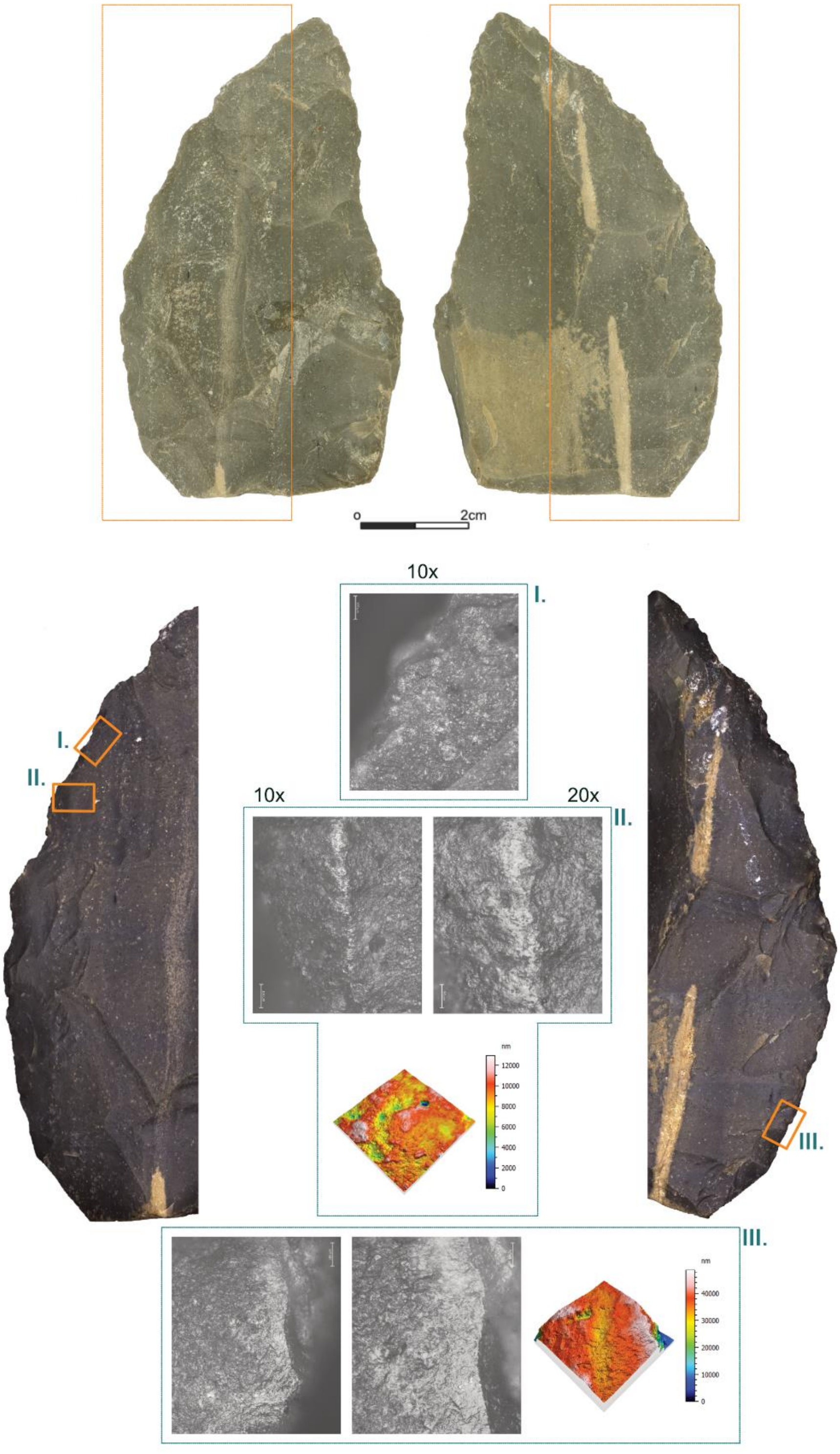


Fig. 87 Balver Höhle, *Keilmesser* [ID MU-199]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x and 20x (I. type I.; II. type IV.; III. type V.). The micro-surface displays the processed result of the confocal data acquisition with the 50x objective.

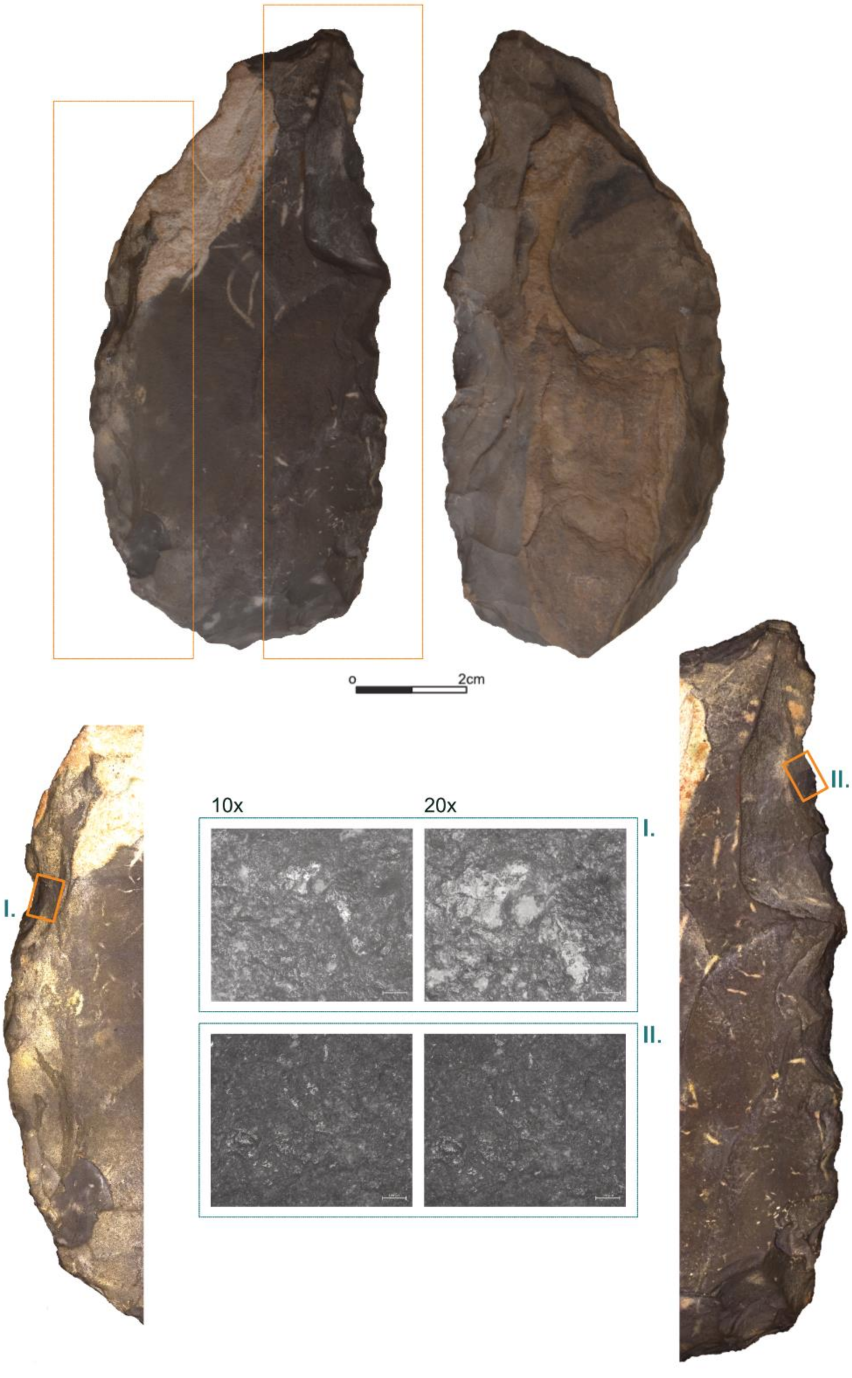


Fig. 88 Balver Höhle, *Keilmesser* [ID MU-202; dorsal]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x and 20x (I. type I.; II. type II.).

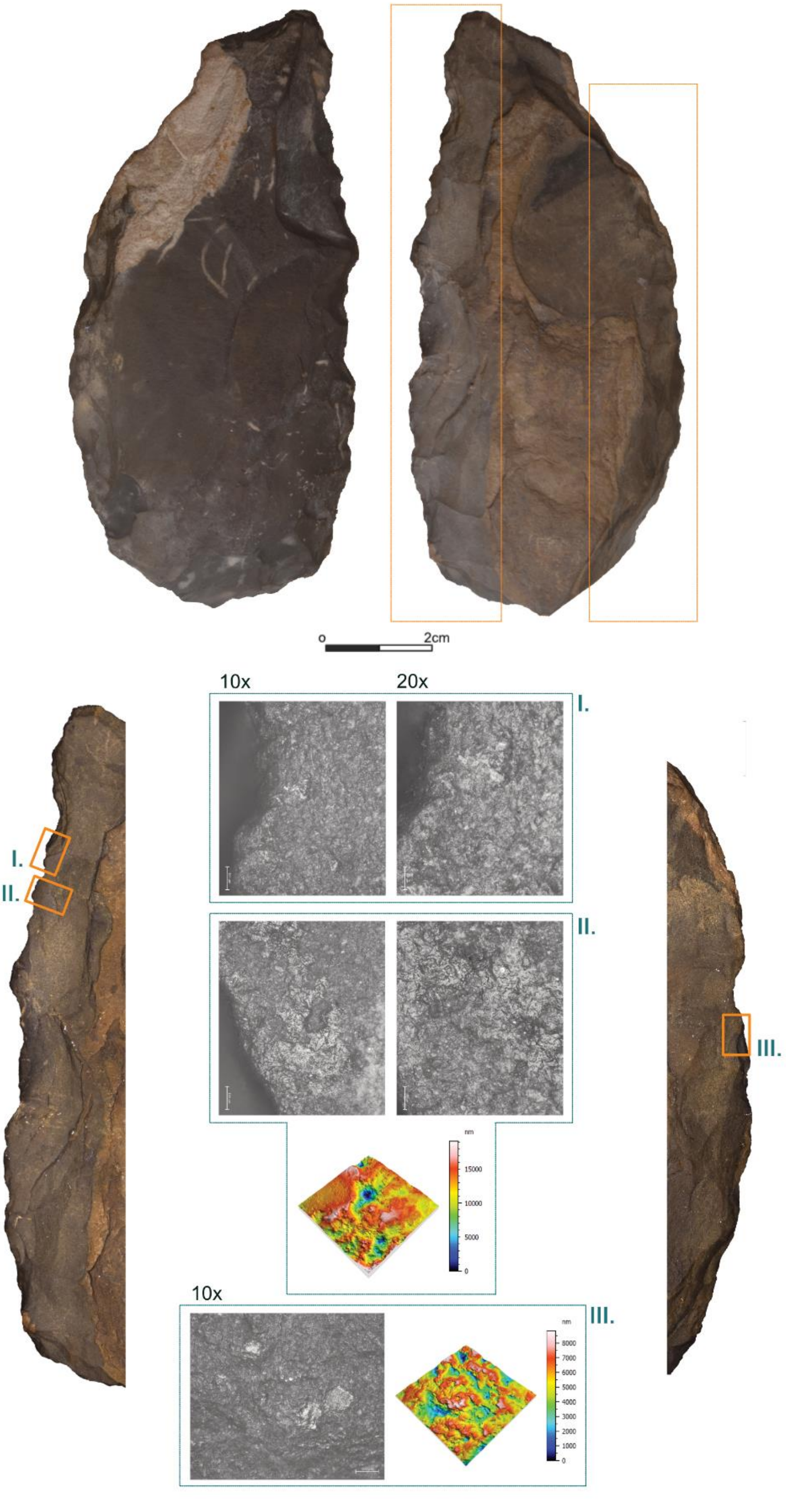


Fig. 89 Balver Höhle, *Keilmesser* [ID MU-202; ventral]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x and 20x (I. type V.; II. type V.; III. type I.). The micro-surface displays the processed result of the confocal data acquisition with the 50x objective.

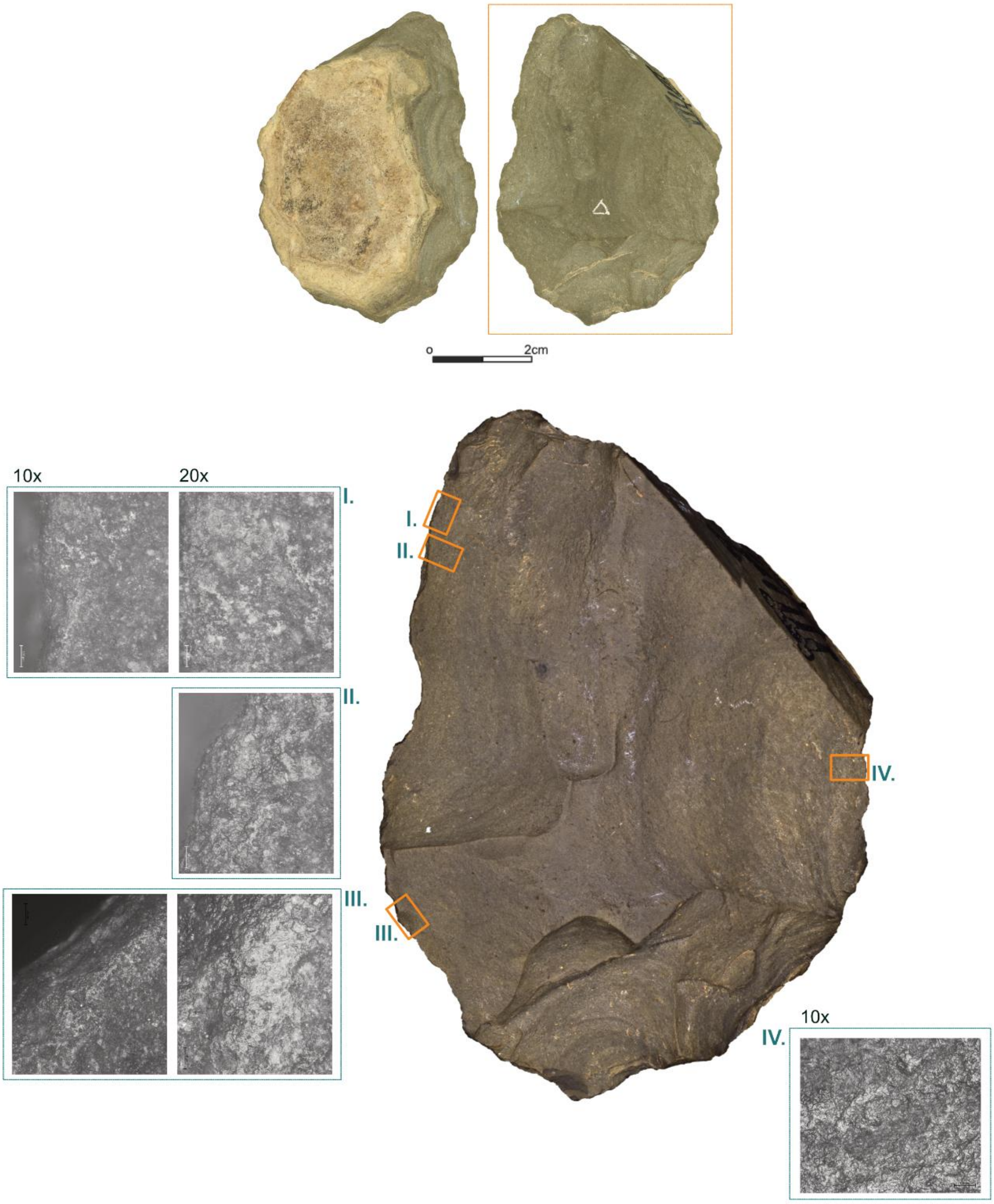


Fig. 90 Balver Höhle, *Keilmesser* [ID MU-214]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x and 20x (I. type V.; II. type V.; III. type V.; IV. type V.).

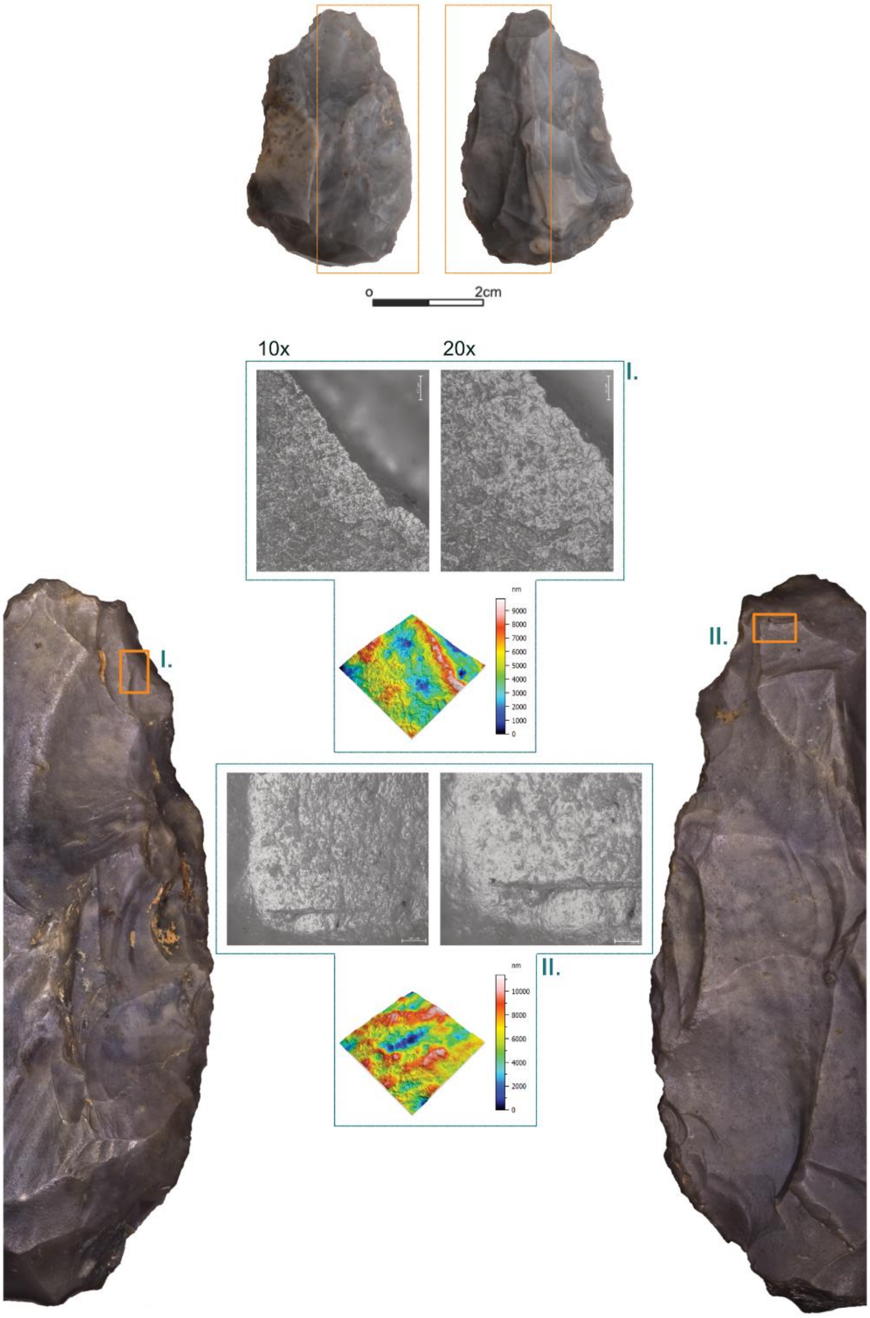


Fig. 91 Balver Höhle, *Keilmesser* [ID MU-224]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x and 20x (I. type III.; II. type V.). The micro-surface displays the processed result of the confocal data acquisition with the 50x objective.

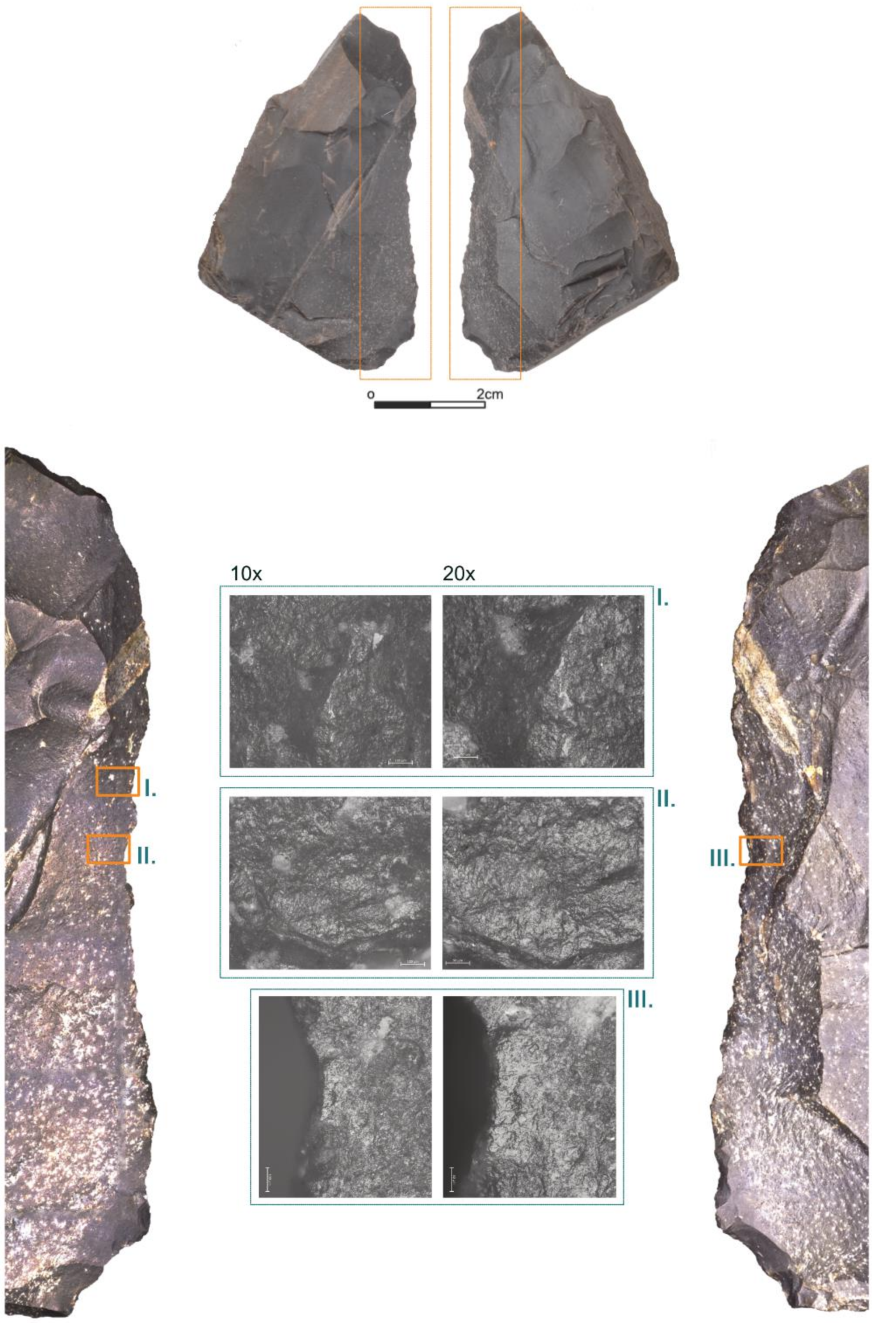
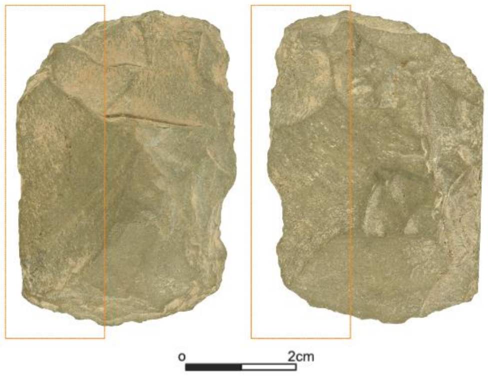


Fig. 92 Balver Höhle, *Keilmesser* [ID MU-226]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x and 20x (I. type V.; II. type IV.; III. type V.).



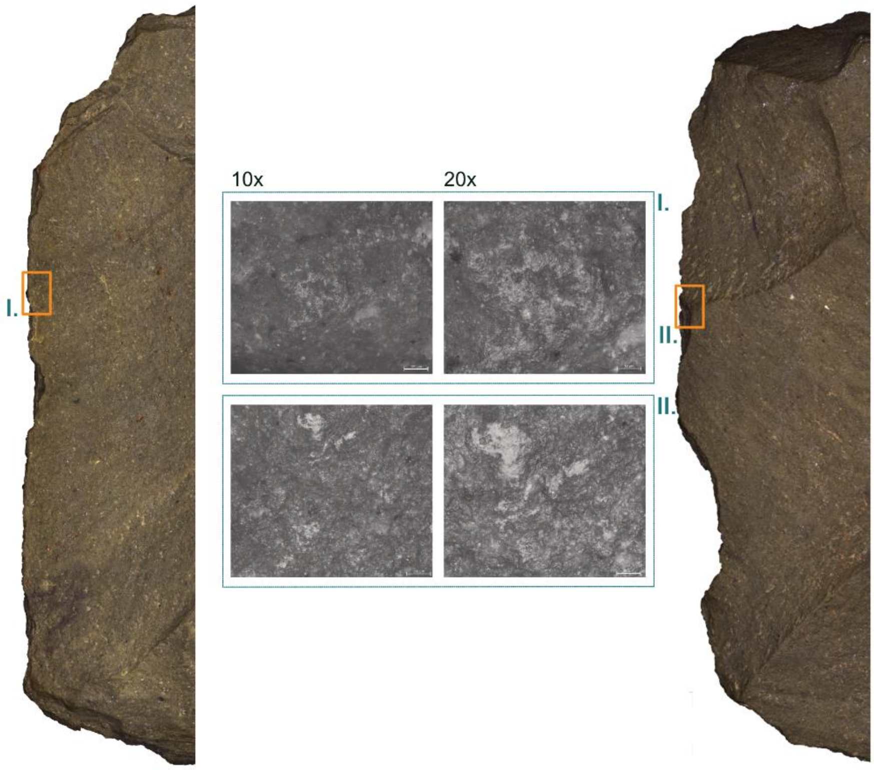


Fig. 93 Balver Höhle, *Keilmesser* [ID MU-230]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x and 20x (I. type II.; II. type II.).

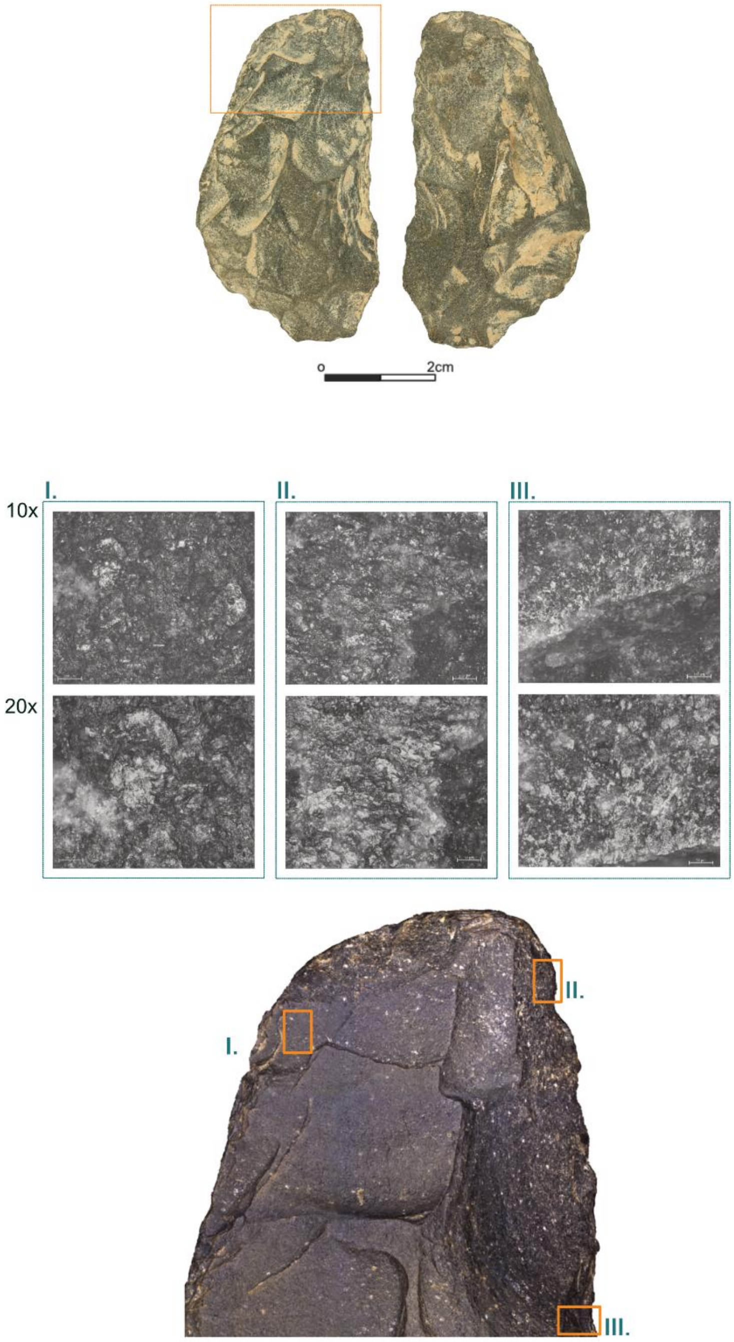


Fig. 94 Balver Höhle, *Keilmesser* [ID MU-231]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x and 20x (I. type I.; II. type V.; III. type V.).

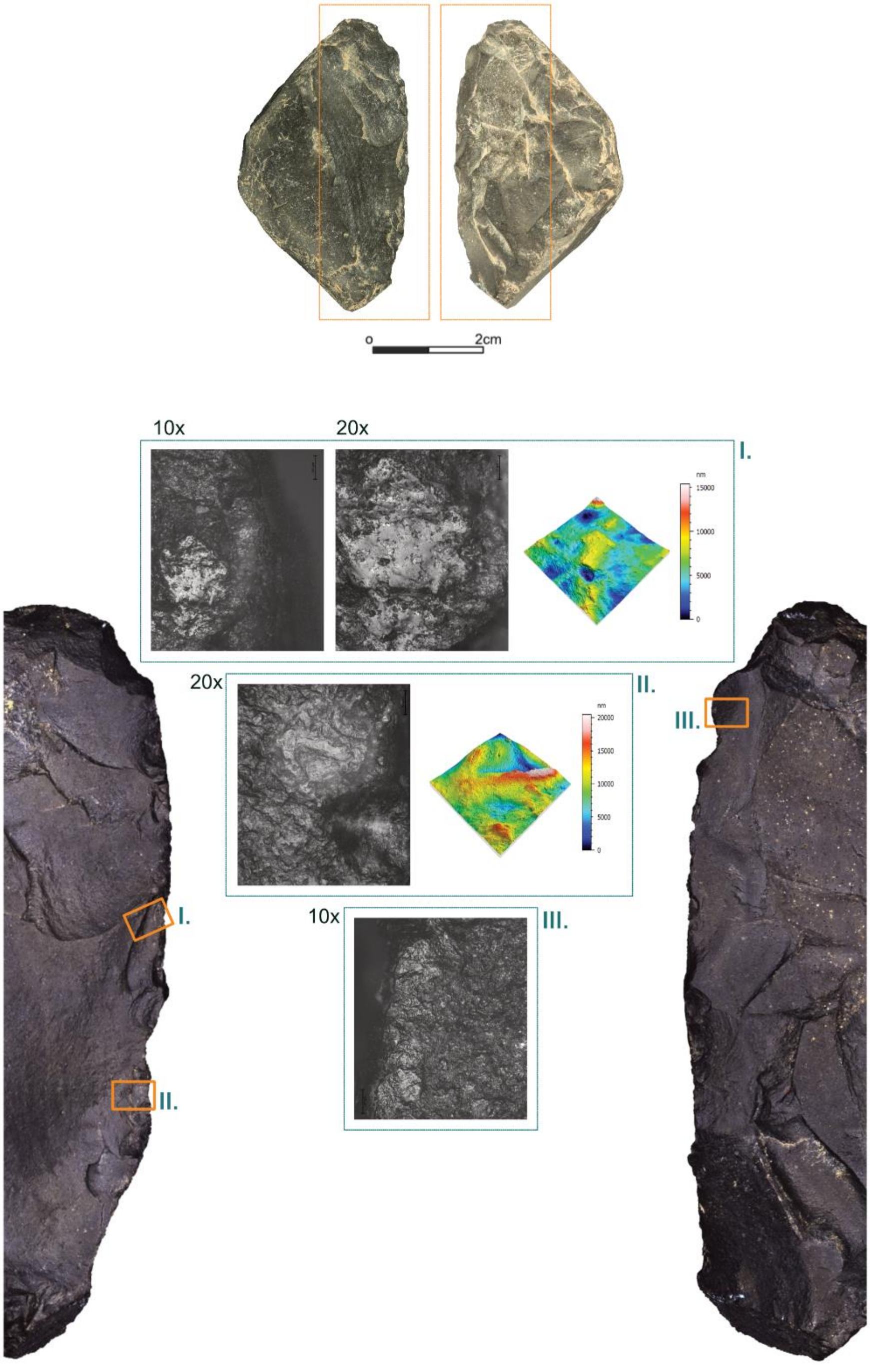


Fig. 95 Balver Höhle, *Keilmesser* [ID MU-232]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x and 20x (I. type IV.; II. type I.; III. type V.). The micro-surface displays the processed result of the confocal data acquisition with the 20x and 50x objective.

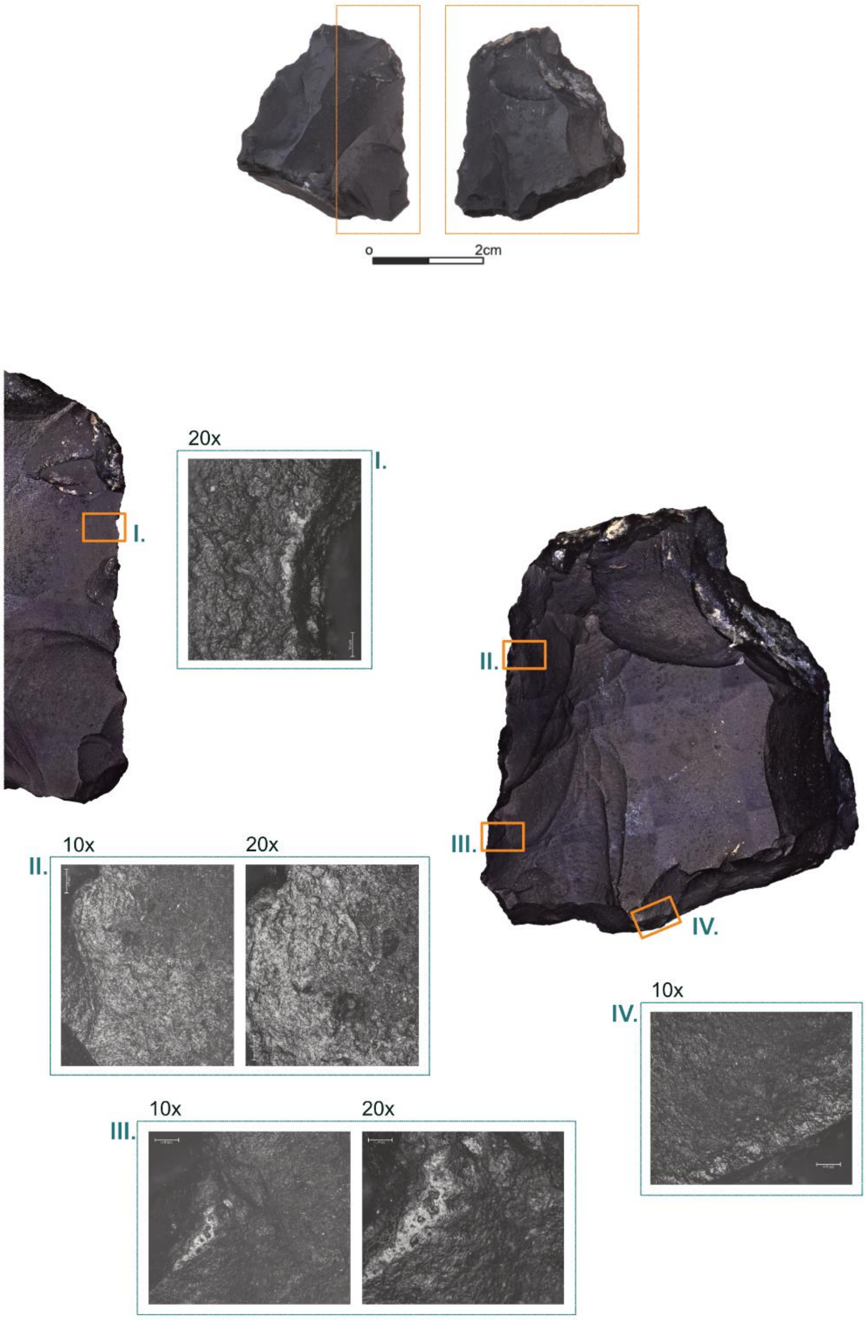


Fig. 96 Balver Höhle, *Keilmesser* [ID MU-234]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x and 20x (I. type IV.; II. type V.; III. type III.; IV. type V.).

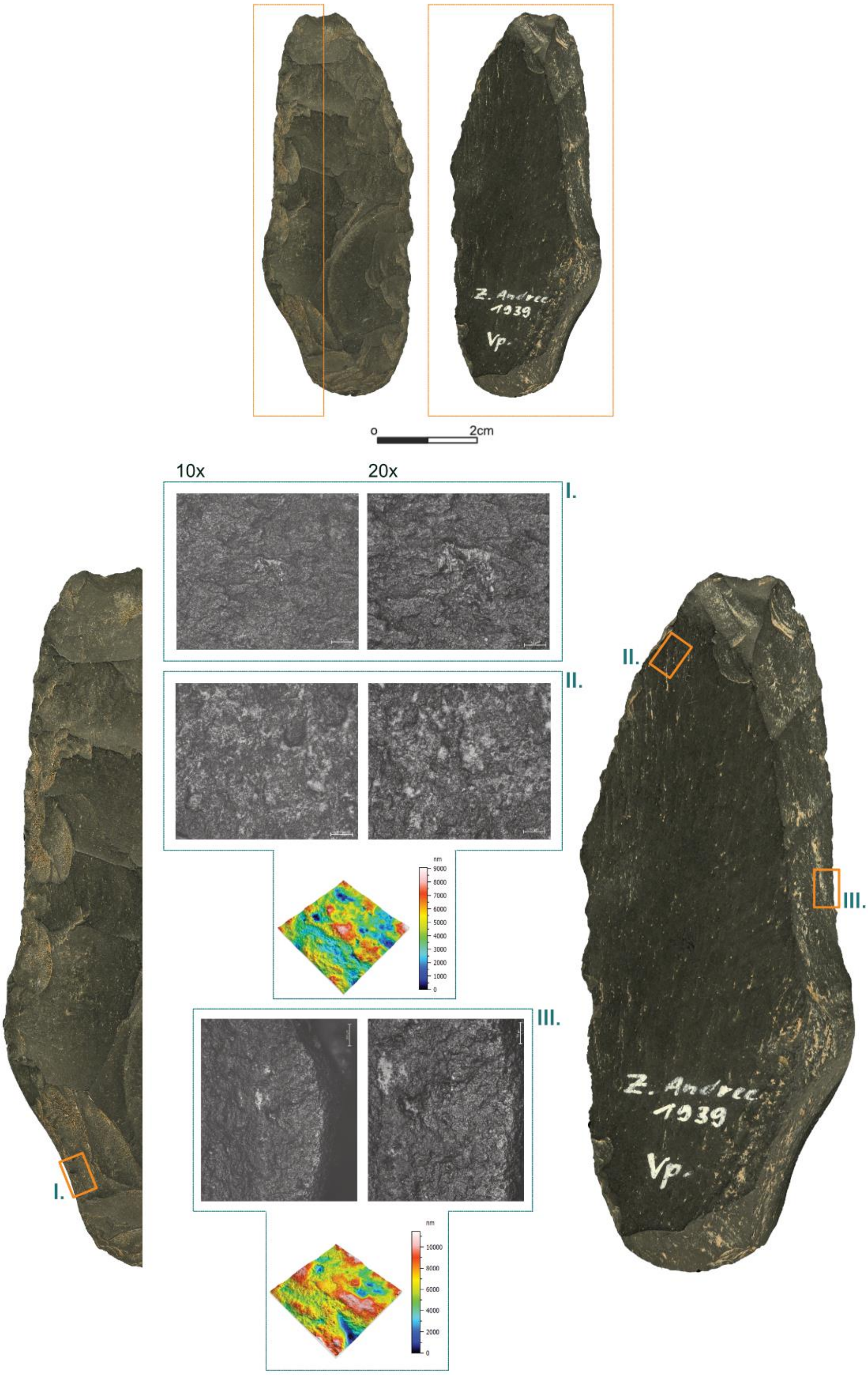


Fig. 97 Balver Höhle, *Keilmesser* [ID MU-240]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x and 20x (I. type V.; II. type VIII.; III. type V. + I.). The micro-surface displays the processed result of the confocal data acquisition with the 50x objective.

Fig. 98 Balver Höhle, *Keilmesser* [ID MU-241]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x (I. type V.; II. type V.).

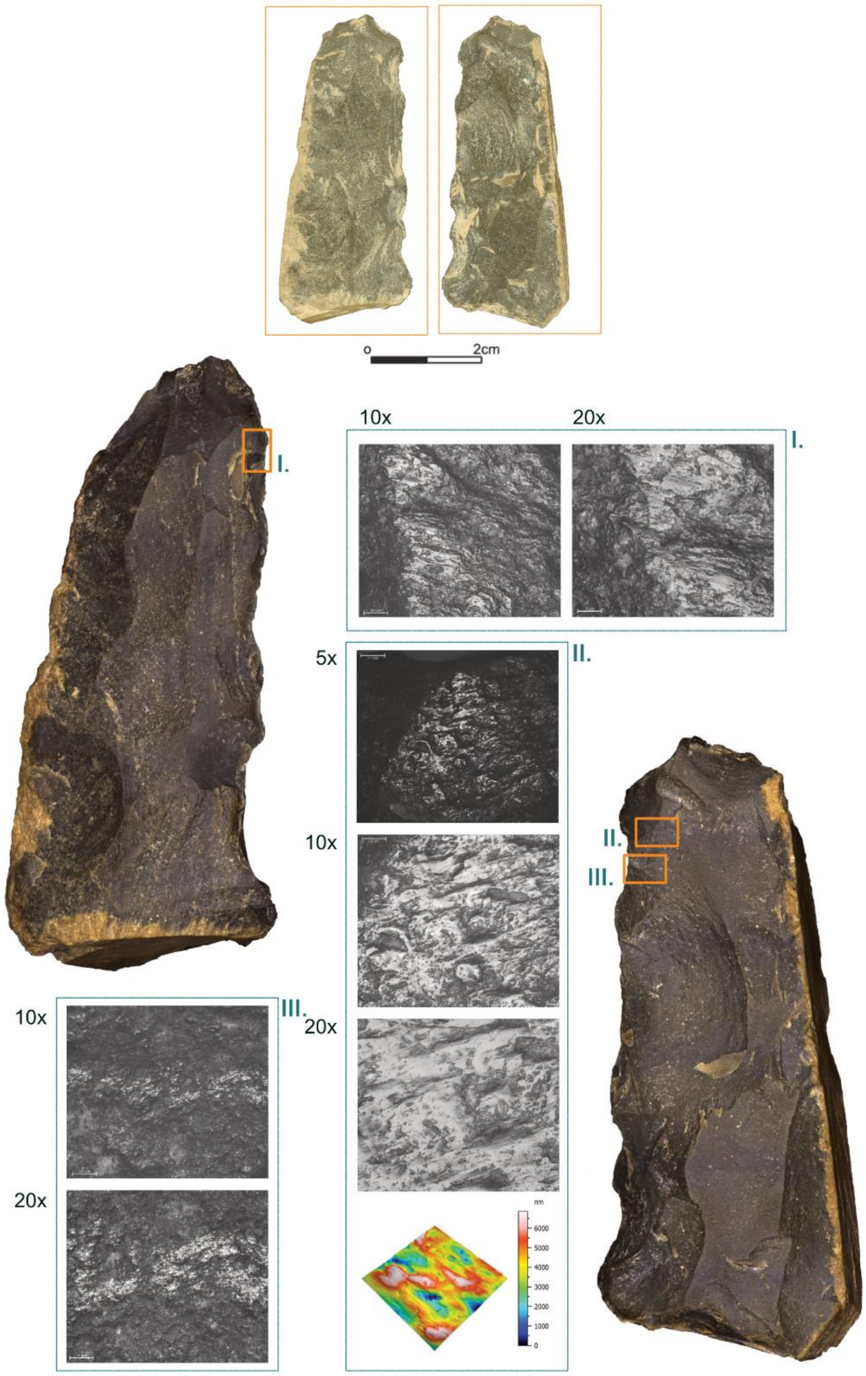


Fig. 99 Balver Höhle, *Keilmesser* [ID MU-246]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 5x, 10x and 20x (I. type V./ IV.; II. type IV.; III. type V. / IV.). The micro-surface displays the processed result of the confocal data acquisition with the 50x objective.

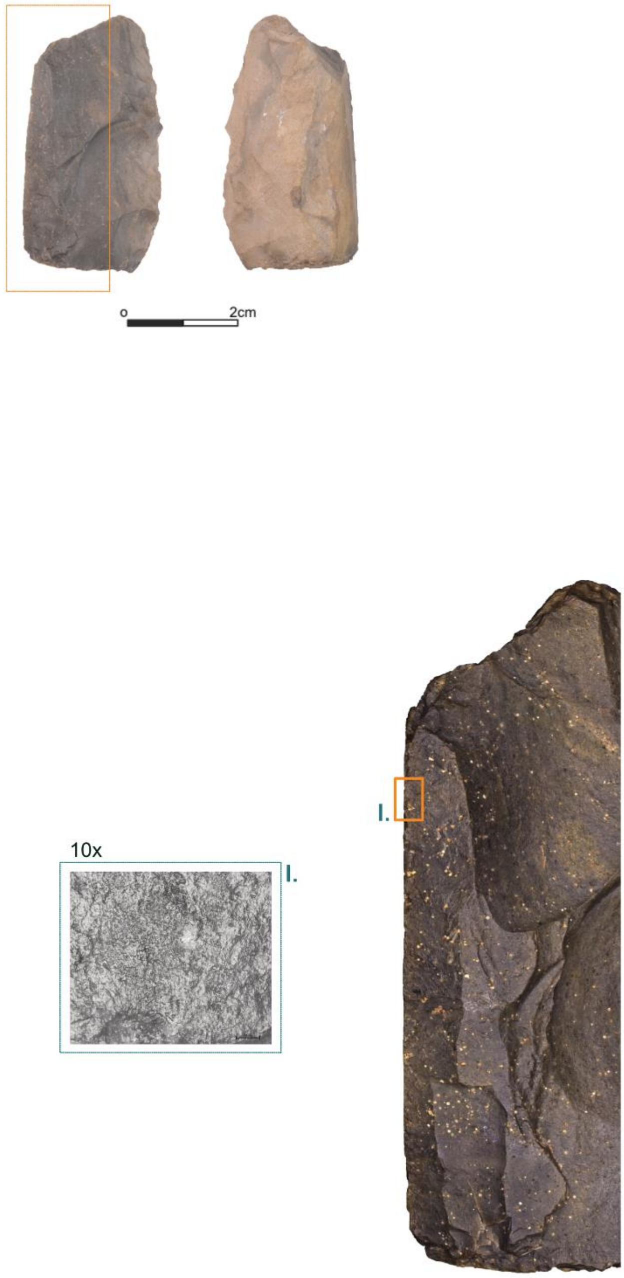


Fig. 100 Balver Höhle, *Keilmesser* [ID MU-249]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear trace is acquired at magnification of 10x (I. type V.).

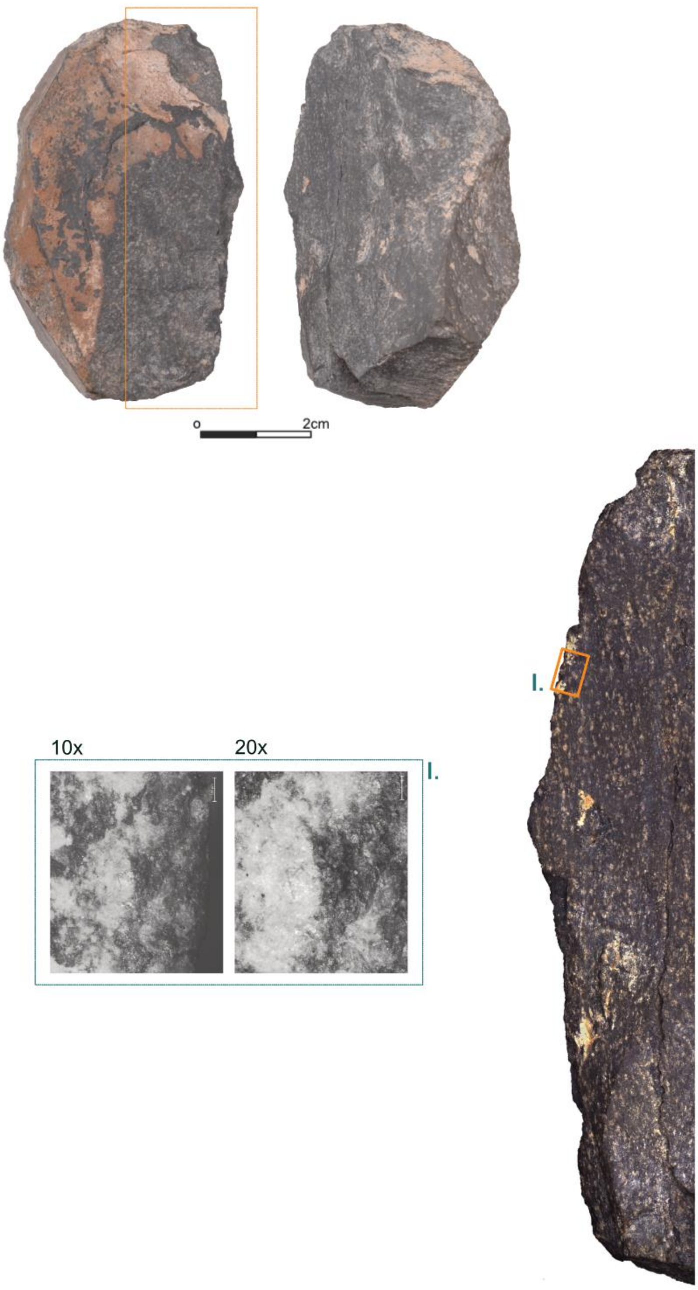


Fig. 101 Balver Höhle, *Keilmesser* [ID MU-272]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear trace is acquired at magnification of 10x and 20x (I. type V. + VIII.).

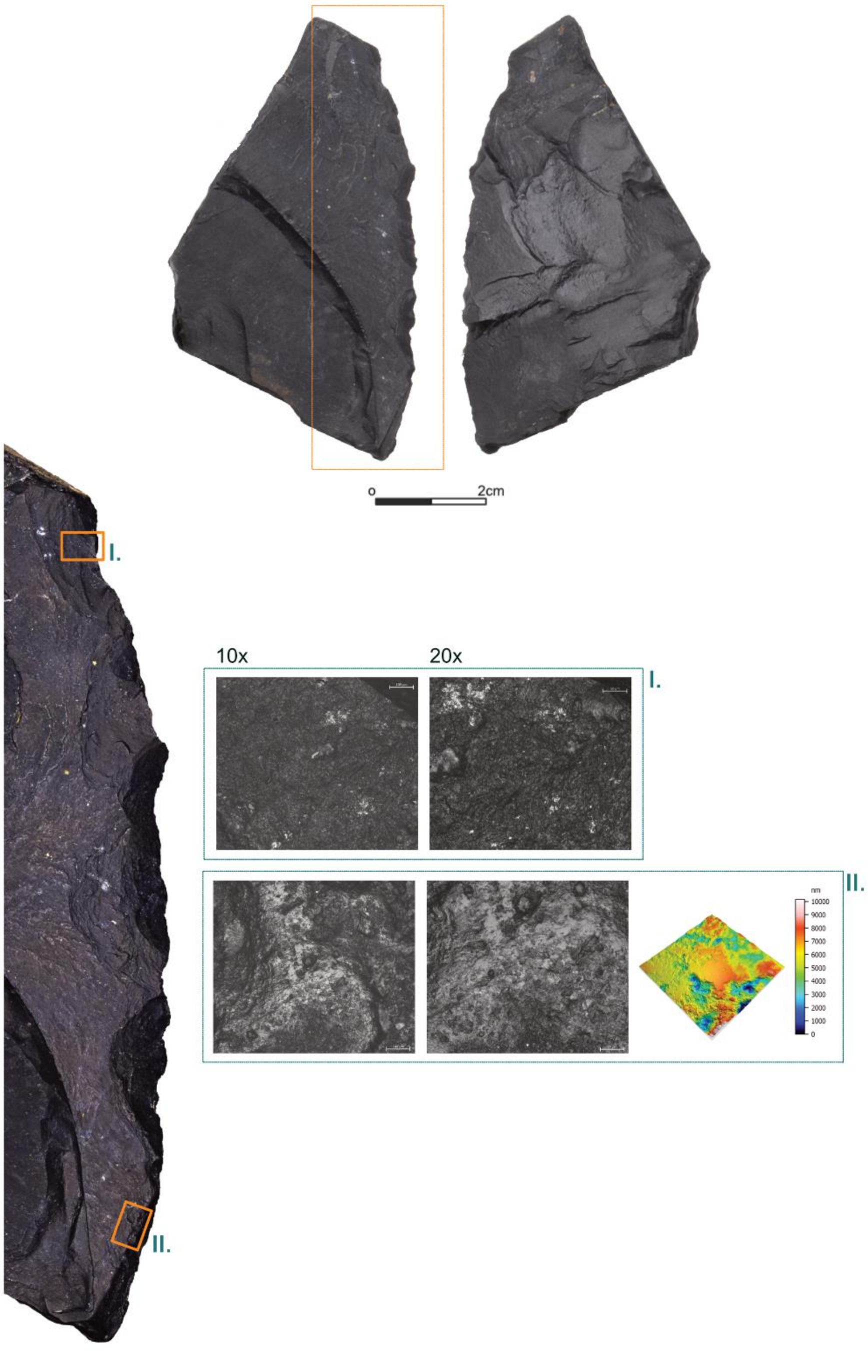


Fig. 102 Balver Höhle, *Keilmesser* [ID MU-273]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x and 20x (I. type I.; II. type V. / IV.). The micro-surface displays the processed result of the confocal data acquisition with the 50x objective.

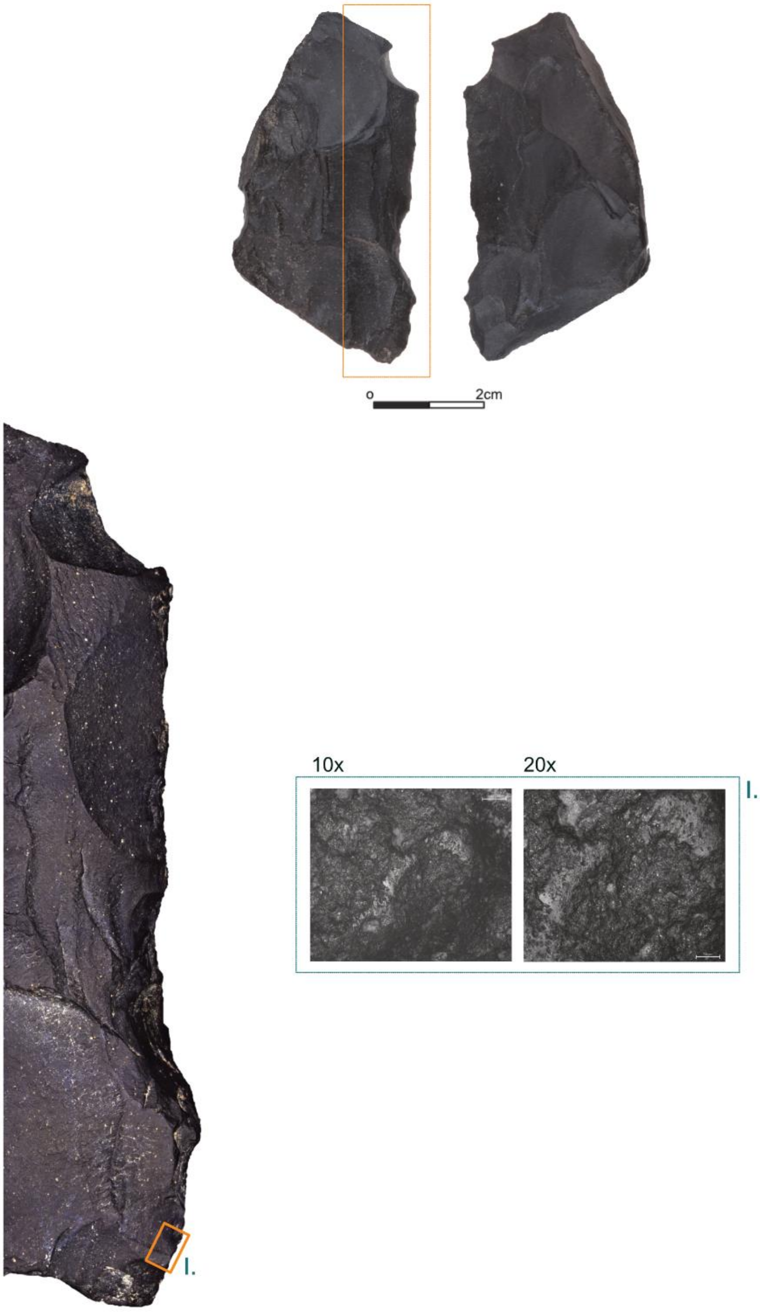


Fig. 103 Balver Höhle, *Keilmesser* [ID MU-276]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear trace is acquired at magnification of 10x and 20x (I. type V. / IV.).

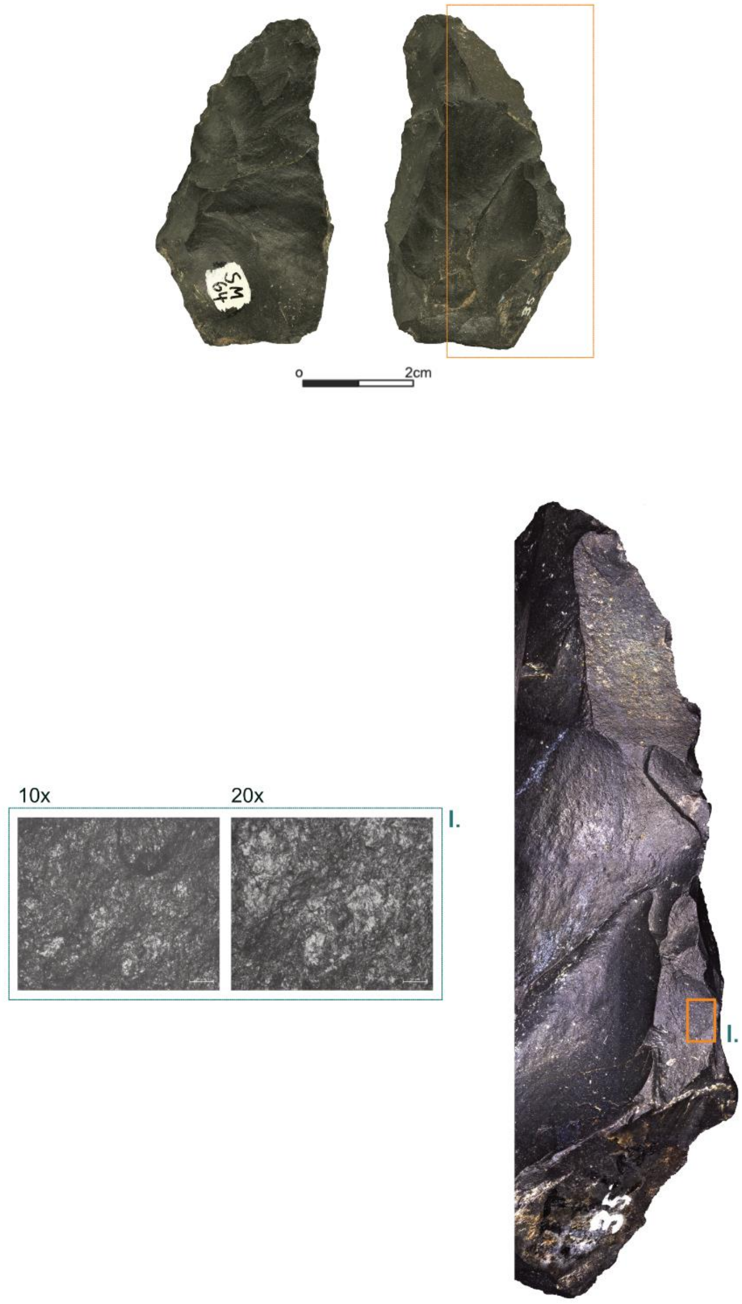


Fig. 104 Balver Höhle, *Keilmesser* [ID MU-280]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear trace is acquired at magnification of 10x and 20x (I. type I.).

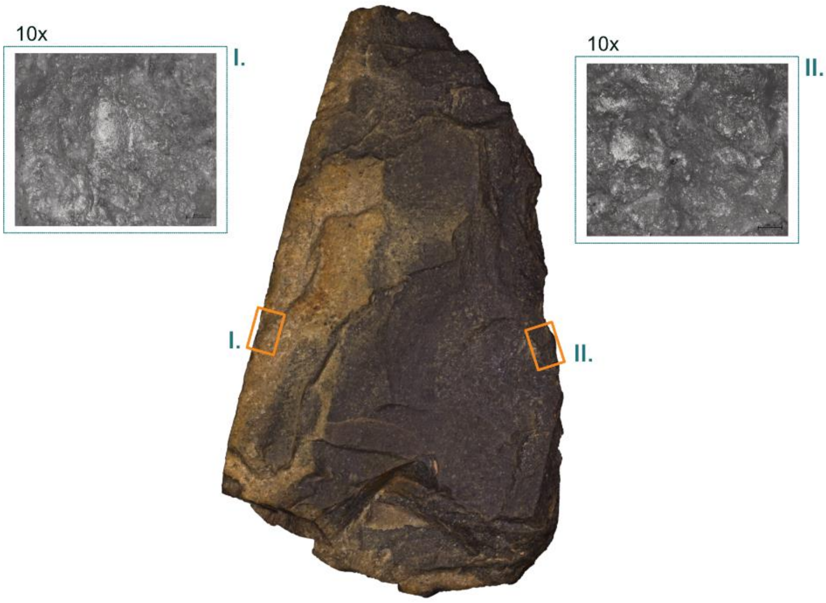


Fig. 105 Balver Höhle, *Keilmesser* [ID MU-283]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x and 20x (I. type II.; II. type II.).

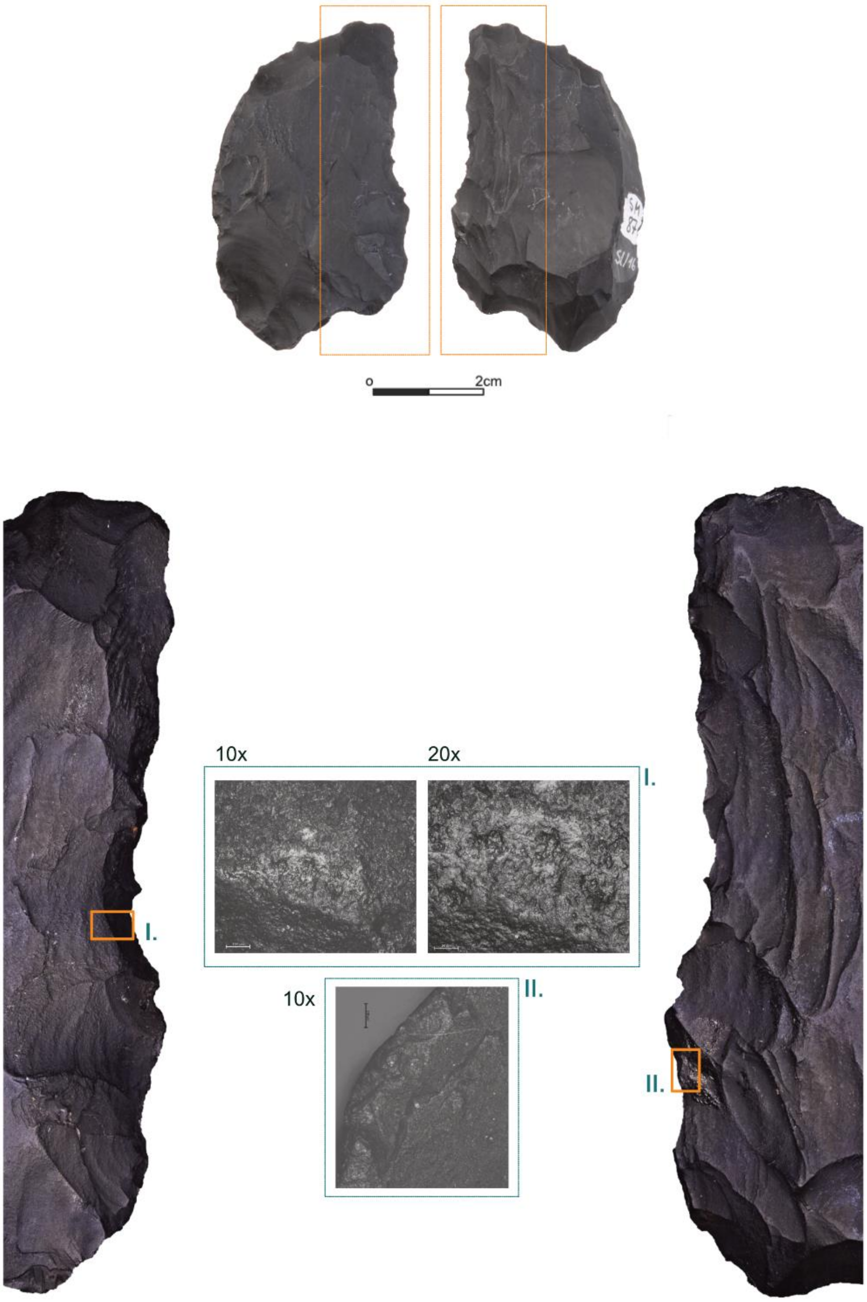


Fig. 106 Balver Höhle, *Keilmesser* [ID MU-286]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x and 20x (I. type VII.; II. type V.).

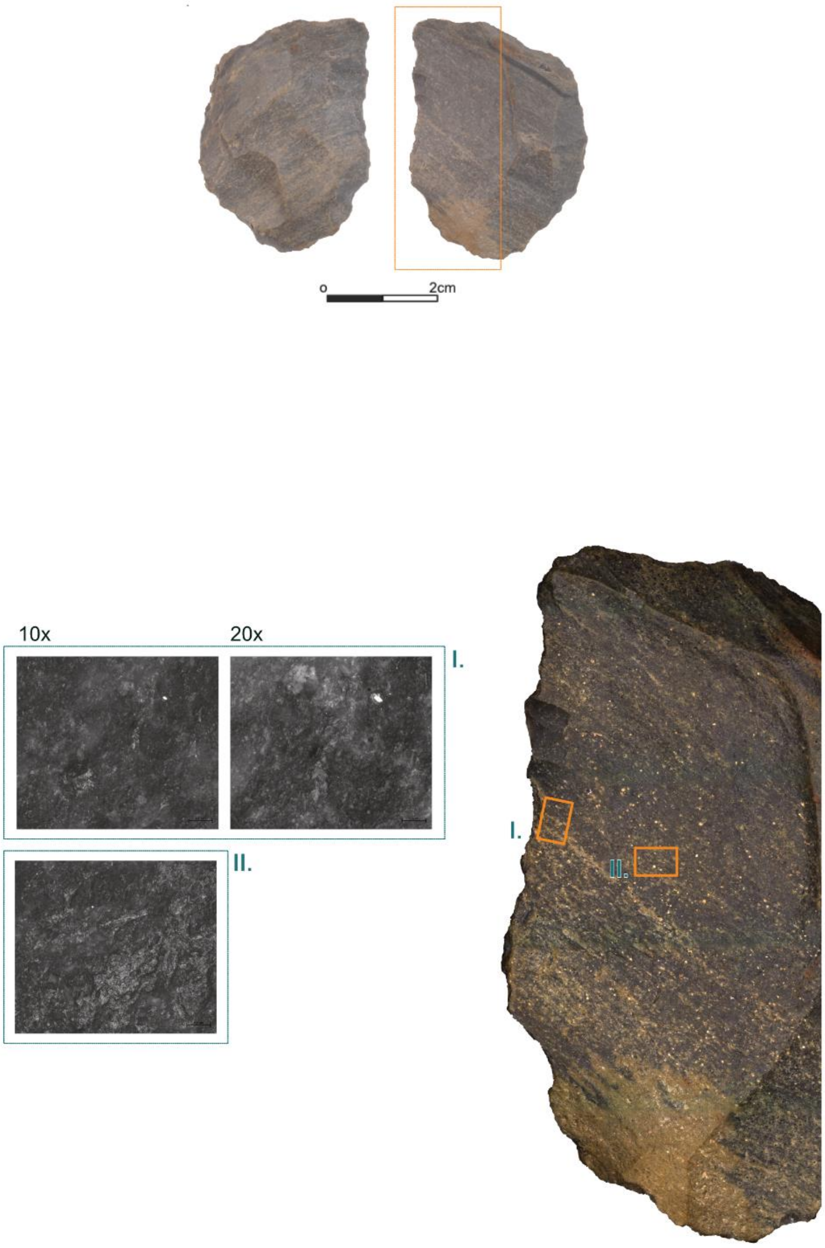


Fig. 107 Balver Höhle, *Keilmesser* [ID MU-288]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x and 20x (I. type II.; II. type V.).

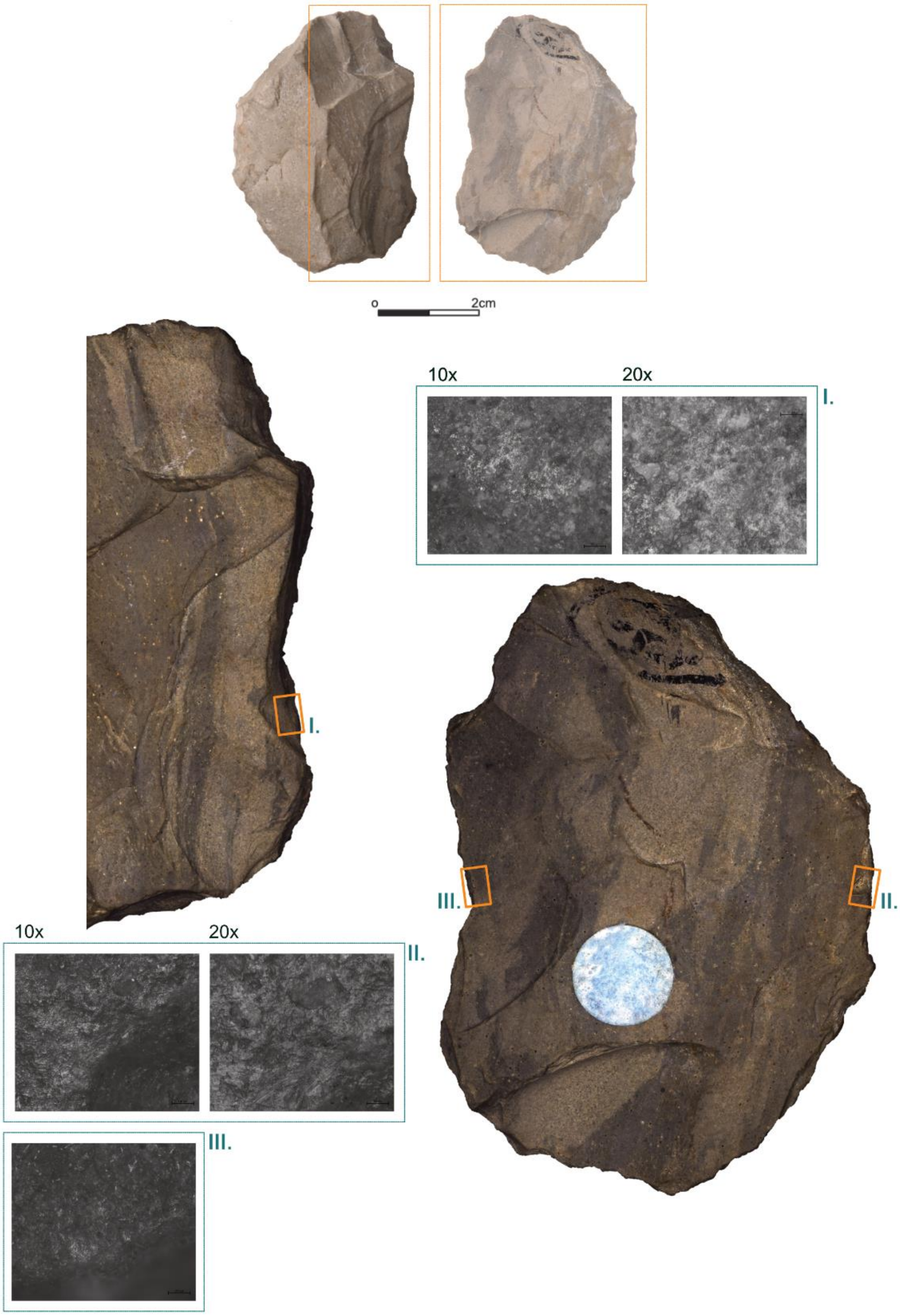


Fig. 108 Balver Höhle, *Keilmesser* [ID MU-293]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x and 20x (I. type VII.; II. type I.; III. type VI.).

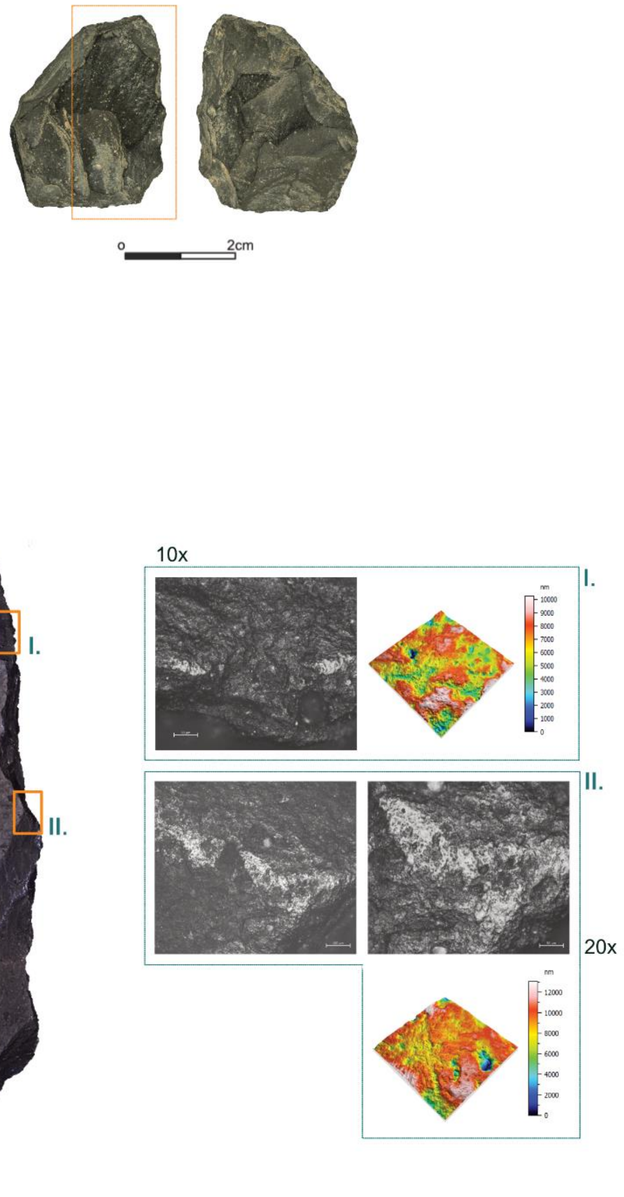


Fig. 109 Balver Höhle, *Keilmesser* tip [ID MU-041]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x and 20x (I. type IV.; II. type IV.). The micro-surface displays the processed result of the confocal data acquisition with the 50x objective.

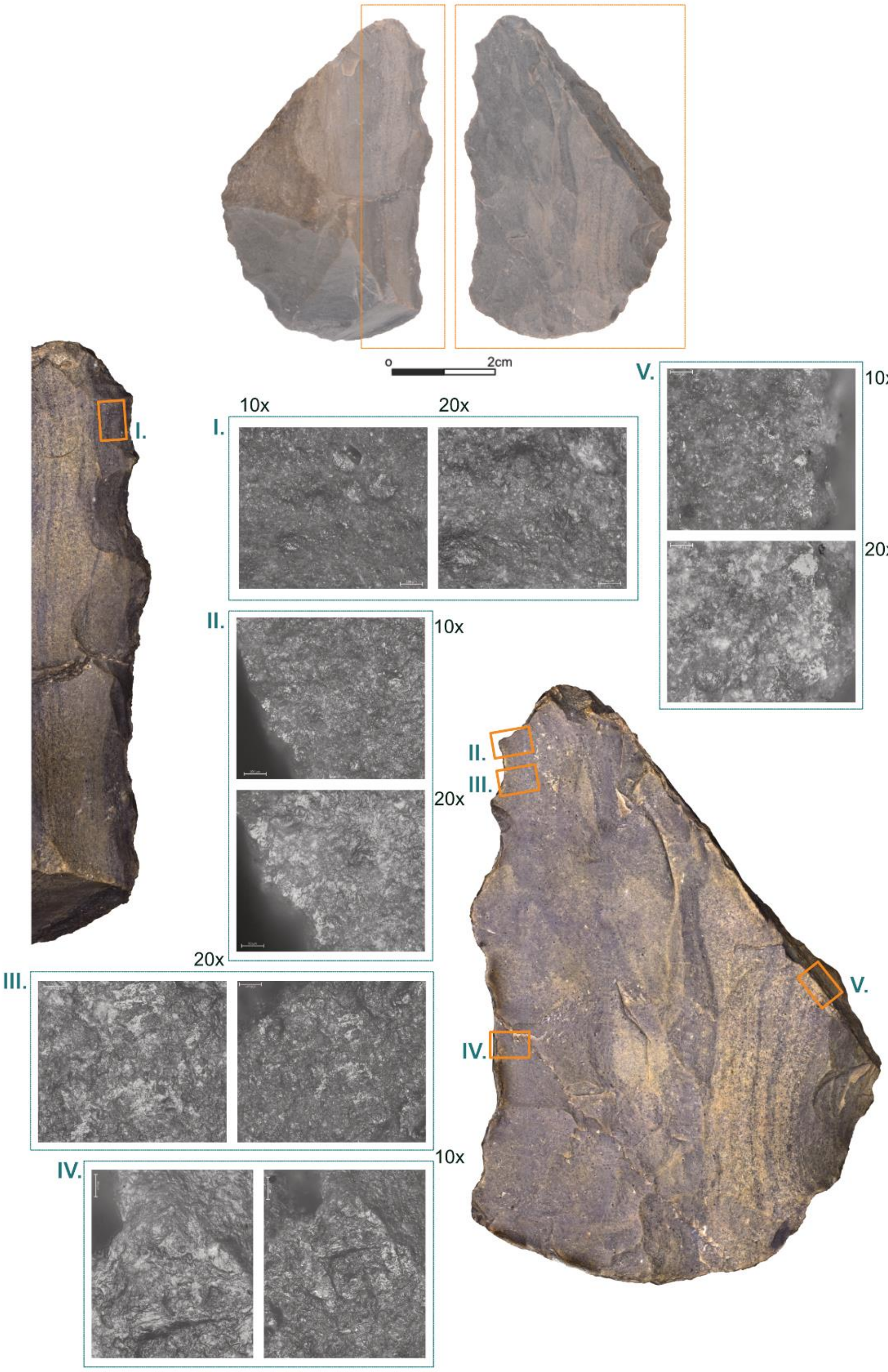


Fig. 110 Balver Höhle, *Keilmesser* tip [ID MU-210]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x and 20x (I. type I.; II. type V.; III. type II.; IV. type V.; V. type I.).

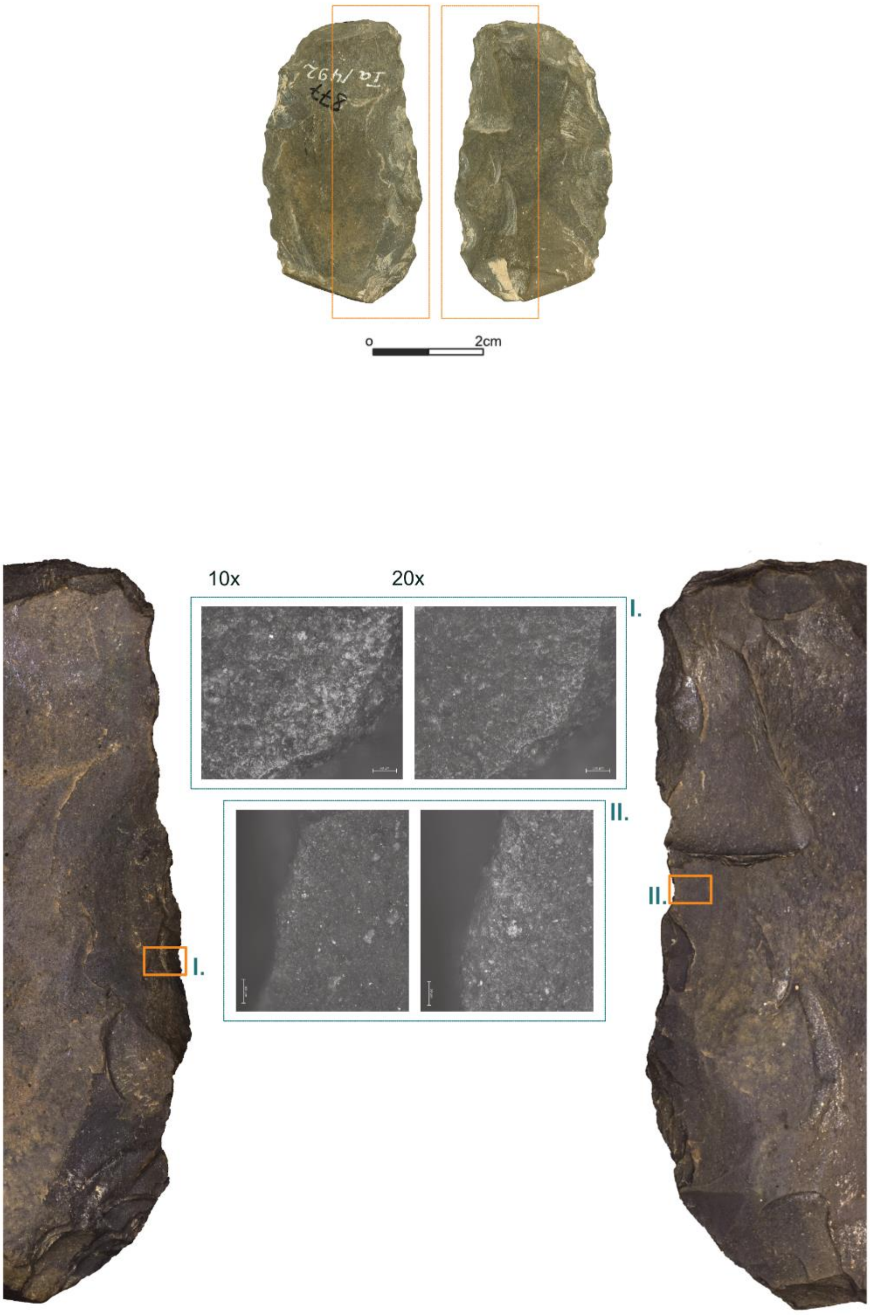


Fig. 111 Balver Höhle, *Prądnik scraper* [ID MU-005]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x and 20x (I. type I.; II. type V.).

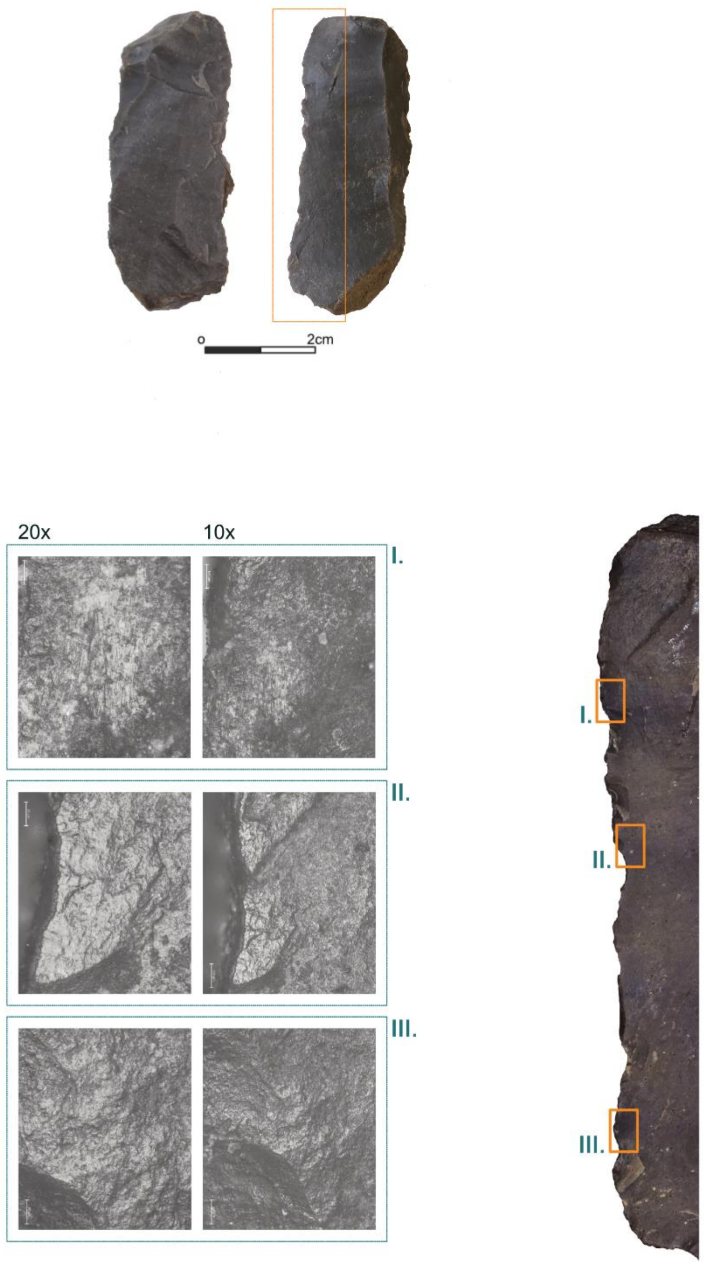


Fig. 112 Balver Höhle, *Prądnik scraper* [ID MU-098]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x and 20x (I. type VII.; II. type V.; III. type V.).

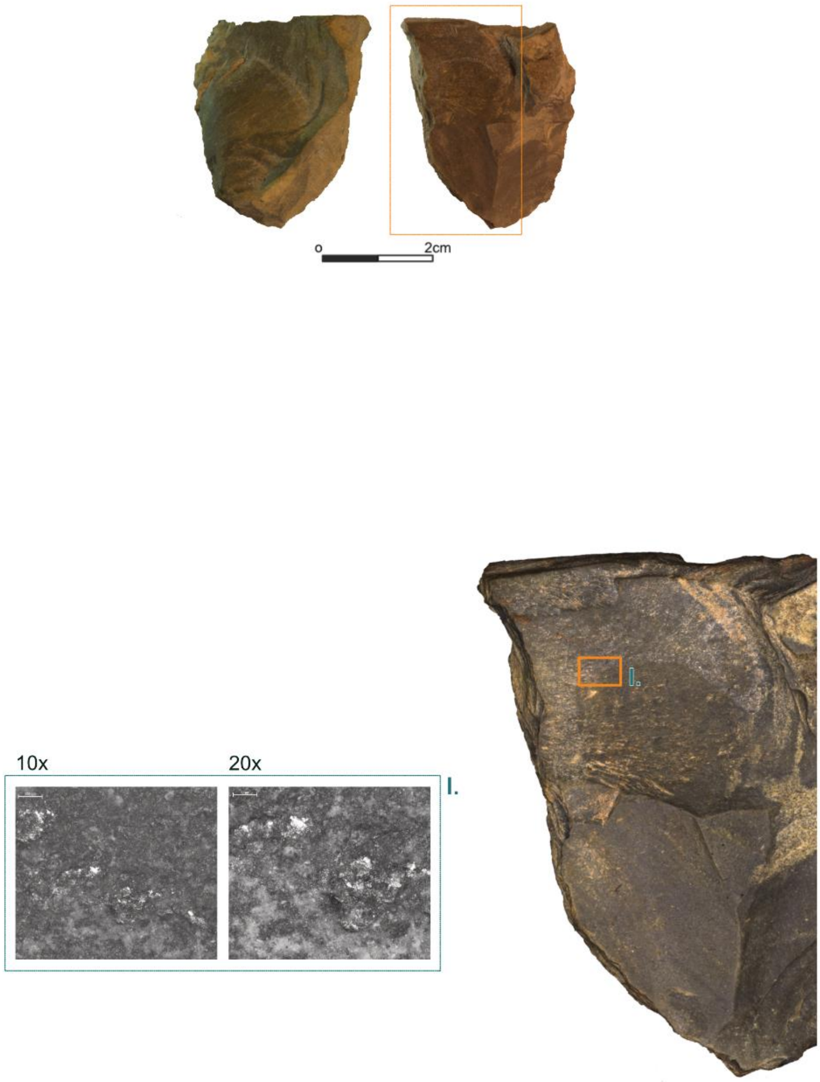


Fig. 113 Balver Höhle, *Prądnik spall* [ID MU-095]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear trace is acquired at magnification of 10x and 20x (I. type II.).

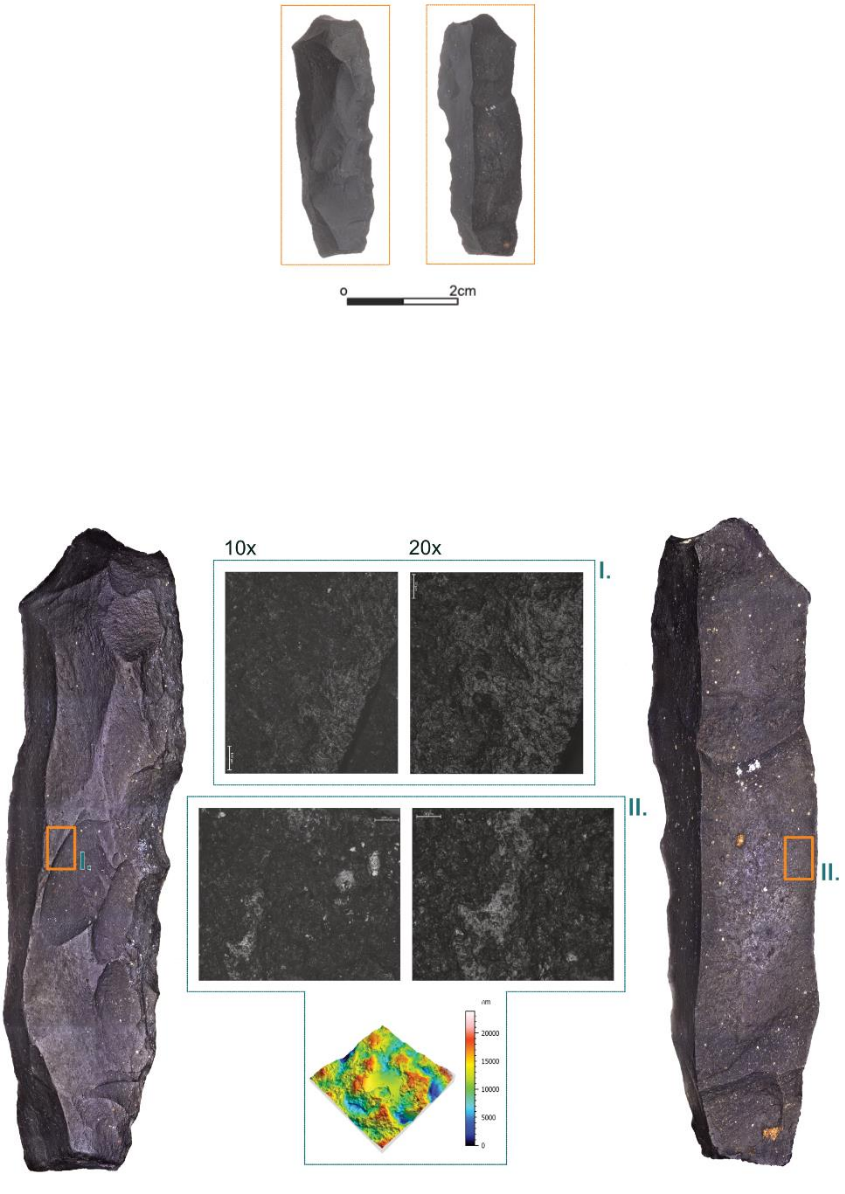


Fig. 114 Balver Höhle, *Prądnik spall* [ID MU-104]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x and 20x (I. type V.; II. type V. / IV.). The micro-surface displays the processed result of the confocal data acquisition with the 50x objective.

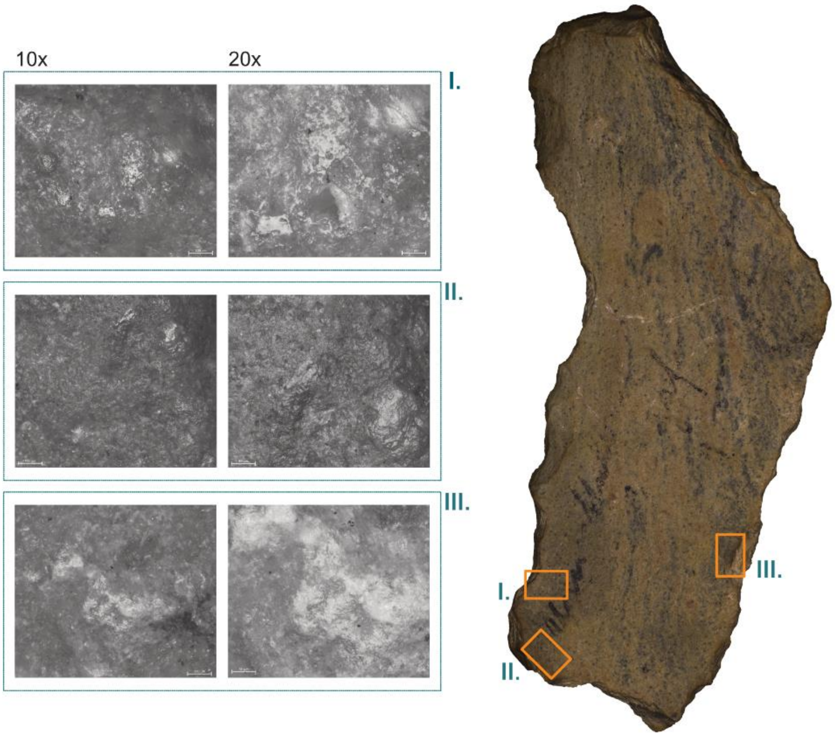


Fig. 115 Balver Höhle, *Prądnik spall* [ID MU-118]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x and 20x (I. type V./ IV; II. type II.; III. type V).

Fig. 116 Balver Höhle, *Prądnik spall* [ID MU-119]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x and 20x (I. type I.; II. type V.; III. type I.). The micro-surface displays the processed result of the confocal data acquisition with the 50x objective.

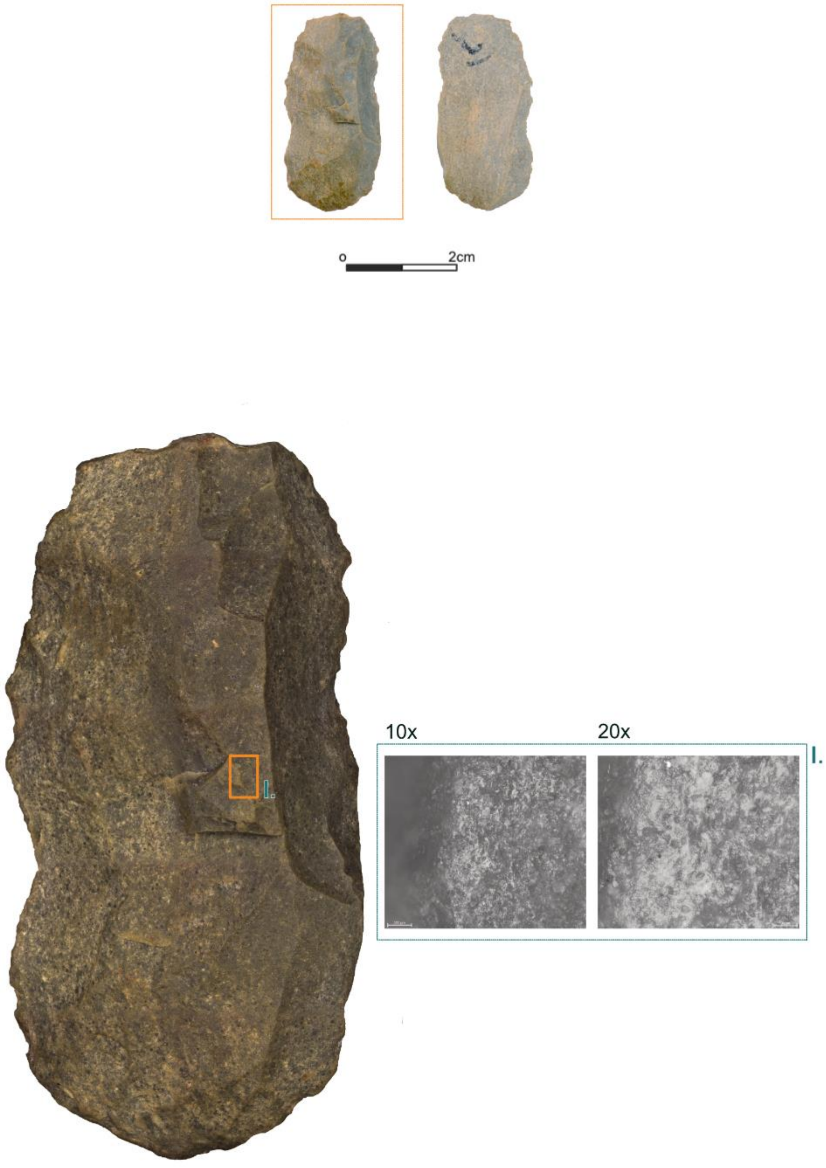


Fig. 117 Balver Höhle, *Prądnik spall* [ID MU-153]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear trace is acquired at magnification of 10x and 20x (I. type V.).

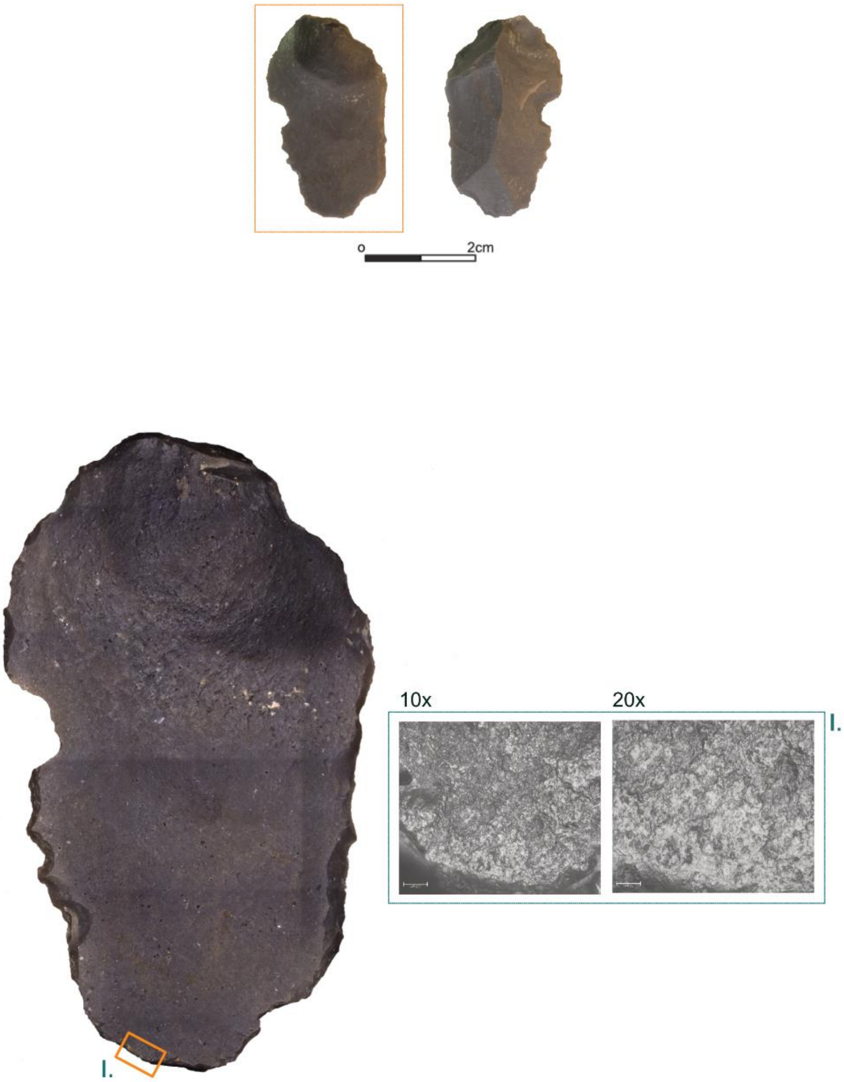


Fig. 118 Balver Höhle, *Prądnik spall* [ID MU-161]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear trace is acquired at magnification of 10x and 20x (I. type V.).

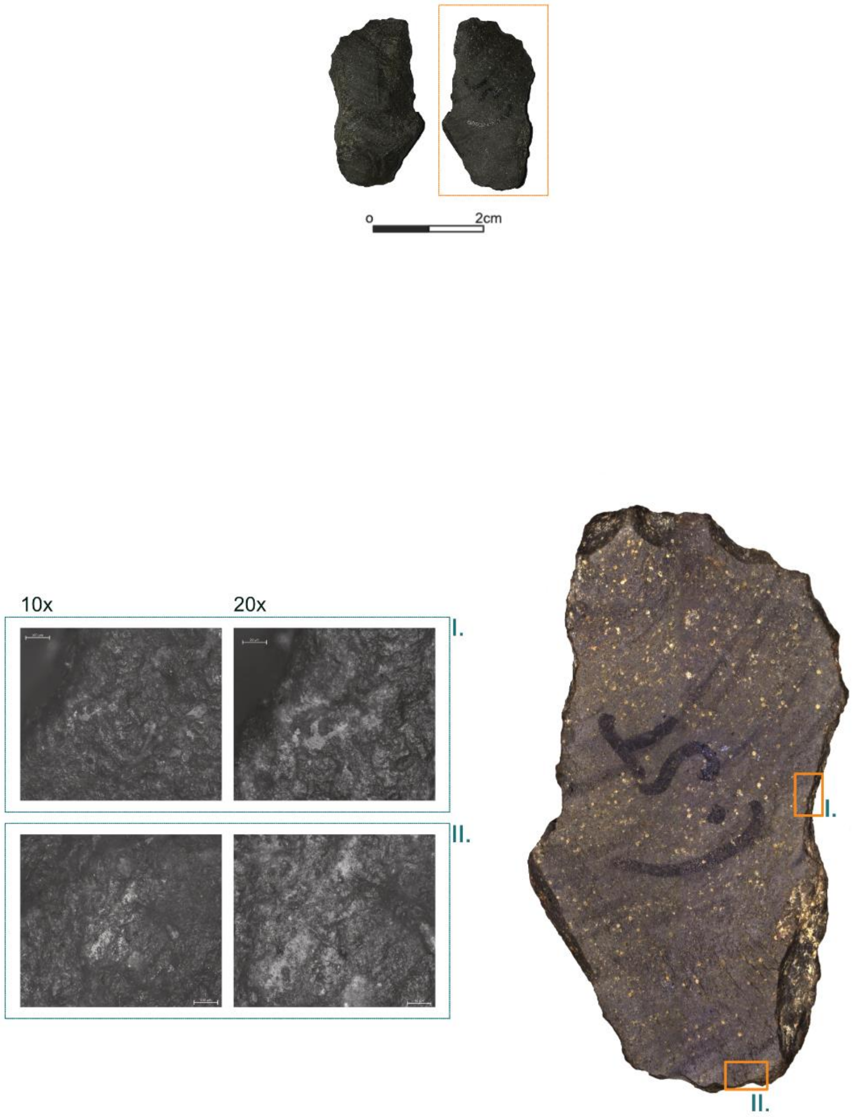


Fig. 119 Balver Höhle, *Prądnik spall* [ID MU-164]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x and 20x (I. type II.; II. type II.).

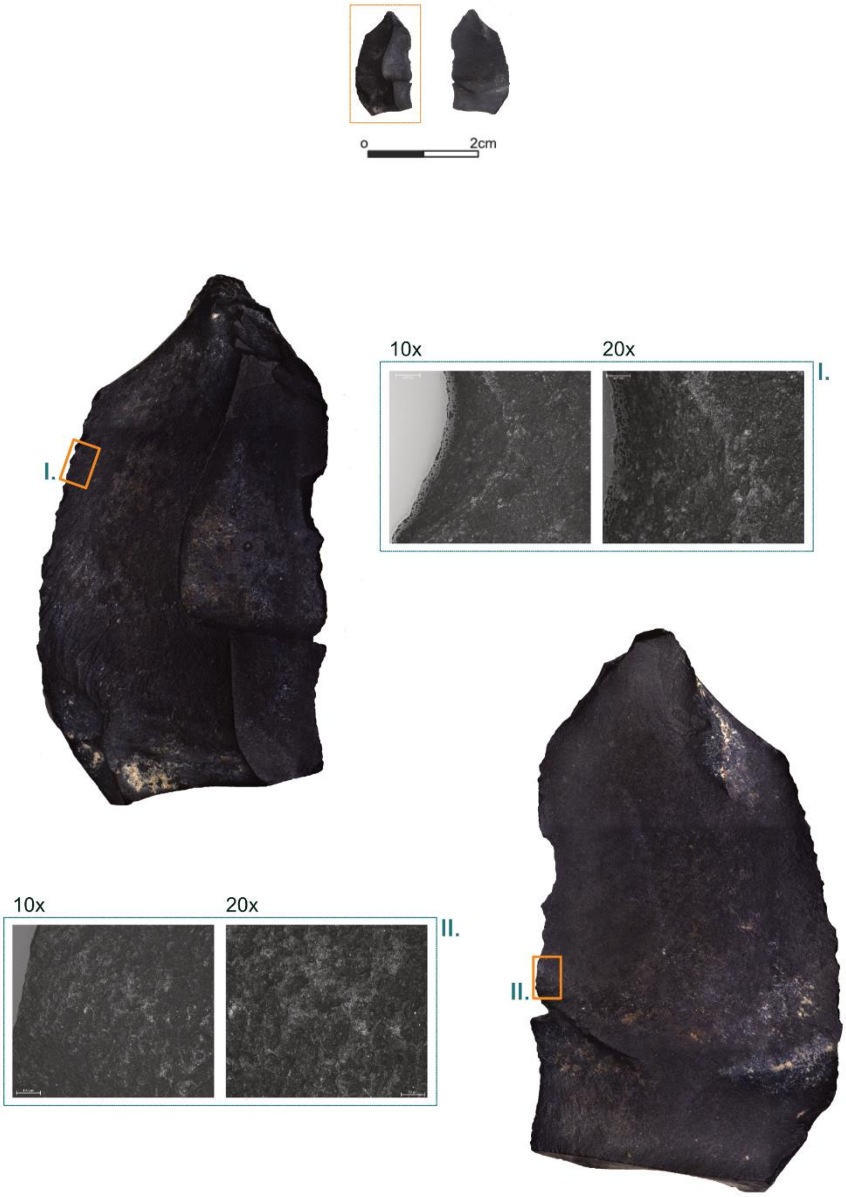


Fig. 120 Balver Höhle, *Prądnik spall* [ID MU-173]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x and 20x (I. type V.; II. type V.).

Fig. 121 Balver Höhle, *Prądnik spall* [ID MU-180]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x and 20x (I. type V.; II. type V.; III. type VIII.; IV. type V.; V. type V).

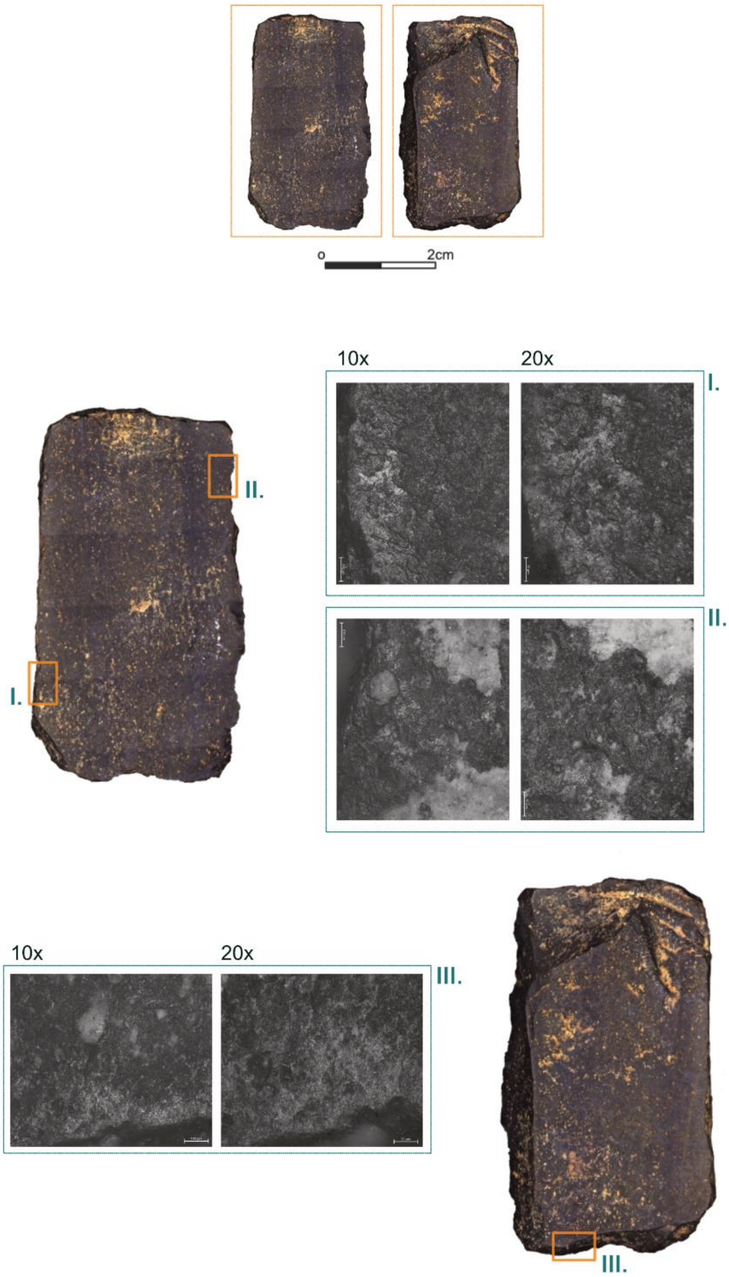


Fig. 122 Balver Höhle, *Prądnik spall* [ID MU-186]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x and 20x (I. type VIII.; II. type V. / IV.; III. type V).

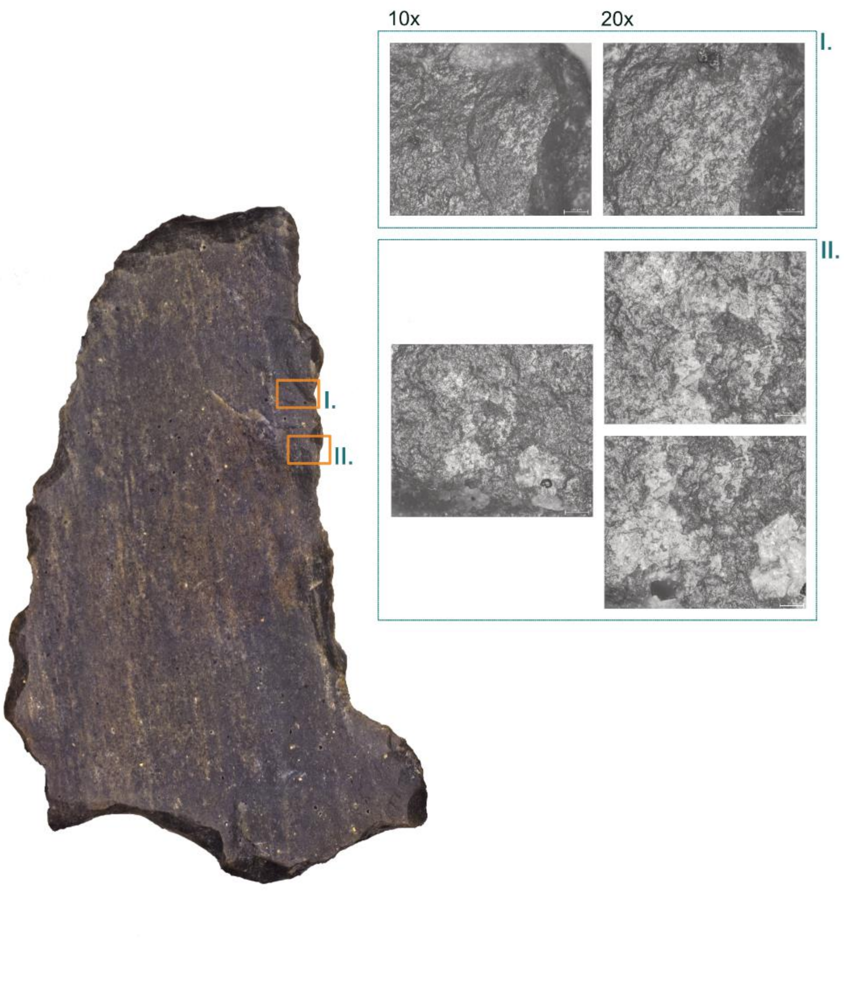


Fig. 123 Balver Höhle, *Prądnik spall* [ID MU-190]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x and 20x (I. type V.; II. type VI.).

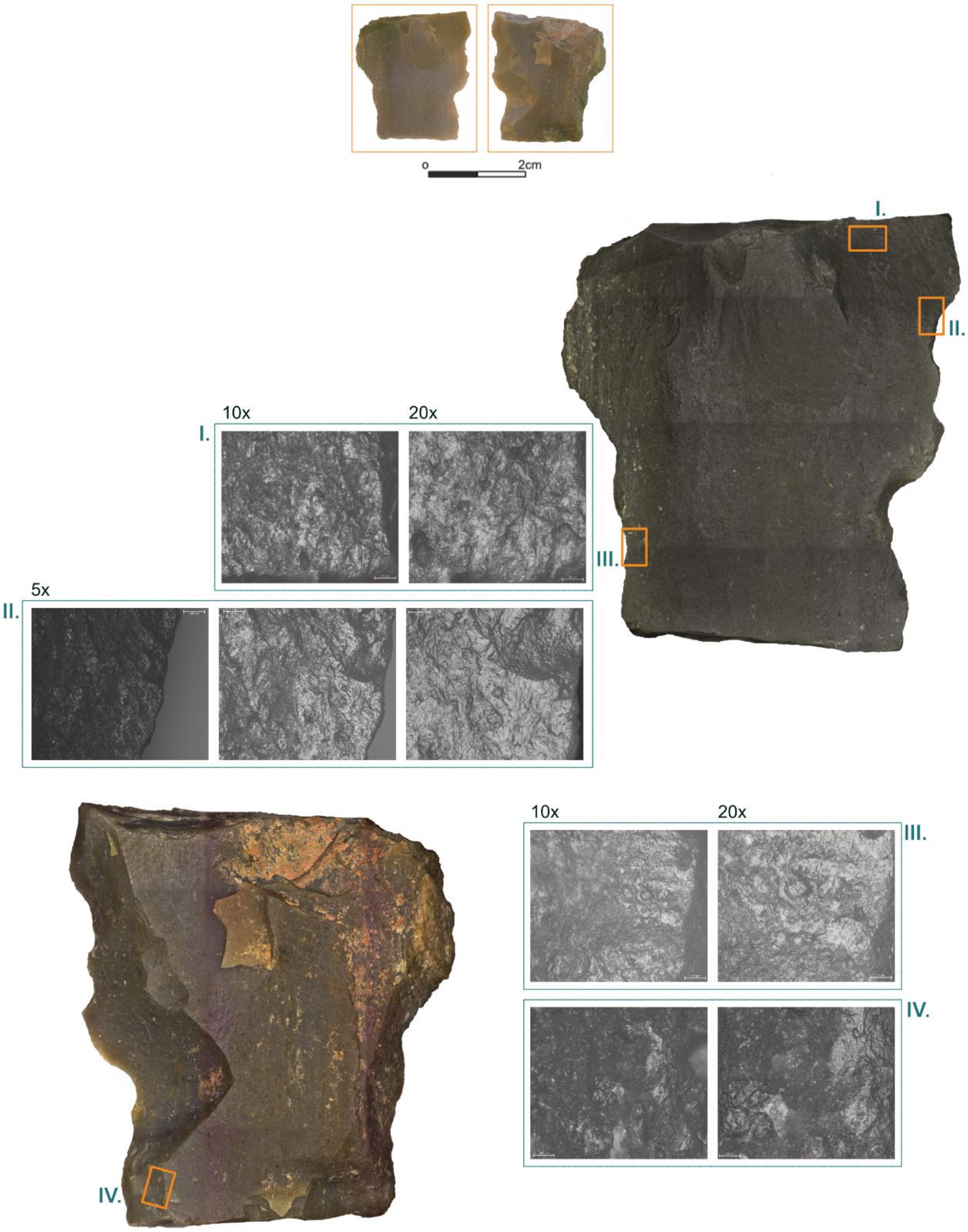
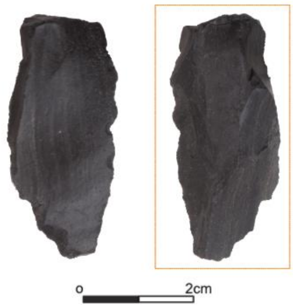


Fig. 124 Balver Höhle, *Prądnik spall* [ID MU-194]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 5x, 10x and 20x (I. type V.; II. type V.; III. type V.; IV. type V.).

Fig. 125 Balver Höhle, *Prądnik spall* [ID MU-203]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear trace is acquired at magnification of 10x and 20x (I. type VI.).



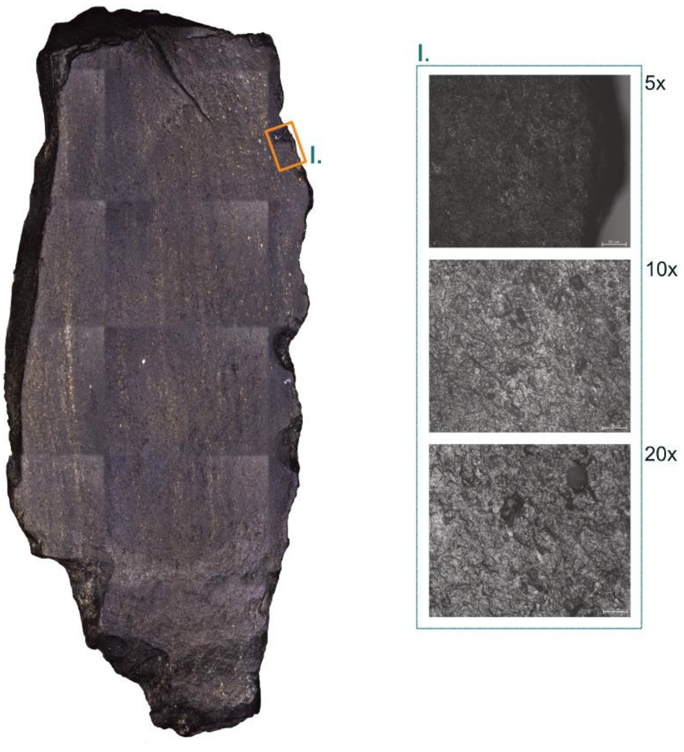


Fig. 126 Balver Höhle, *Prądnik spall* [ID MU-204]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear trace is acquired at magnification of 5x, 10x and 20x (I. type V.).

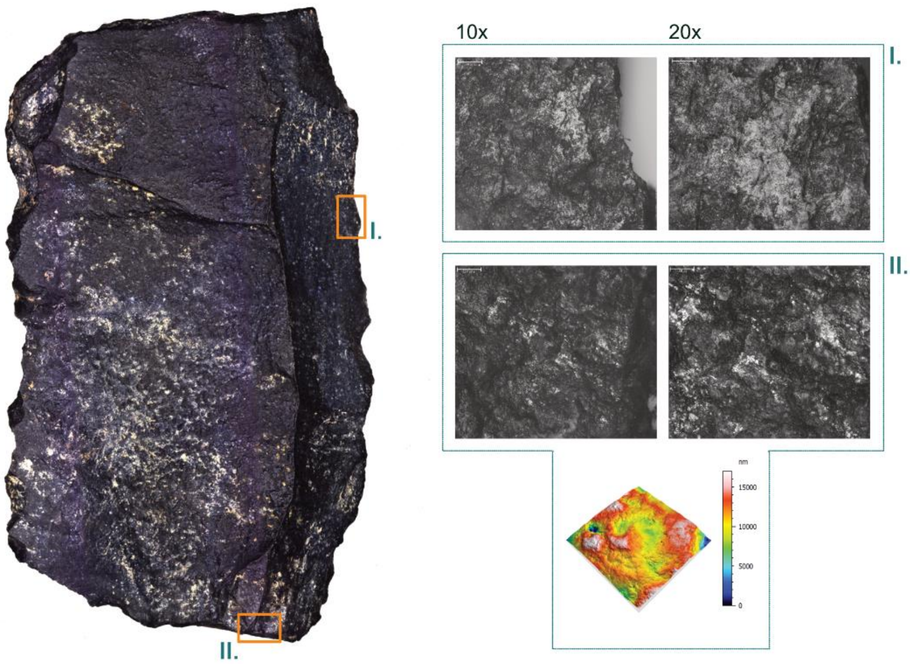


Fig. 127 Balver Höhle, *Prądnik spall* [ID MU-217]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x and 20x (I. type V. /IV.; II. type I.). The micro-surface displays the processed result of the confocal data acquisition with the 50x objective.

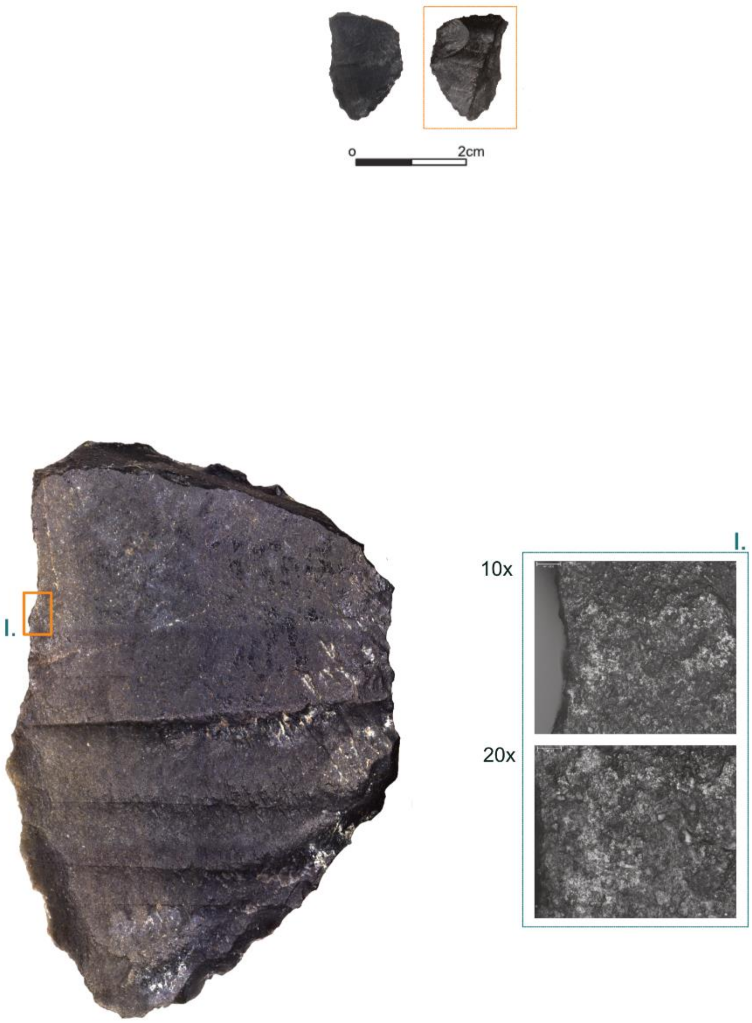


Fig. 128 Balver Höhle, *Prądnik spall* [ID MU-301]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear trace is acquired at magnification of 10x and 20x (I. type V.).

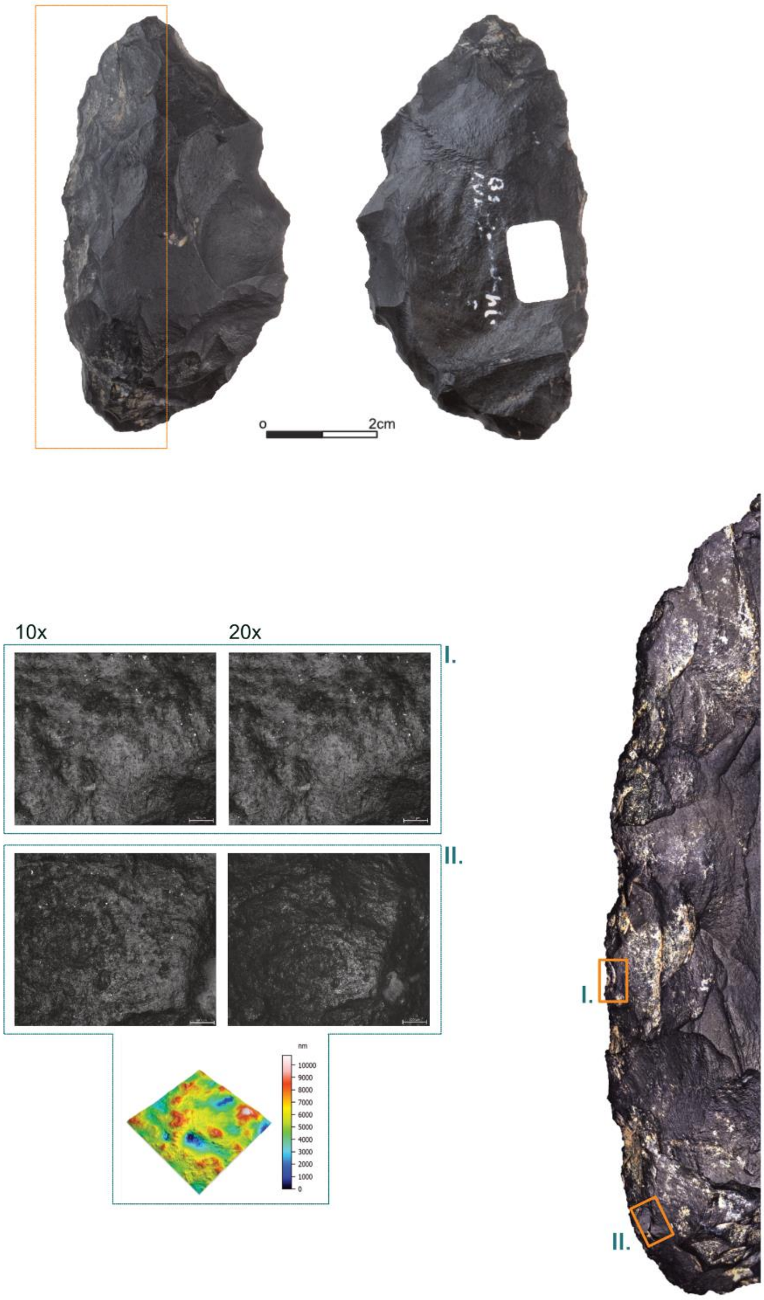


Fig. 129 Balver Höhle, scraper [ID MU-019]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x and 20x (I. type VII.; II. type VII.). The micro-surface displays the processed result of the confocal data acquisition with the 50x objective.

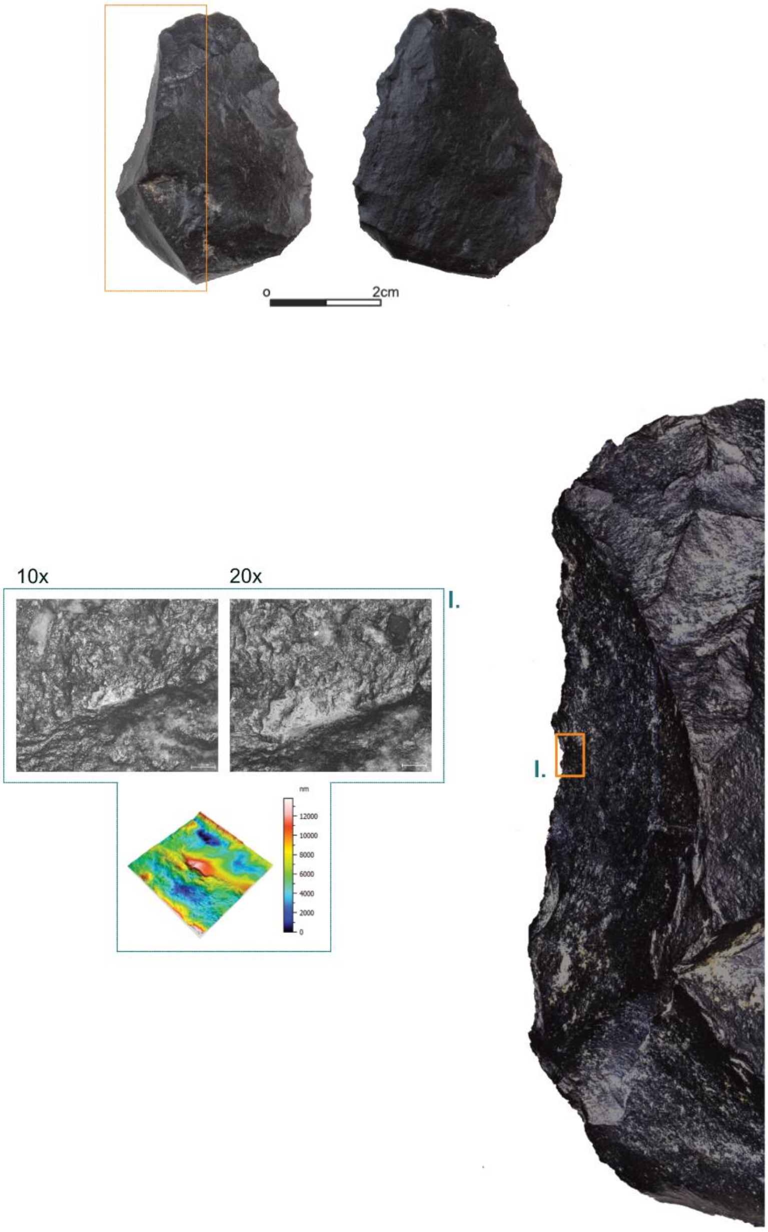


Fig. 130 Balver Höhle, scraper [ID MU-025]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear trace is acquired at magnification of 10x and 20x (I. type II.). The micro-surface displays the processed result of the confocal data acquisition with the 50x objective.

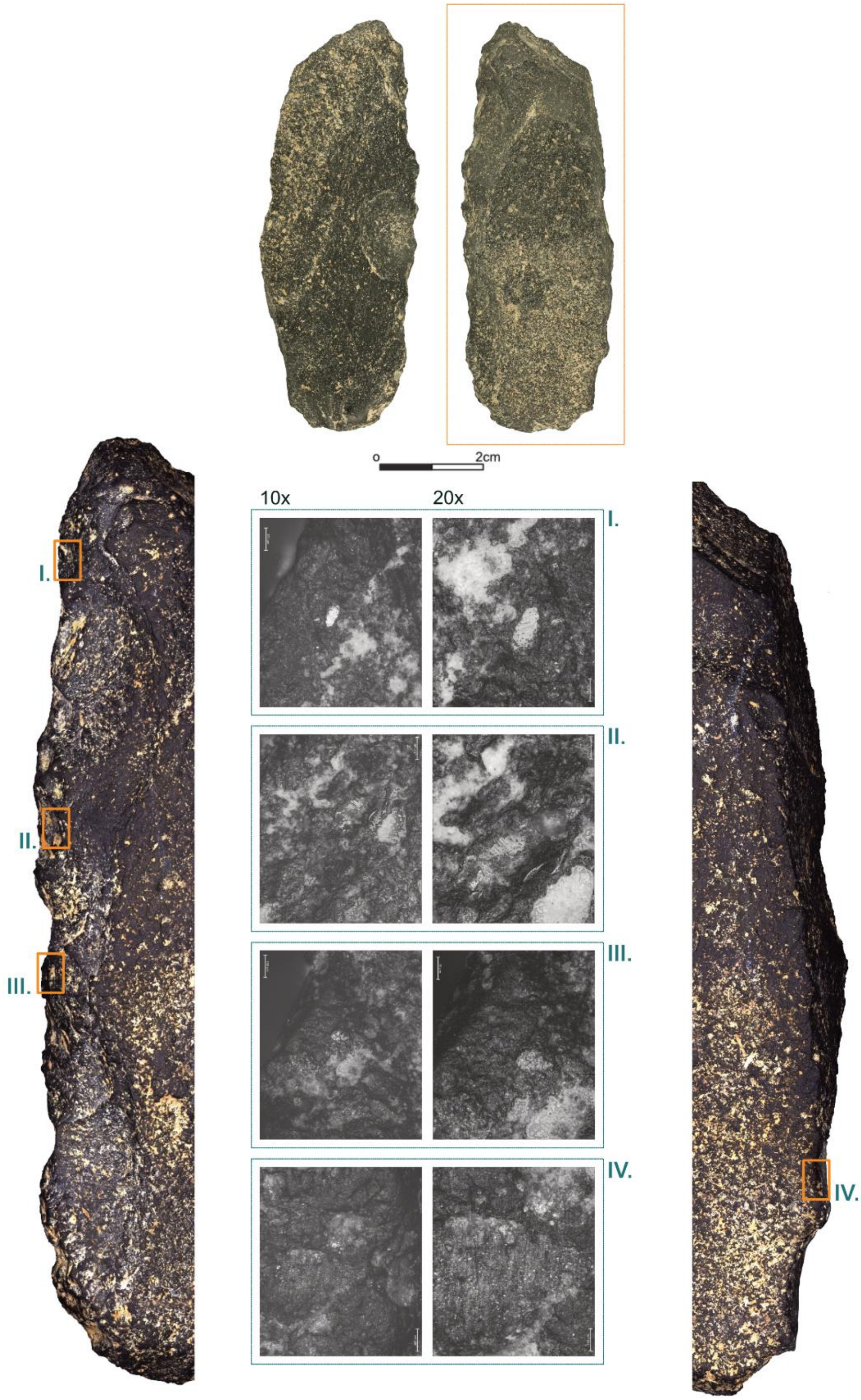


Fig. 131 Balver Höhle, scraper [ID MU-030]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x and 20x (I. type IV.; II. type VIII.; III. type I.; IV. type VIII.).

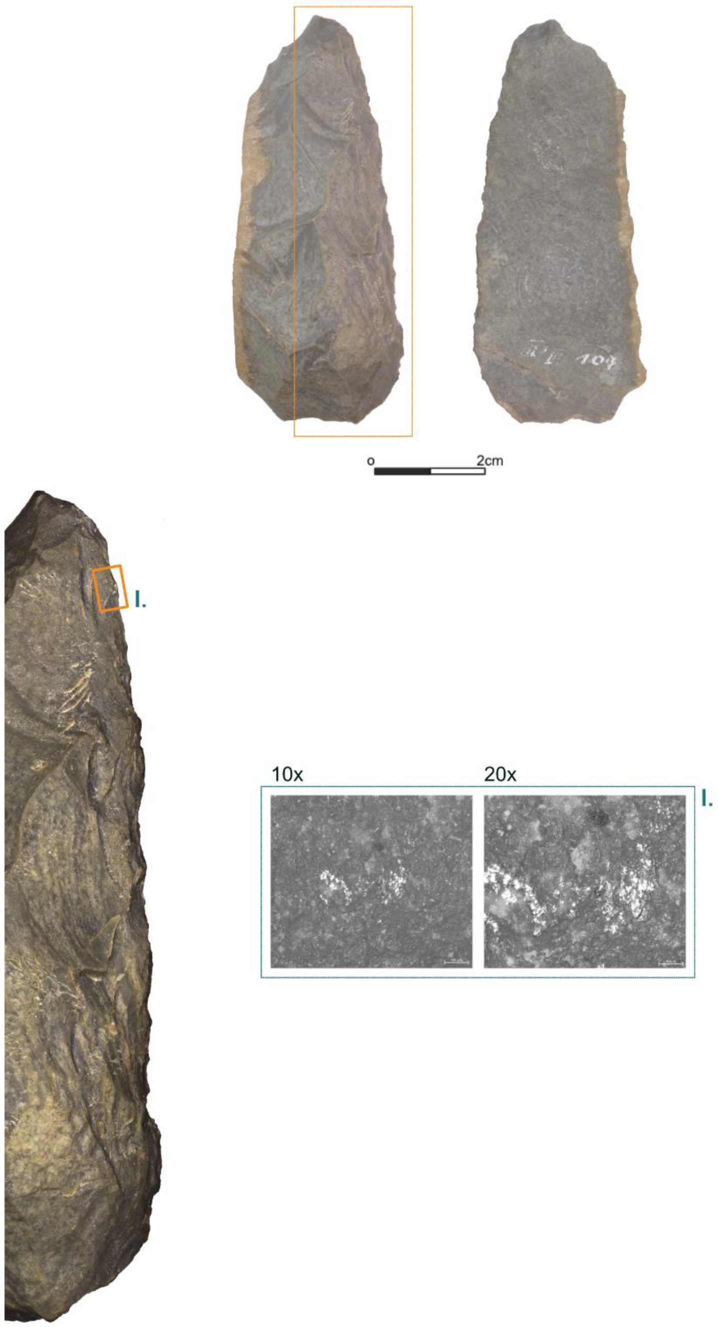


Fig. 132 Balver Höhle, scraper [ID MU-201]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear trace is acquired at magnification of 10x and 20x (I. type I.).

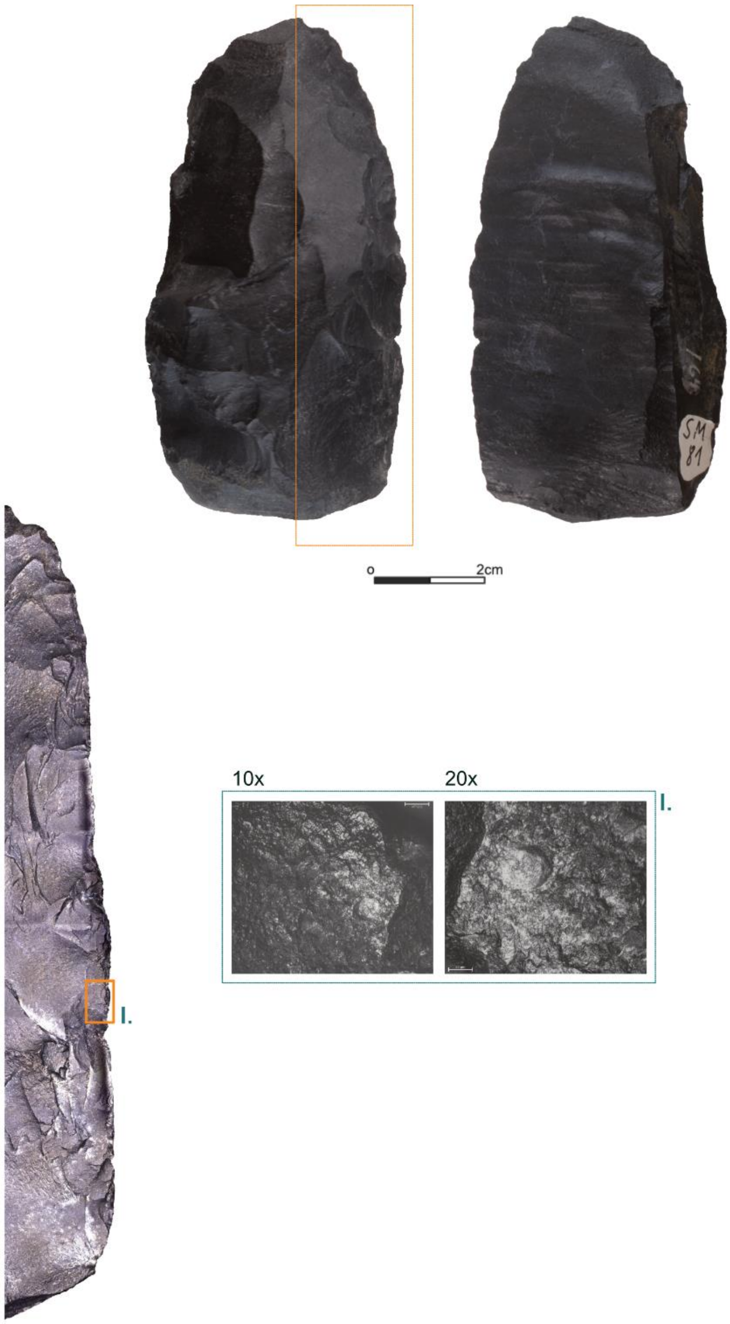


Fig. 133 Balver Höhle, scraper [ID MU-274]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear trace is acquired at magnification of 10x and 20x (I. type V.).

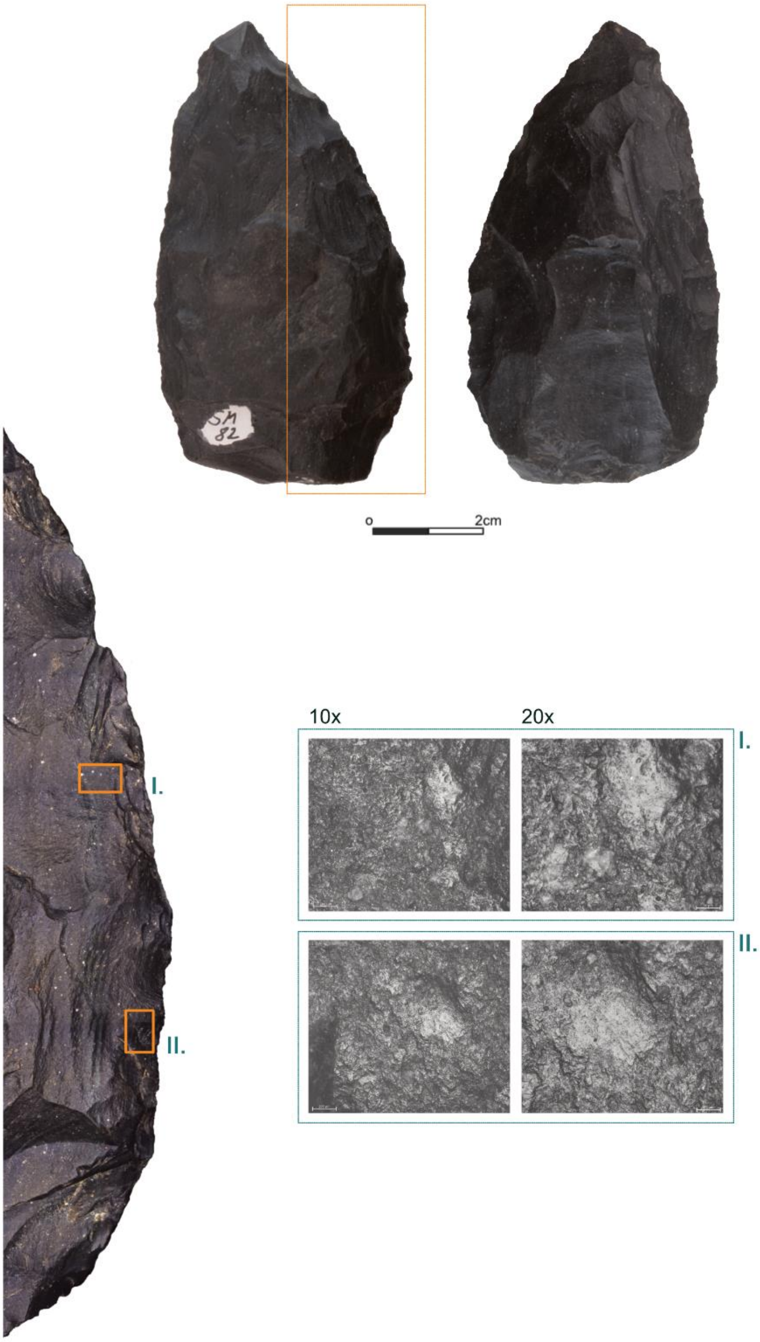


Fig. 134 Balver Höhle, scraper [ID MU-278; dorsal]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x and 20x (I. type II.; II. type II.).

Fig. 135 Balver Höhle, scraper [ID MU-278; ventral]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x and 20x (I. type V.; II. type V.; III. type V.).

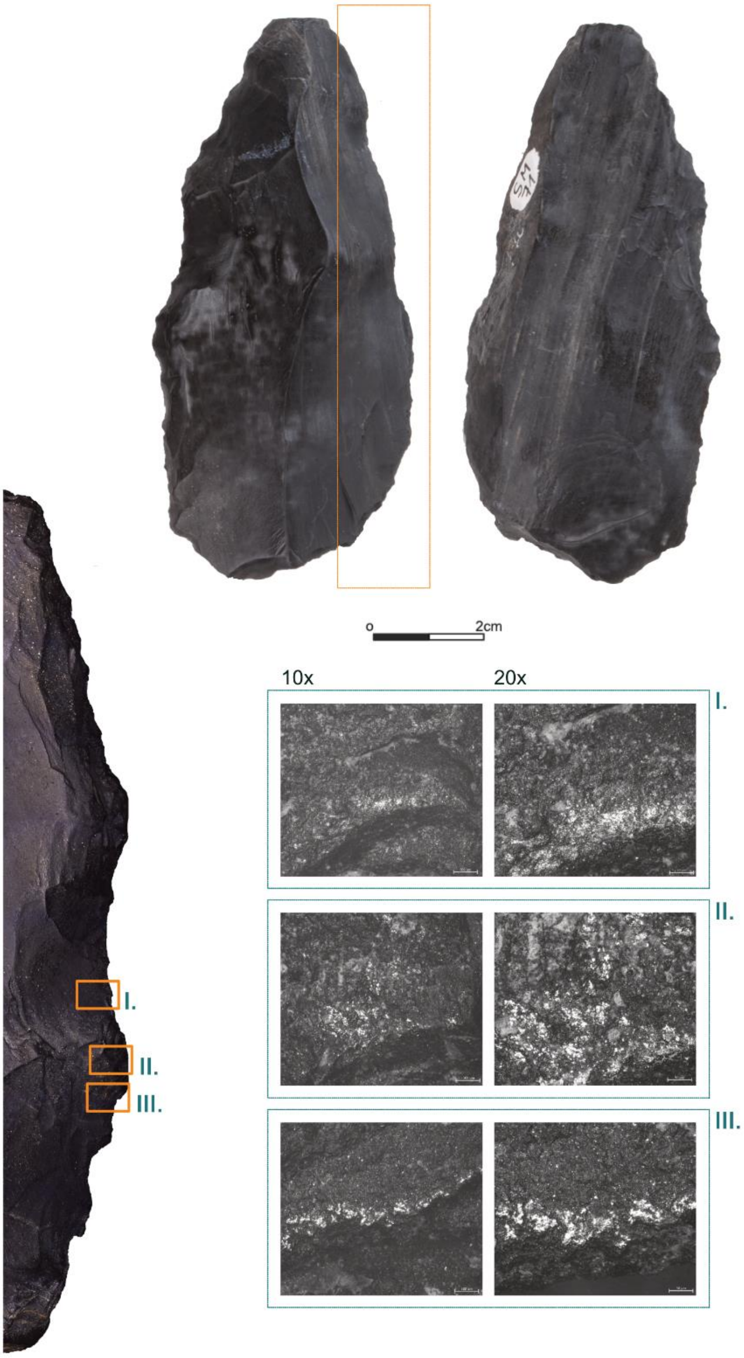


Fig. 136 Balver Höhle, scraper [ID MU-279; dorsal]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x and 20x (I. type V.; II. type IV.; III. type IV.).

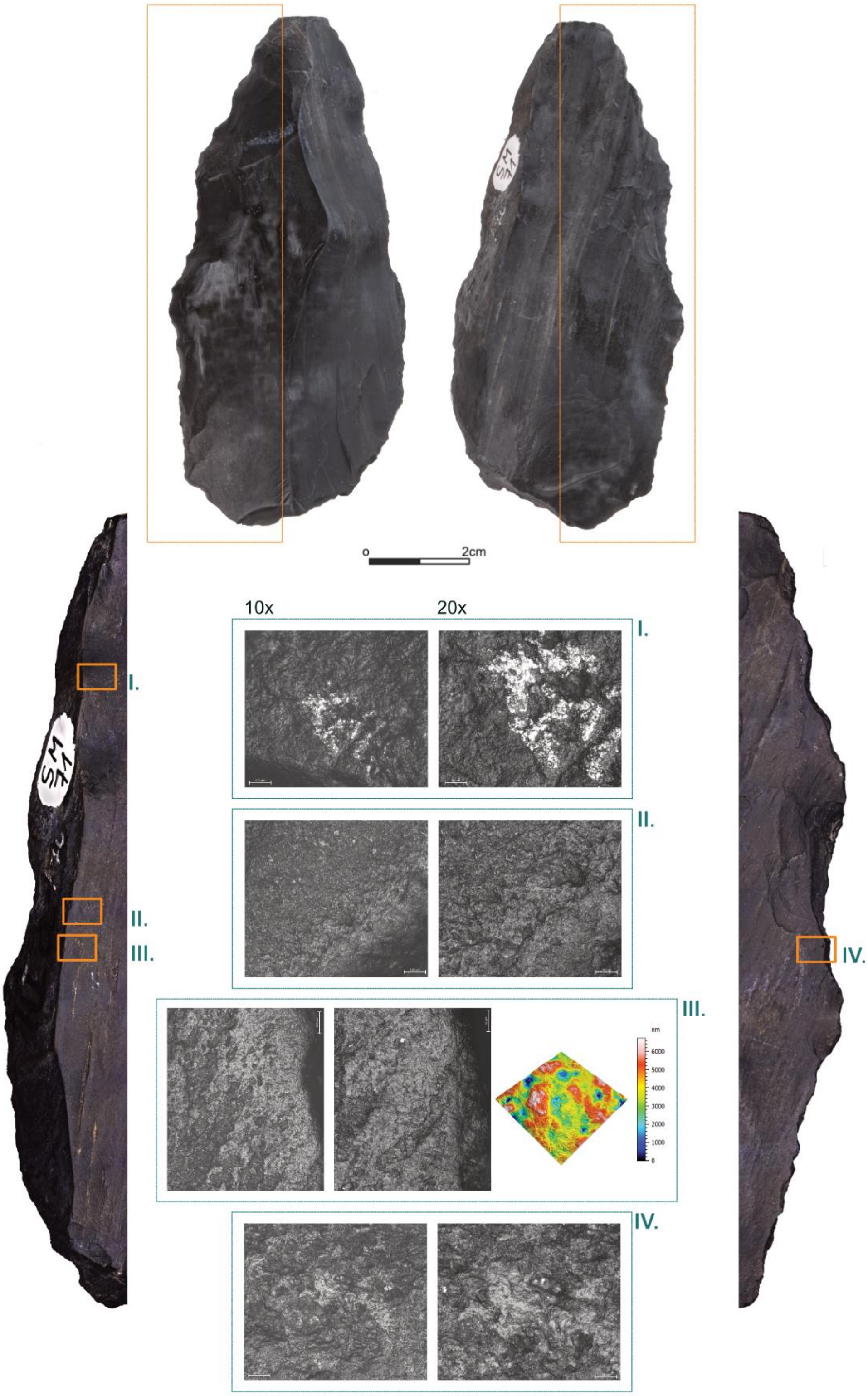


Fig. 137 Balver Höhle, scraper [ID MU-279; ventral]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x and 20x (I. type IV.; II. type V.; III. type V.; IV. type V.). The micro-surface displays the processed result of the confocal data acquisition with the 50x objective.

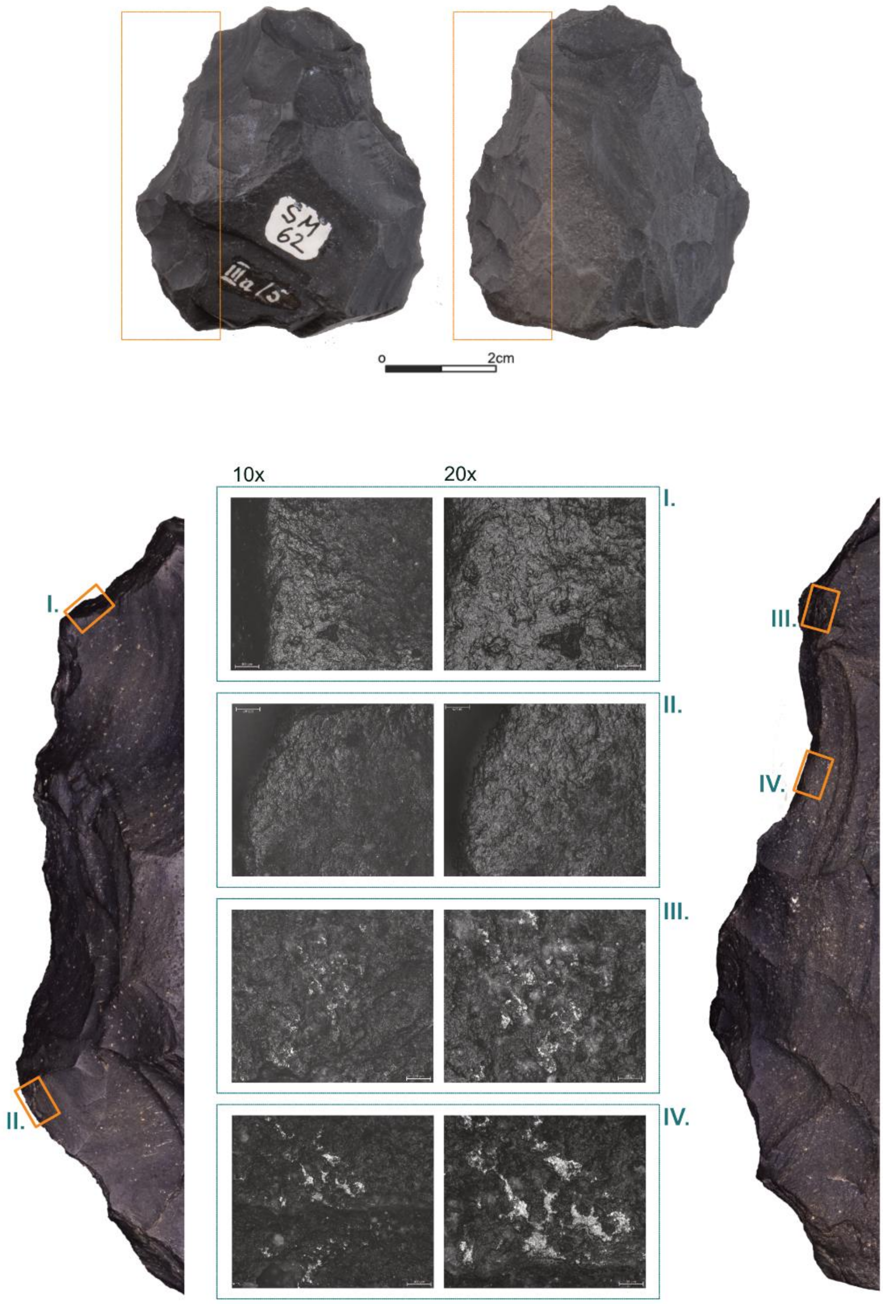


Fig. 138 Balver Höhle, scraper [ID MU-285]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x and 20x (I. type V.; II. type V.; III. type I.; IV. type I.).

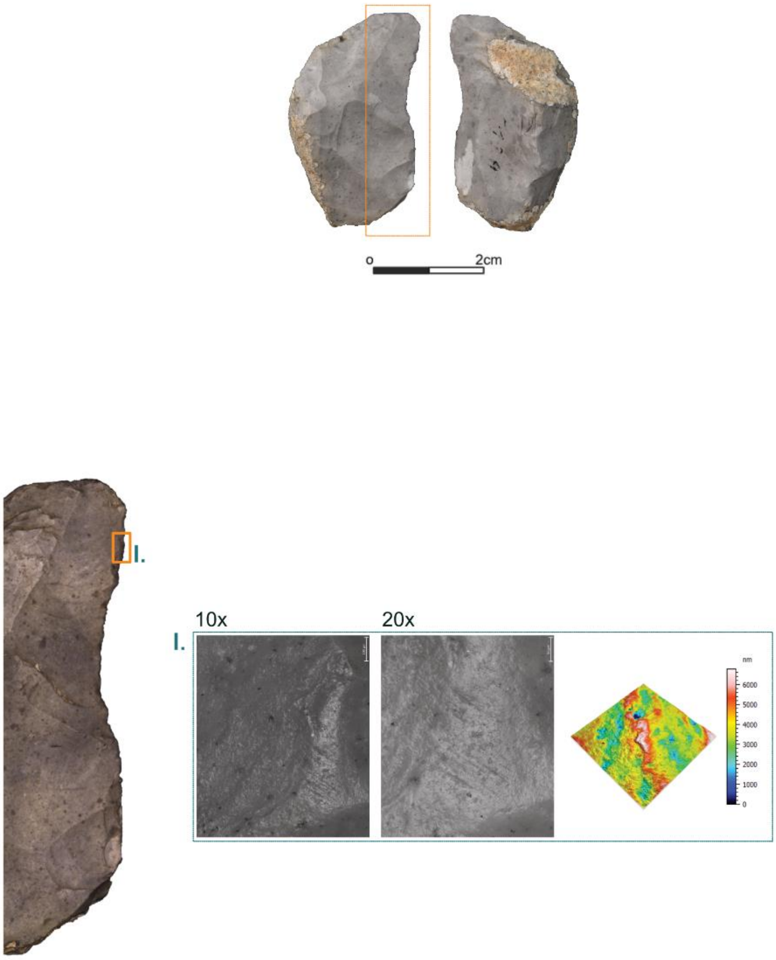


Fig. 139 Ramioul, *Keilmesser* [ID R-002]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear trace is acquired at magnification of 10x and 20x (I. type VI.). The micro-surface displays the processed result of the confocal data acquisition with the 50x objective.

Fig. 140 Ramioul, *Keilmesser* [ID R-006]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear trace is acquired at magnification of 10x and 20x (I. type IV.). The micro-surface displays the processed result of the confocal data acquisition with the 50x objective.

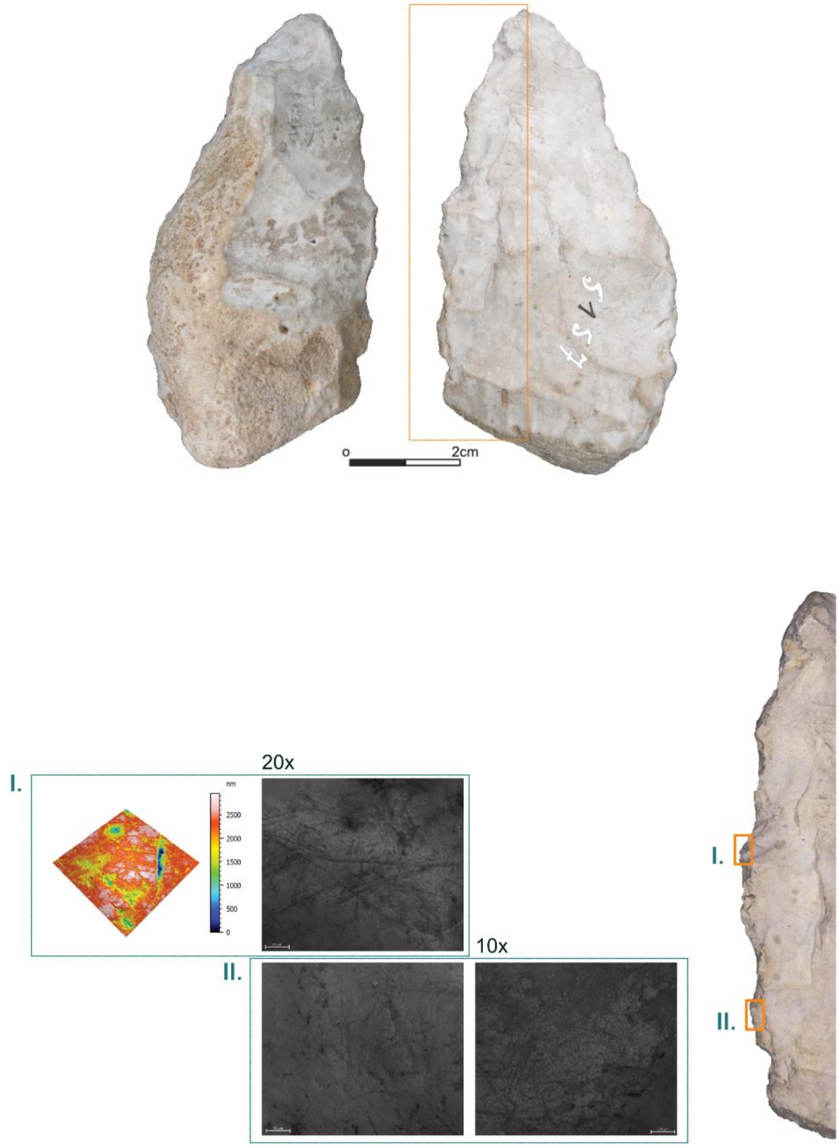


Fig. 141 Ramioul, *Keilmesser* [ID R-007]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x and 20x (I. type IX.; II. type IX.). The micro-surface displays the processed result of the confocal data acquisition with the 50x objective.

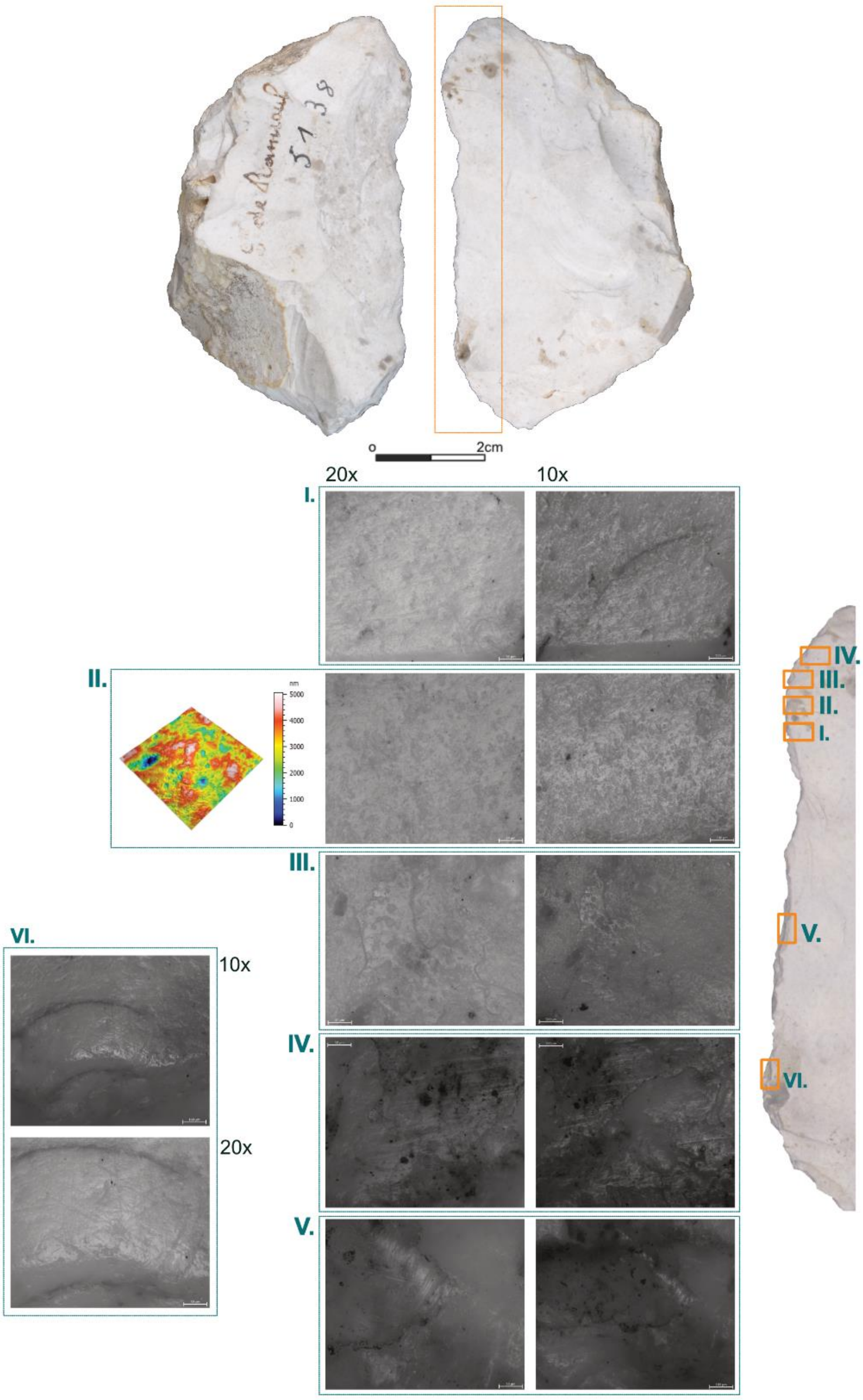


Fig. 142 Ramioul, *Keilmesser* [ID R-008]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x and 20x (I. type VI.; II. type VI.; III. type V.; IV. type VI.; V. type VI.; VI. type VI.). The micro-surface displays the processed result of the confocal data acquisition with the 50x objective.

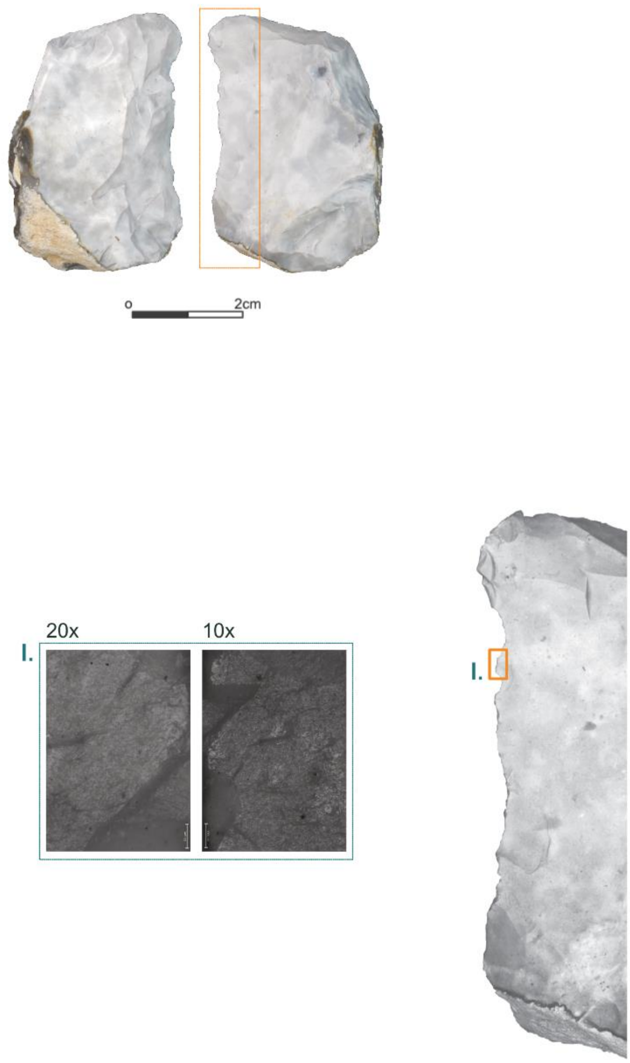


Fig. 143 Ramioul, *Keilmesser* [ID R-011]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear trace is acquired at magnification of 10x and 20x (I. type IV.).

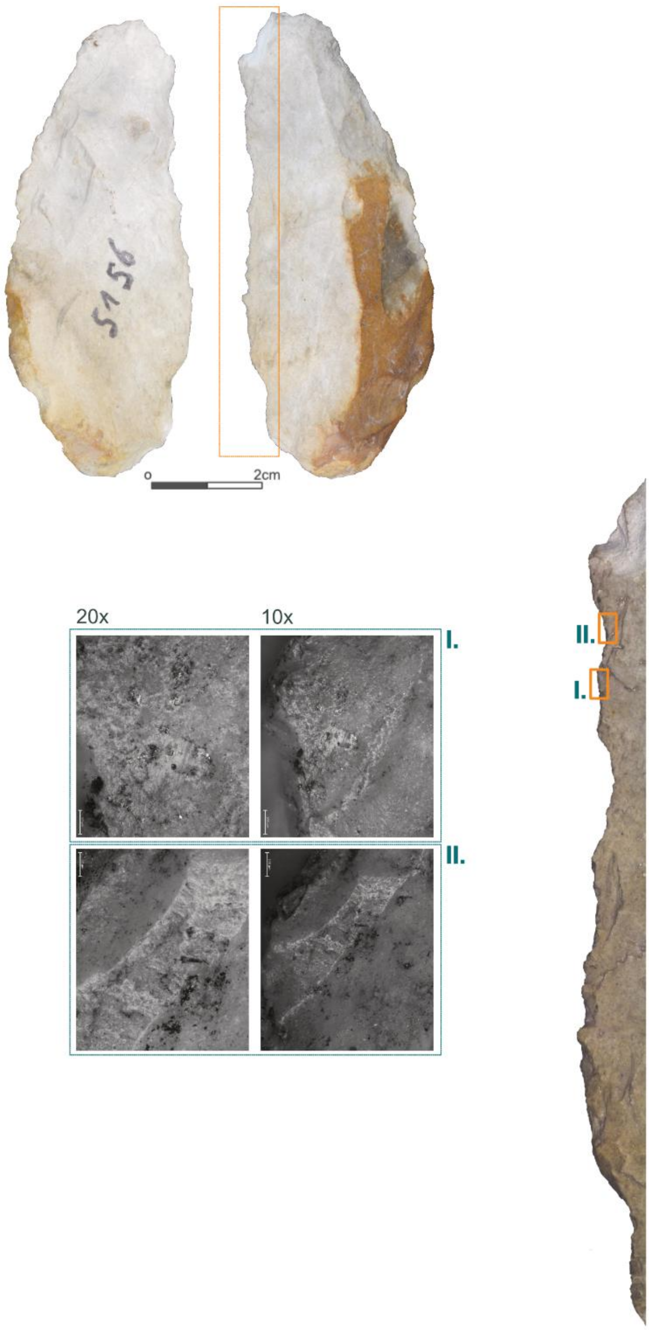


Fig. 144 Ramioul, *Keilmesser* [ID R-018]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x and 20x (I. type V. / VI.; II. type V.).

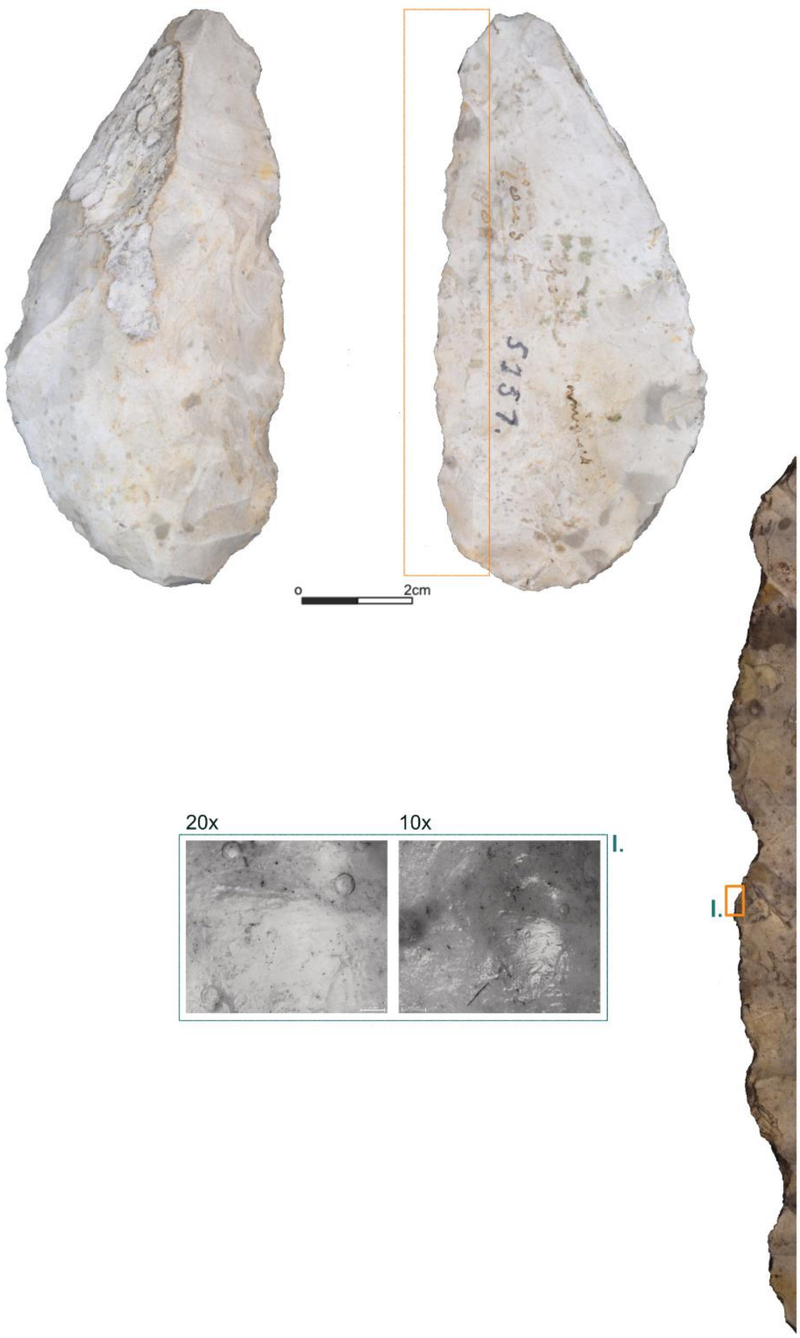


Fig. 145 Ramioul, *Keilmesser* [ID R-019]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear trace is acquired at magnification of 10x and 20x (I. type II.).

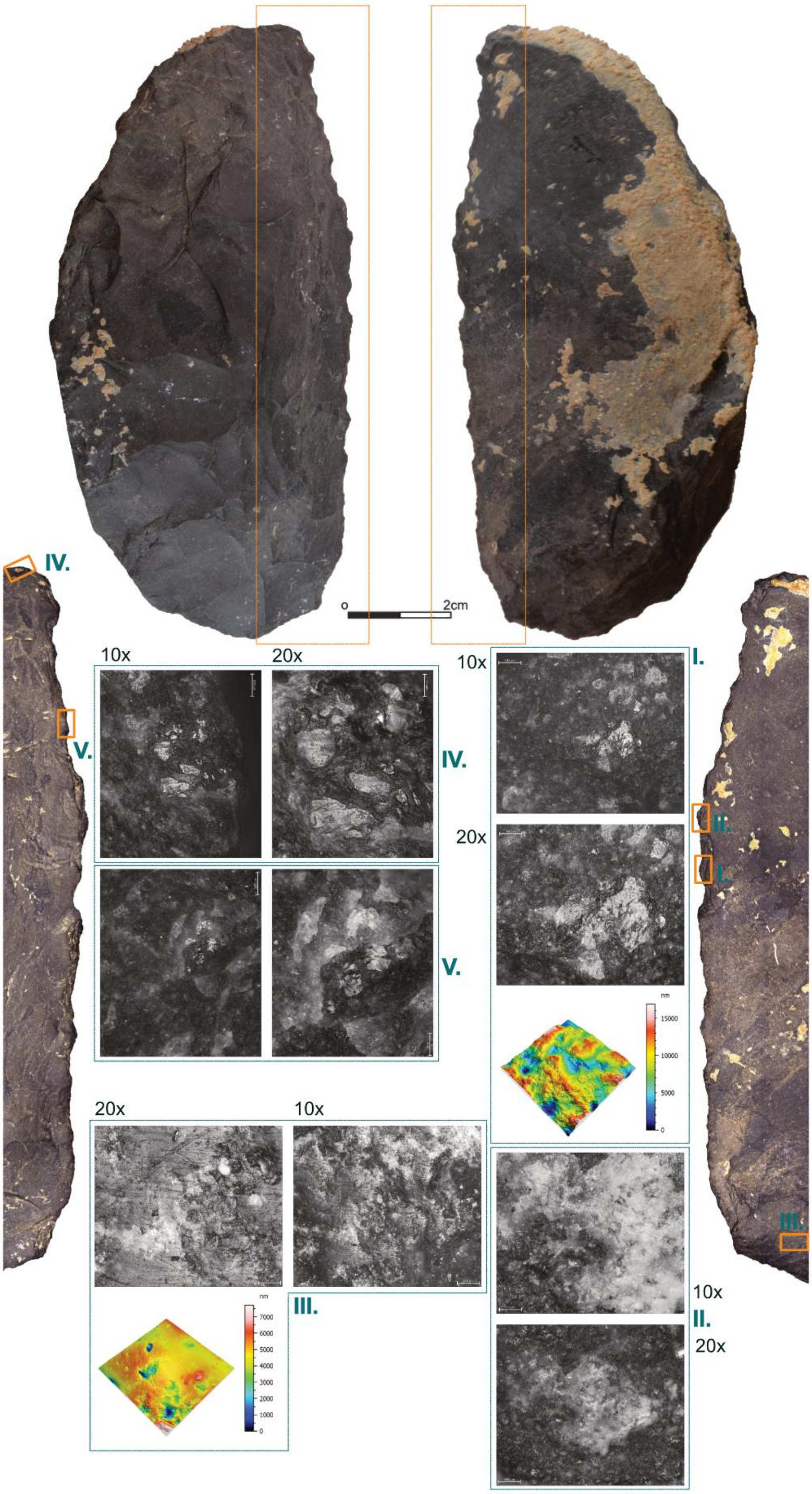


Fig. 146 Ramioul, *Keilmesser* [ID R-020]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x and 20x (I. type I.; II. type VIII.; III. type IX.; IV. type II.; V. type II.). The micro-surface displays the processed result of the confocal data acquisition with the 50x objective.

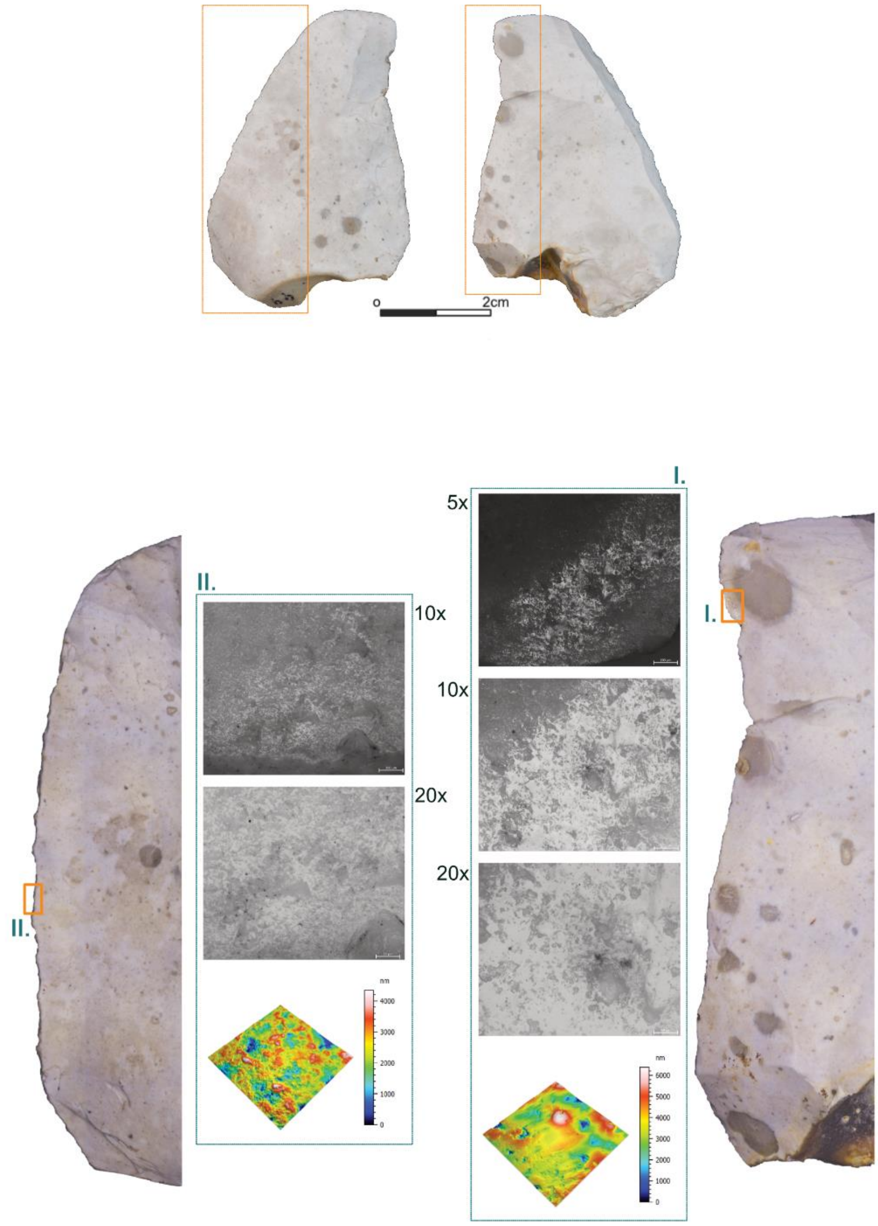


Fig. 147 Ramioul, *Prądnik scraper* [ID R-010]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 5x, 10x and 20x (I. type V. / IV; II. type V.). The micro-surface displays the processed result of the confocal data acquisition with the 50x objective.

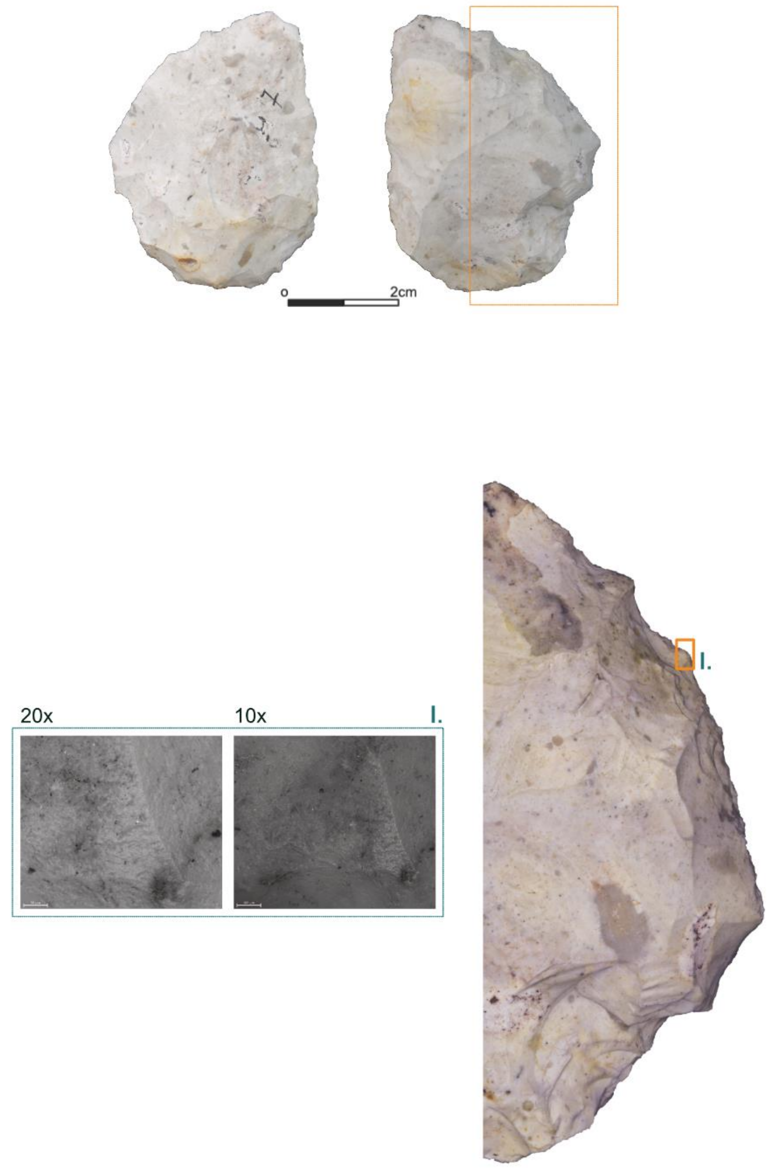
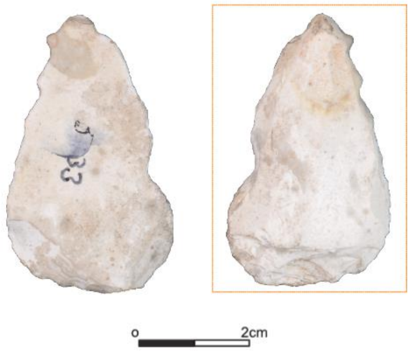


Fig. 148 Ramioul, *Prądnik scraper* [ID R-014]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear trace is acquired at magnification of 10x and 20x (I. type V.).

Fig. 149 Ramioul, *Prądnik scraper* [ID R-016]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x and 20x (I. type IX.; II. type IX.).



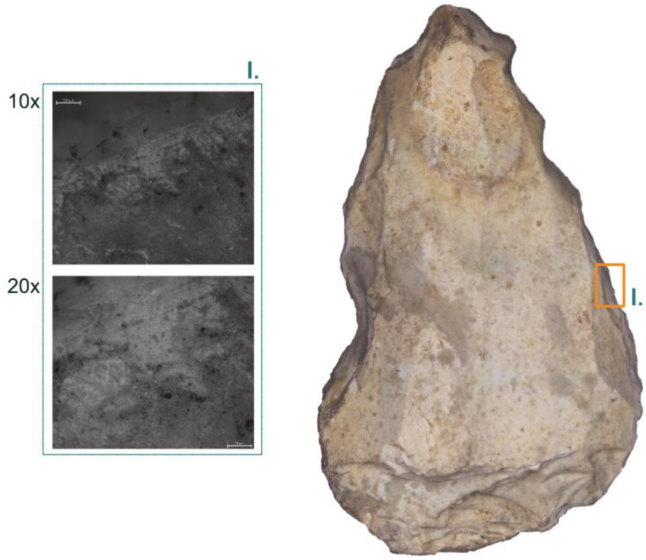


Fig. 150 Ramioul, *Prądnik scraper* [ID R-013; dorsal]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear trace is acquired at magnification of 10x and 20x (I. type IX.).

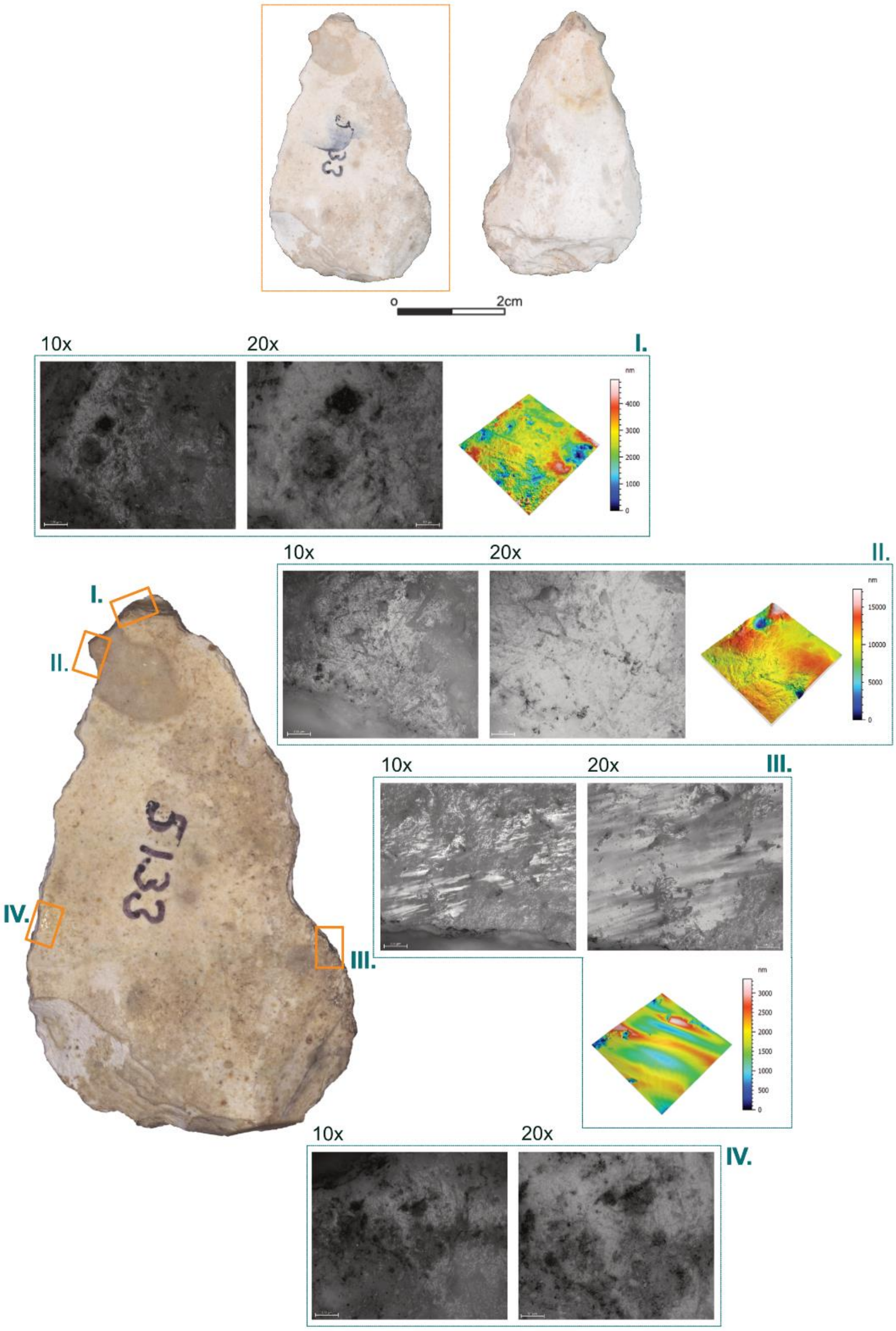


Fig. 151 Ramioul, *Prądnik scraper* [ID R-013; ventral]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x and 20x (I. type IX.; II. type IX.; III. type V. / IV.; IV. type VII.). The micro-surface displays the processed result of the confocal data acquisition with the 50x objective.

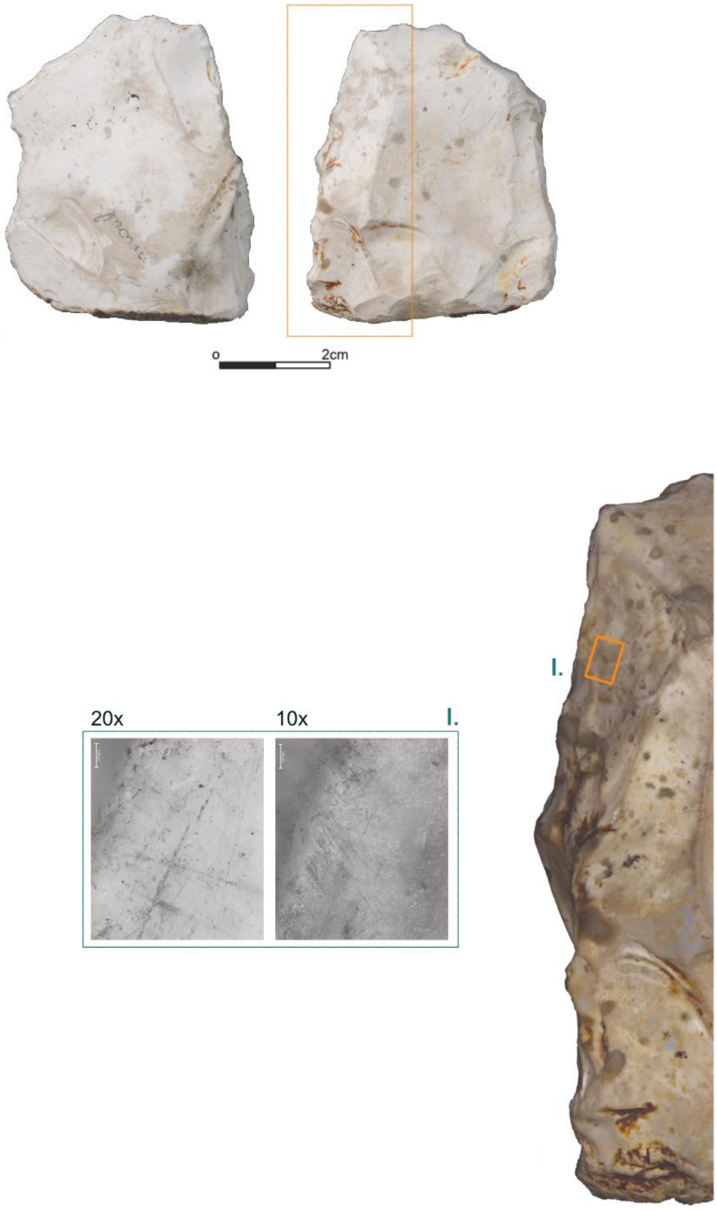


Fig. 152 Ramioul, scraper [ID R-015]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear trace is acquired at magnification of 10x and 20x (I. type IX.).

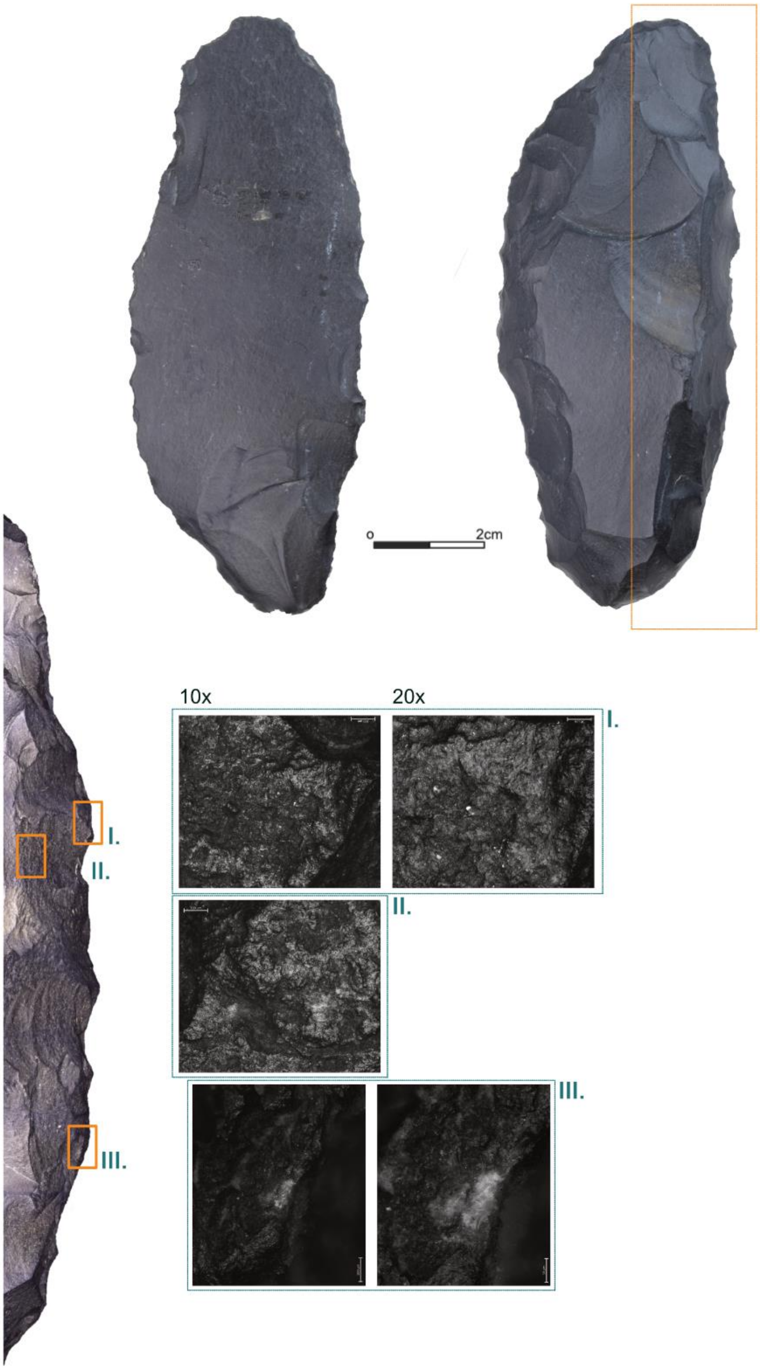


Fig. 153 Ramioul, scraper [ID R-017]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x and 20x (I. type V.; II. type V.; III. type IV.).

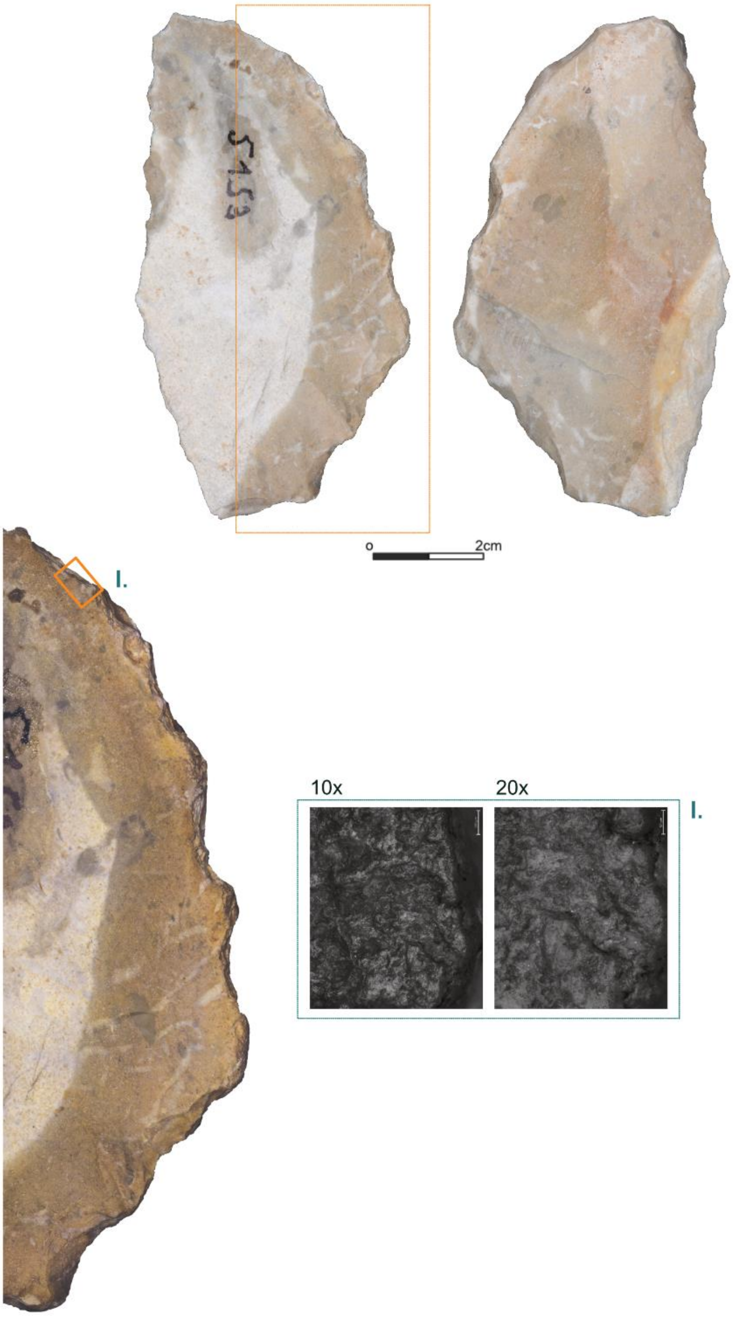


Fig. 154 Ramioul, scraper [ID R-012]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear trace is acquired at magnification of 10x and 20x (I. type V.).

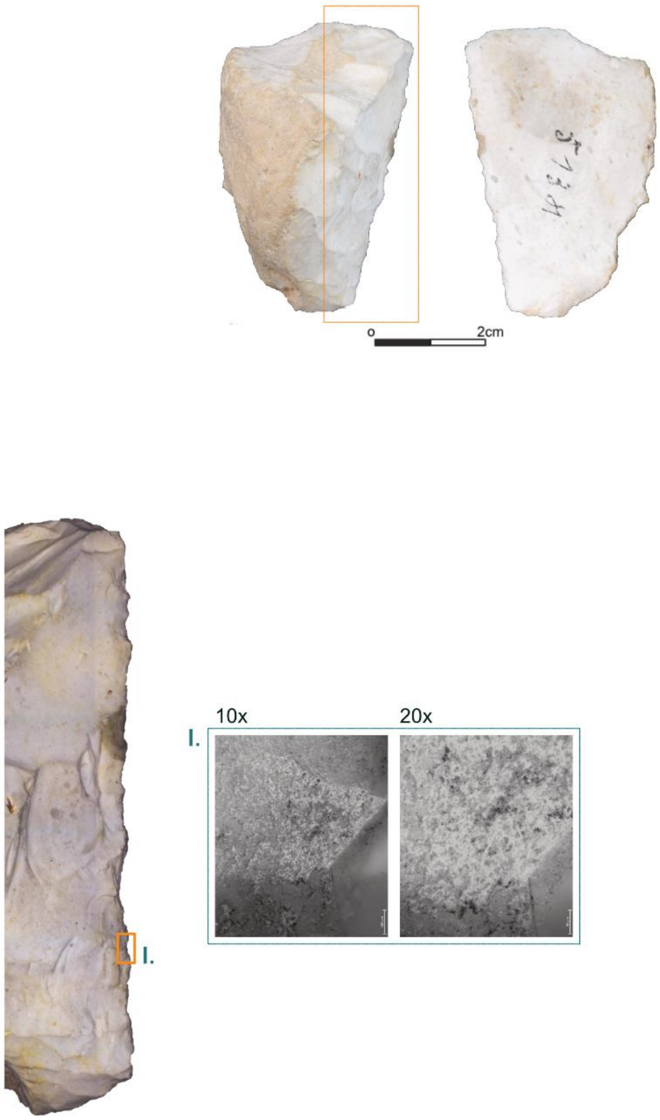


Fig. 155 Ramioul, scraper [ID R-003]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear trace is acquired at magnification of 10x and 20x (I. type V.).

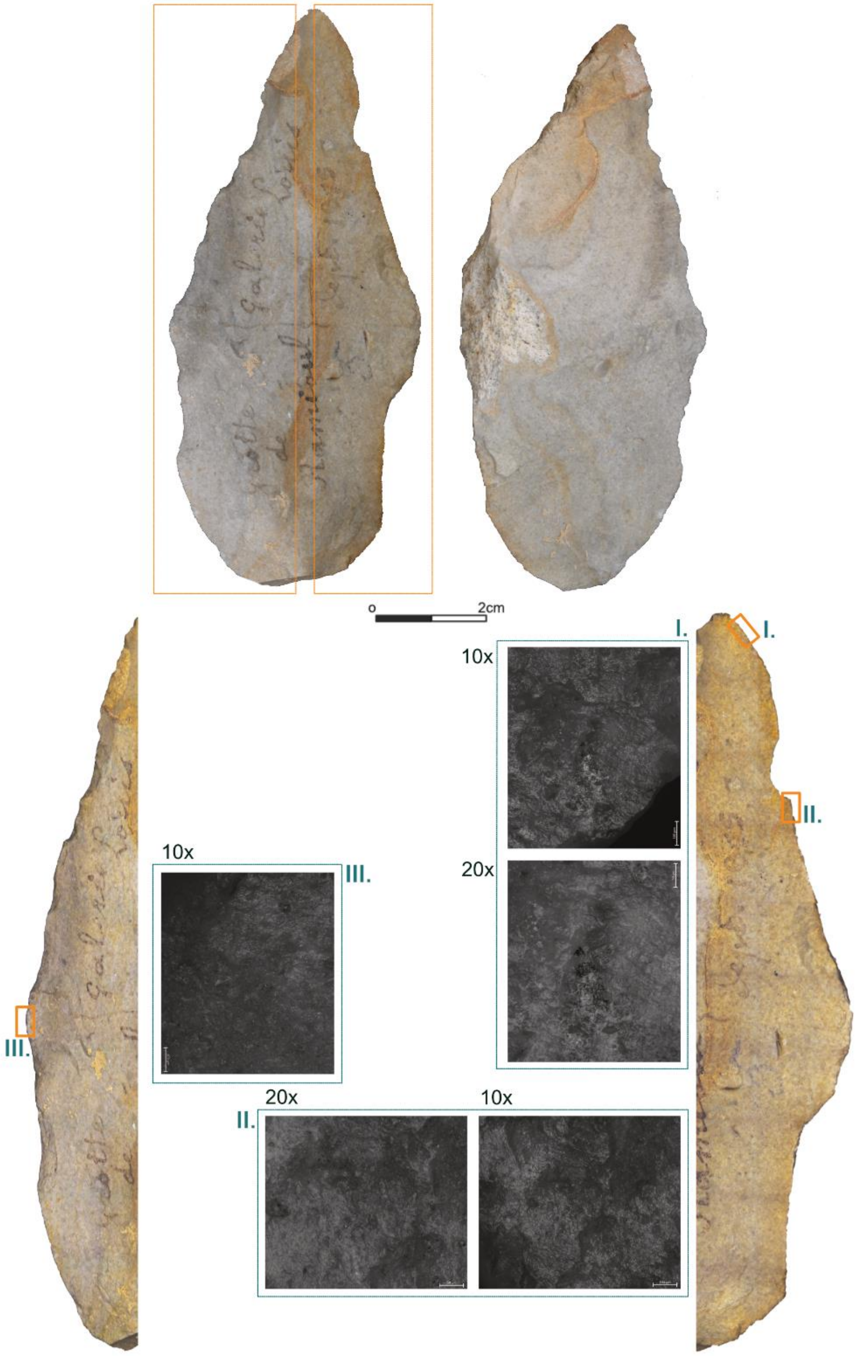


Fig. 156 Ramioul, flake [ID R-009]. The topmost image displays the artefact in original size. The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x and 20x (I. type V.; II. type V.; III. type V.).

Appendix IV.

Results of the qualitative and quantitative use-wear analyses performed on standard samples used during the ‘artificial VS. natural’ experiment and the tool function experiment.

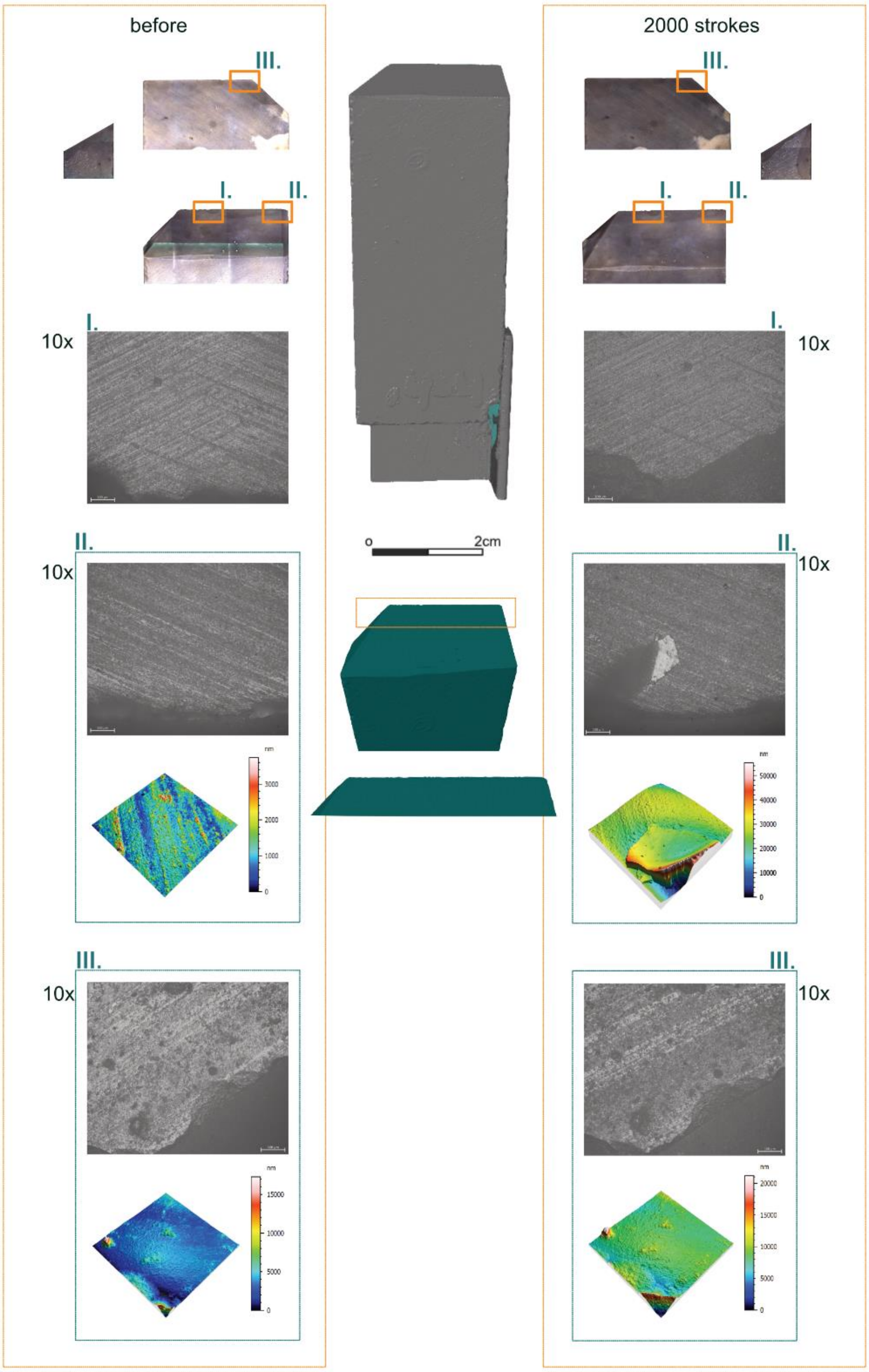


Fig. 1 , 'artificial VS. natural' experiment, flint sample FLT4-4. The topmost image displays the sample in original size before and after 2000 strokes. The 3D model of the sample is shown in the middle (grey) and as a close-up of the edge (turquoise). The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x. The micro-surface displays the processed result of the confocal data acquisition with the 50x objective.

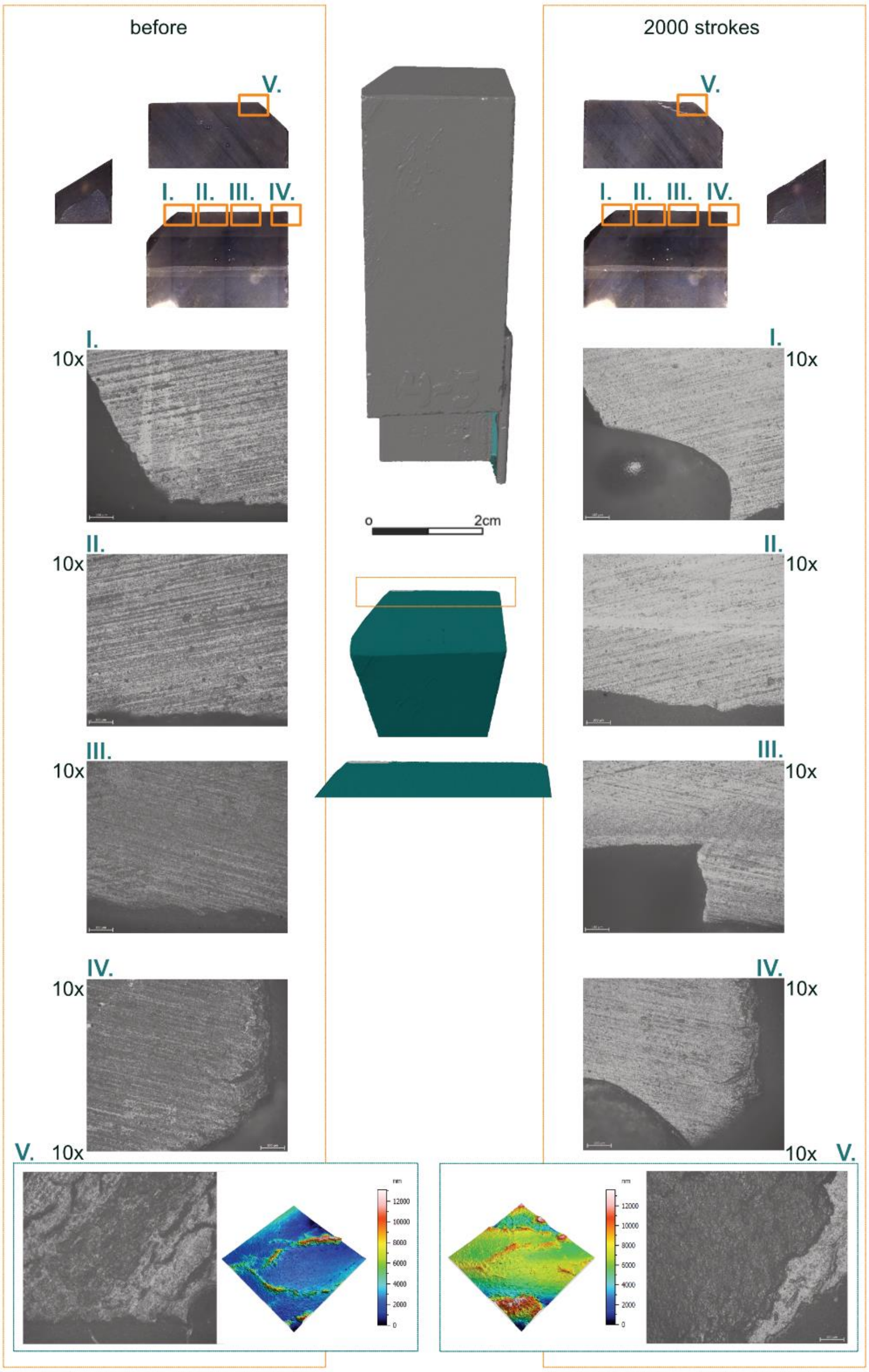


Fig. 2 'artificial VS. natural' experiment, flint sample FLT4-5. The topmost image displays the sample in original size before and after 2000 strokes. The 3D model of the sample is shown in the middle (grey) and as a close-up of the edge (turquoise). The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x. The micro-surface displays the processed result of the confocal data acquisition with the 50x objective.

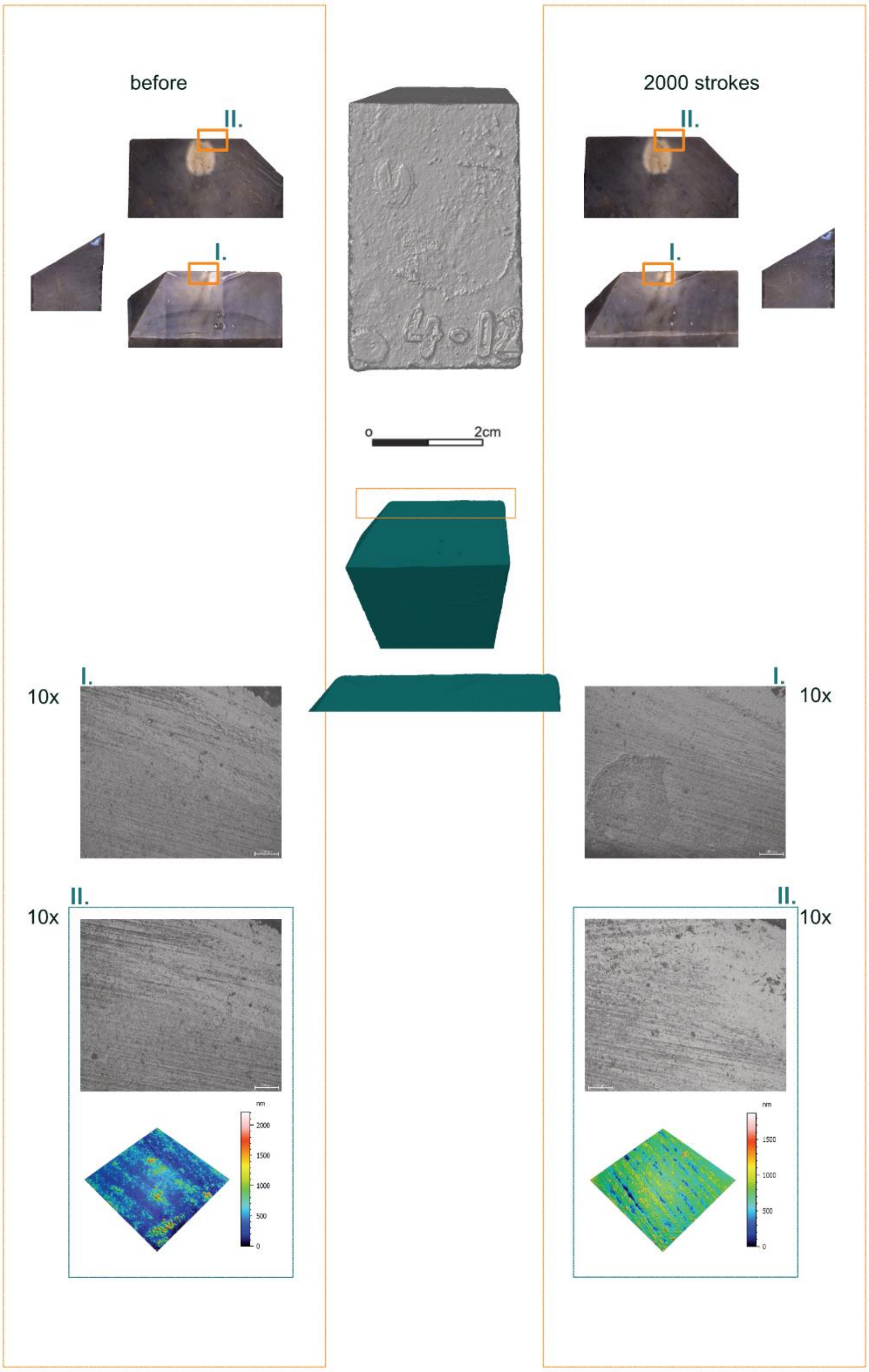


Fig. 3 'artificial VS. natural' experiment, flint sample FLT4-12. The topmost image displays the sample in original size before and after 2000 strokes. The 3D model of the sample is shown in the middle (grey) and as a close-up of the edge (turquoise). The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x. The micro-surface displays the processed result of the confocal data acquisition with the 50x objective.

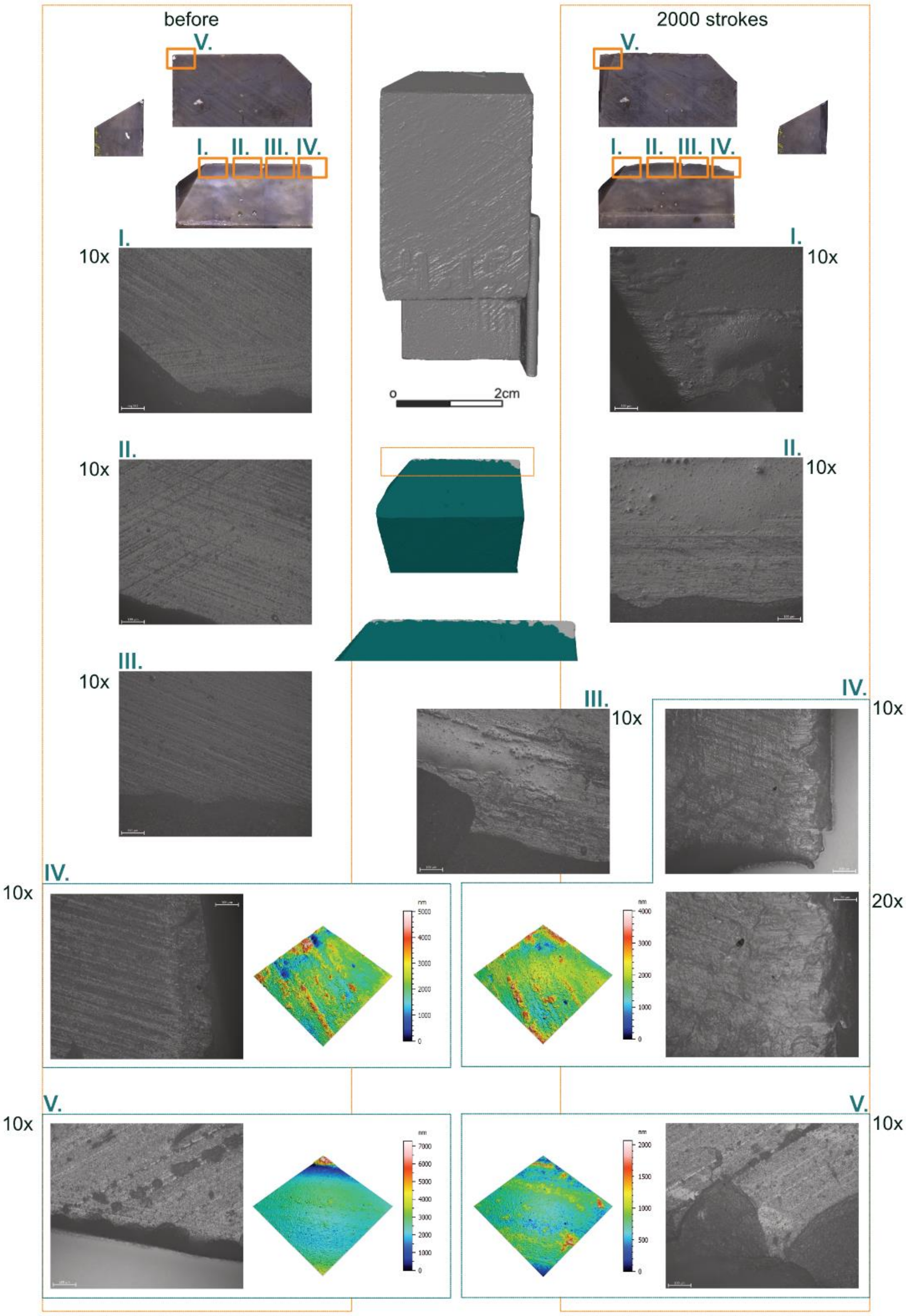


Fig. 4 'artificial VS. natural' experiment, flint sample FLT4-15. The topmost image displays the sample in original size before and after 2000 strokes. The 3D model of the sample is shown in the middle (grey) and as a close-up of the edge (turquoise). The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x and 20x. The micro-surface displays the processed result of the confocal data acquisition with the 50x objective.

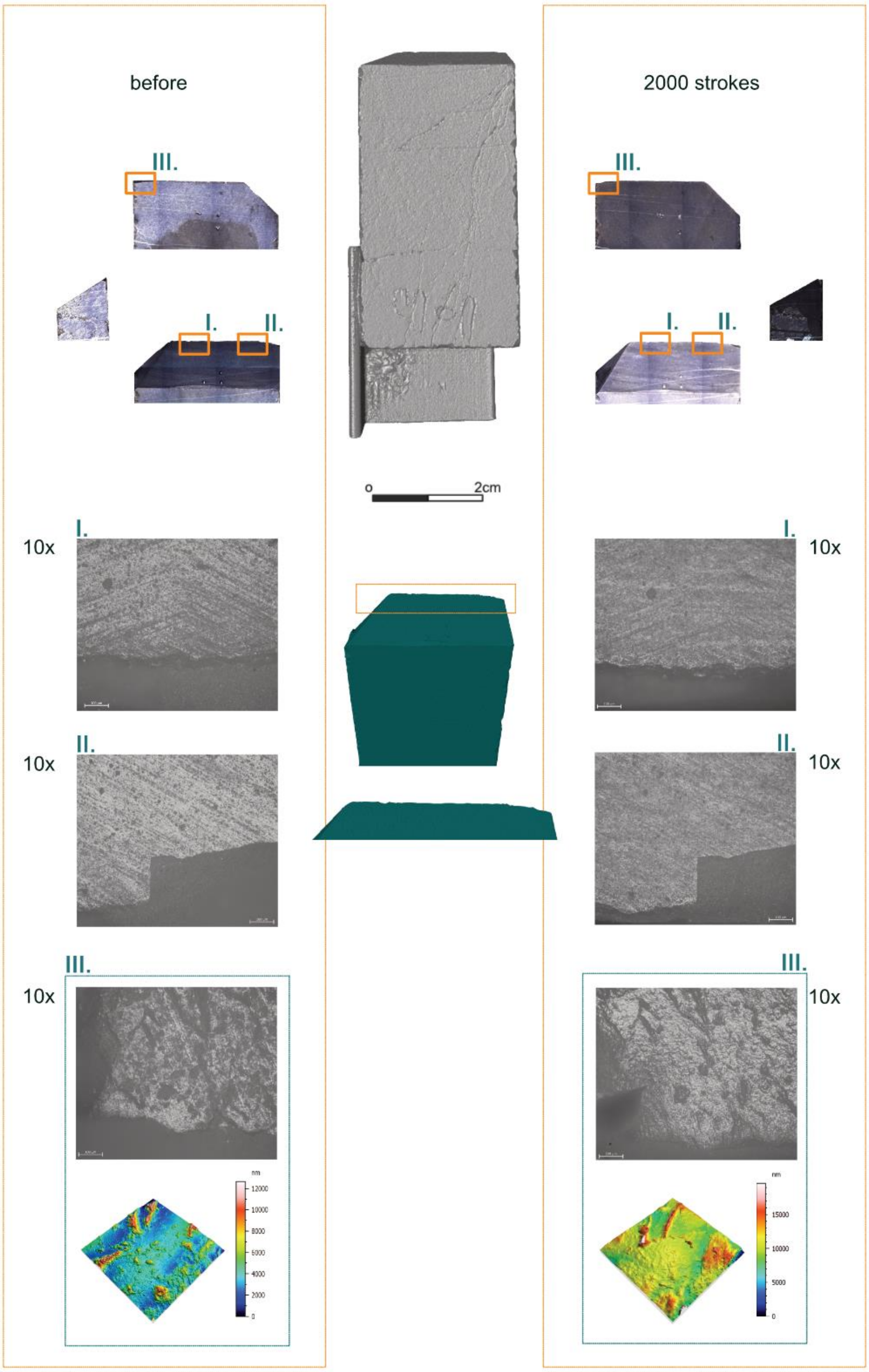


Fig. 5 'artificial VS. natural' experiment, lydite sample LYDIT4-1. The topmost image displays the sample in original size before and after 2000 strokes. The 3D model of the sample is shown in the middle (grey) and as a close-up of the edge (turquoise). The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x. The micro-surface displays the processed result of the confocal data acquisition with the 50x objective.

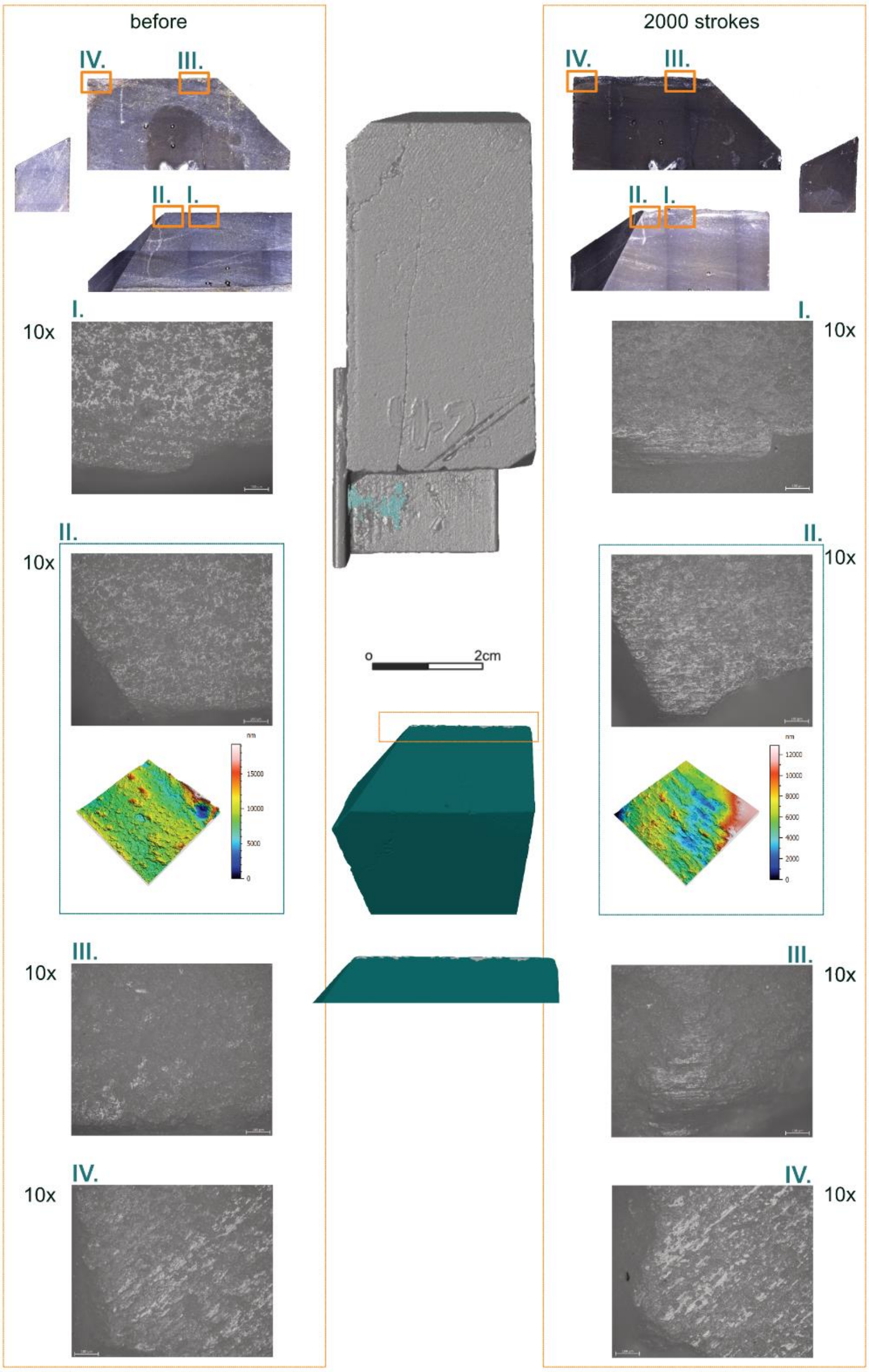


Fig. 6 ‘artificial VS. natural’ experiment, lydite sample LYDIT4-2. The topmost image displays the sample in original size before and after 2000 strokes. The 3D model of the sample is shown in the middle (grey) and as a close-up of the edge (turquoise). The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x. The micro-surface displays the processed result of the confocal data acquisition with the 50x objective.

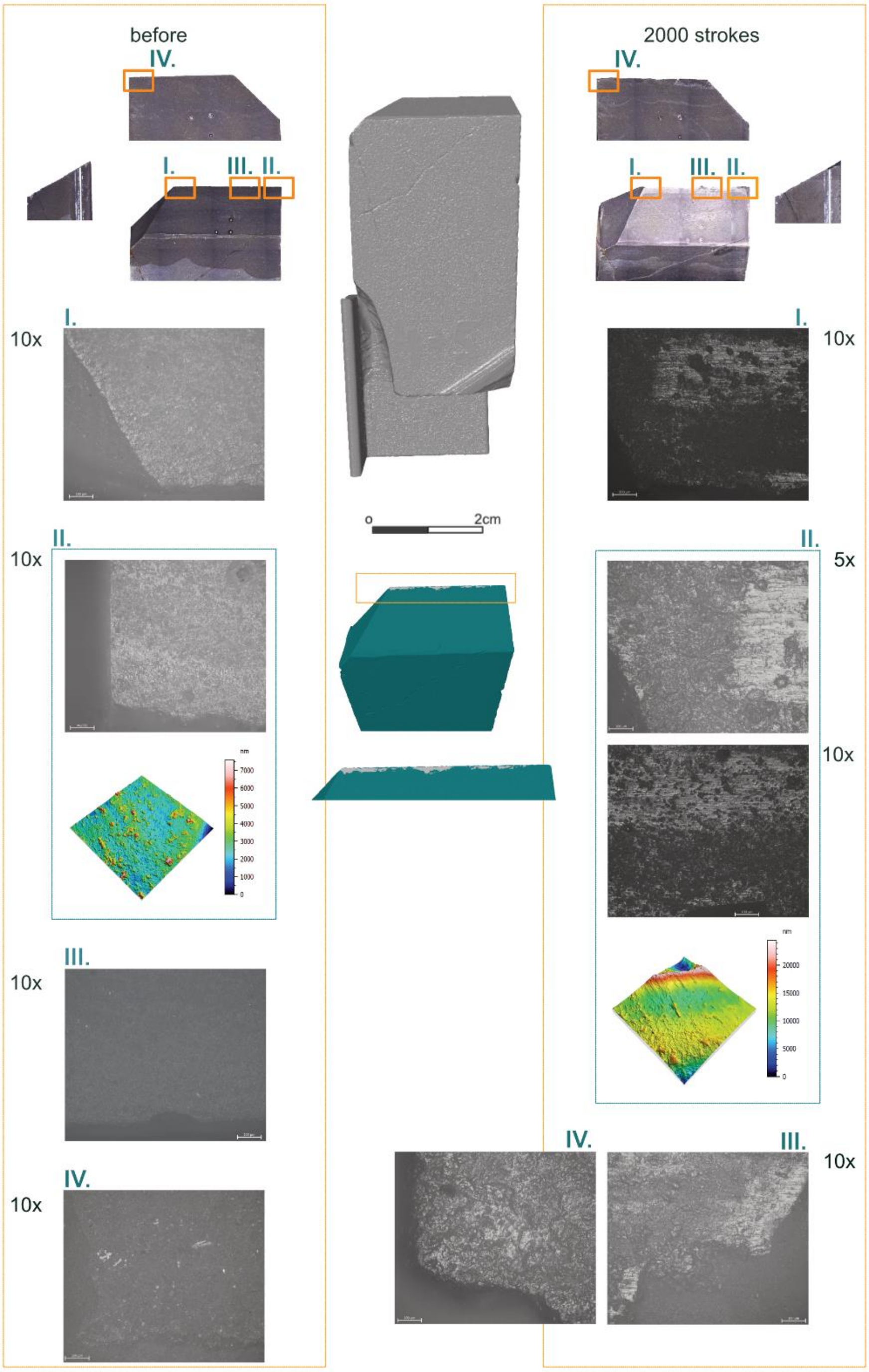


Fig. 7 'artificial VS. natural' experiment, lydite sample LYDIT4-5. The topmost image displays the sample in original size before and after 2000 strokes. The 3D model of the sample is shown in the middle (grey) and as a close-up of the edge (turquoise). The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 5x and 10x. The micro-surface displays the processed result of the confocal data acquisition with the 50x objective.

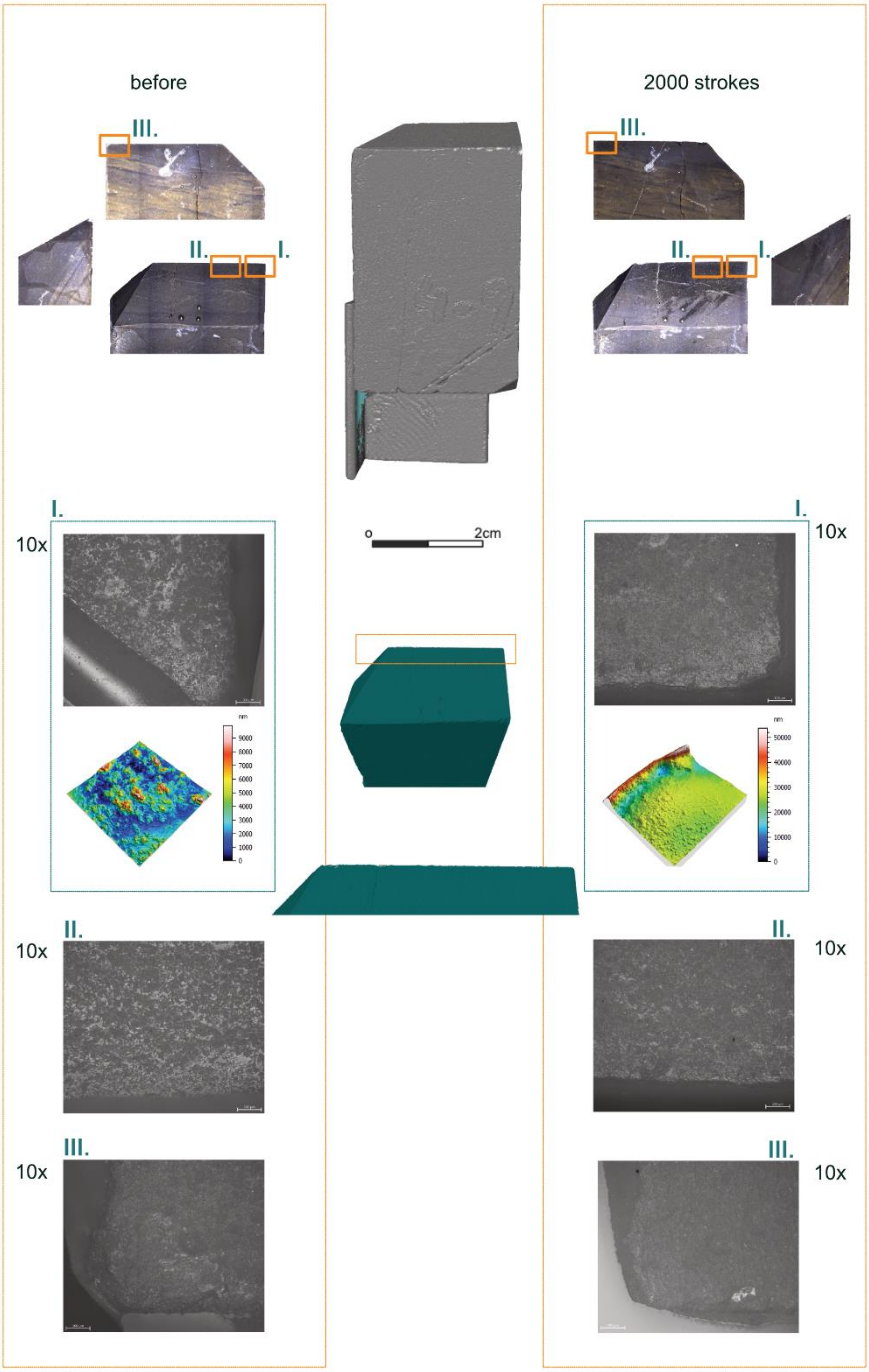


Fig. 8 'artificial VS. natural' experiment, lydite sample LYDIT4-9. The topmost image displays the sample in original size before and after 2000 strokes. The 3D model of the sample is shown in the middle (grey) and as a close-up of the edge (turquoise). The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x. The micro-surface displays the processed result of the confocal data acquisition with the 50x objective.

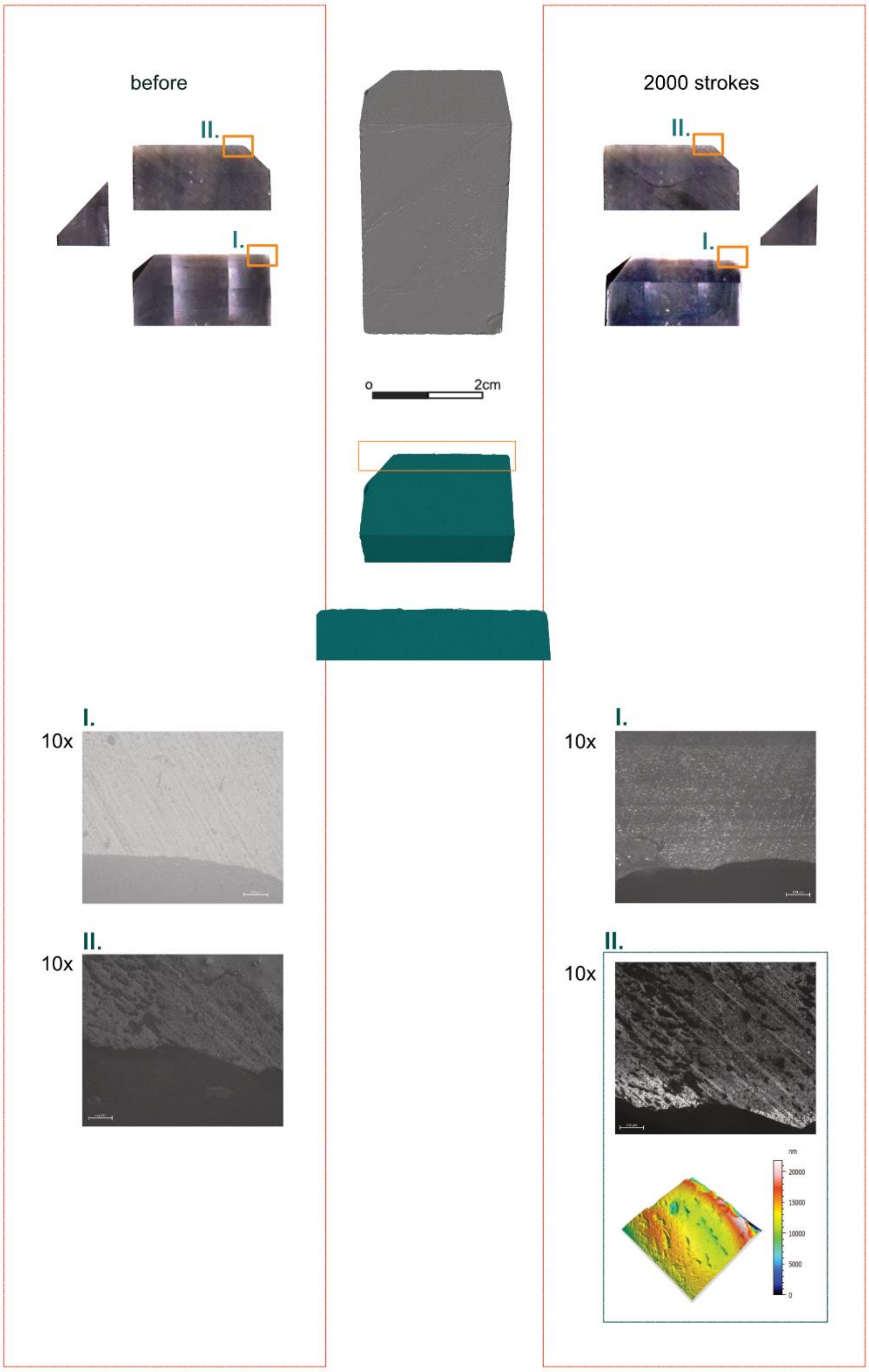


Fig. 9 Tool function experiment, flint sample FLT8-2. The topmost image displays the sample in original size before and after 2000 strokes. The 3D model of the sample is shown in the middle (grey) and as a close-up of the edge (turquoise). The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x. The micro-surface displays the processed result of the confocal data acquisition with the 50x objective.

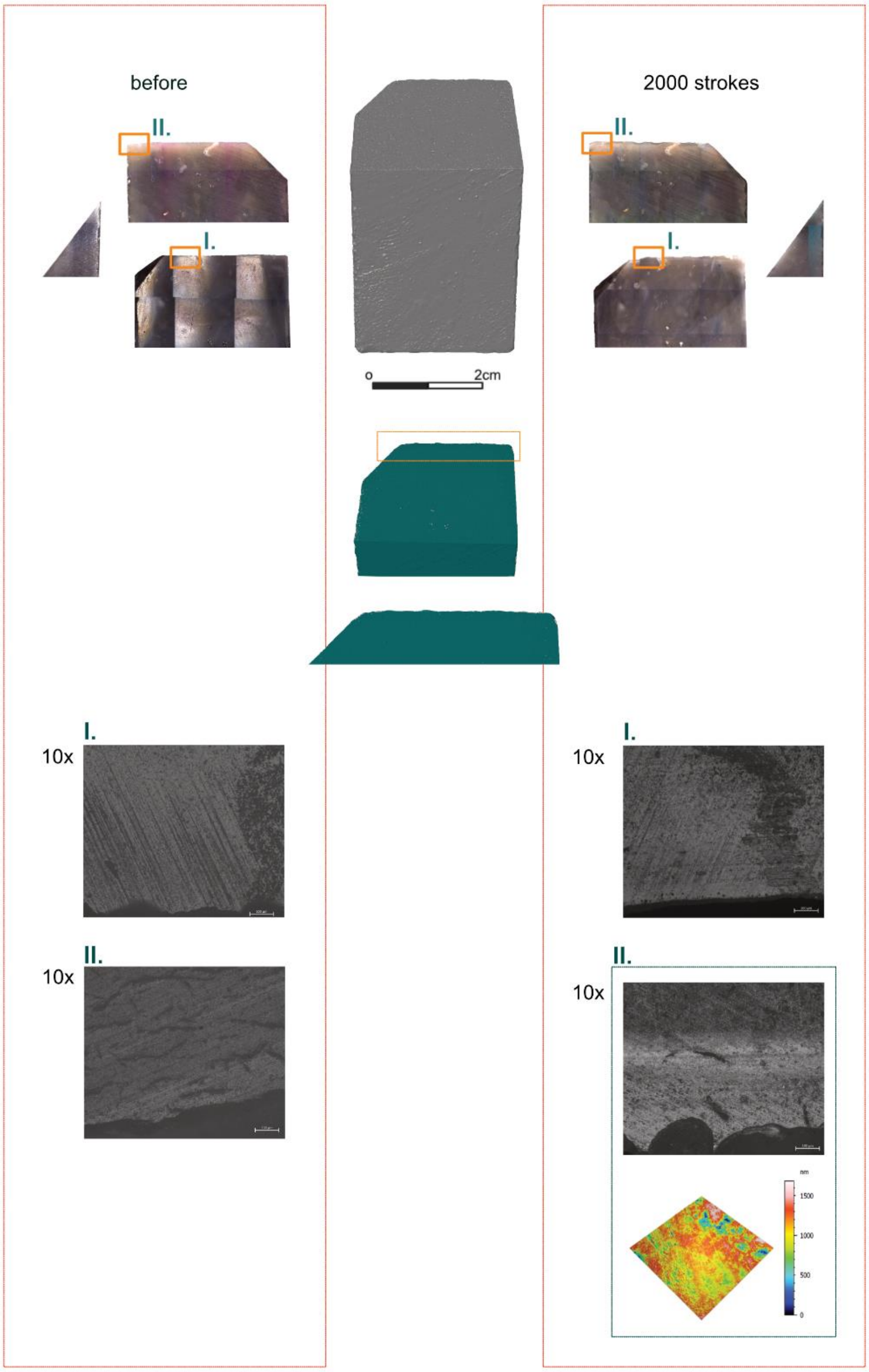


Fig. 10 Tool function experiment, flint sample FLT8-5. The topmost image displays the sample in original size before and after 2000 strokes. The 3D model of the sample is shown in the middle (grey) and as a close-up of the edge (turquoise). The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x. The micro-surface displays the processed result of the confocal data acquisition with the 50x objective.

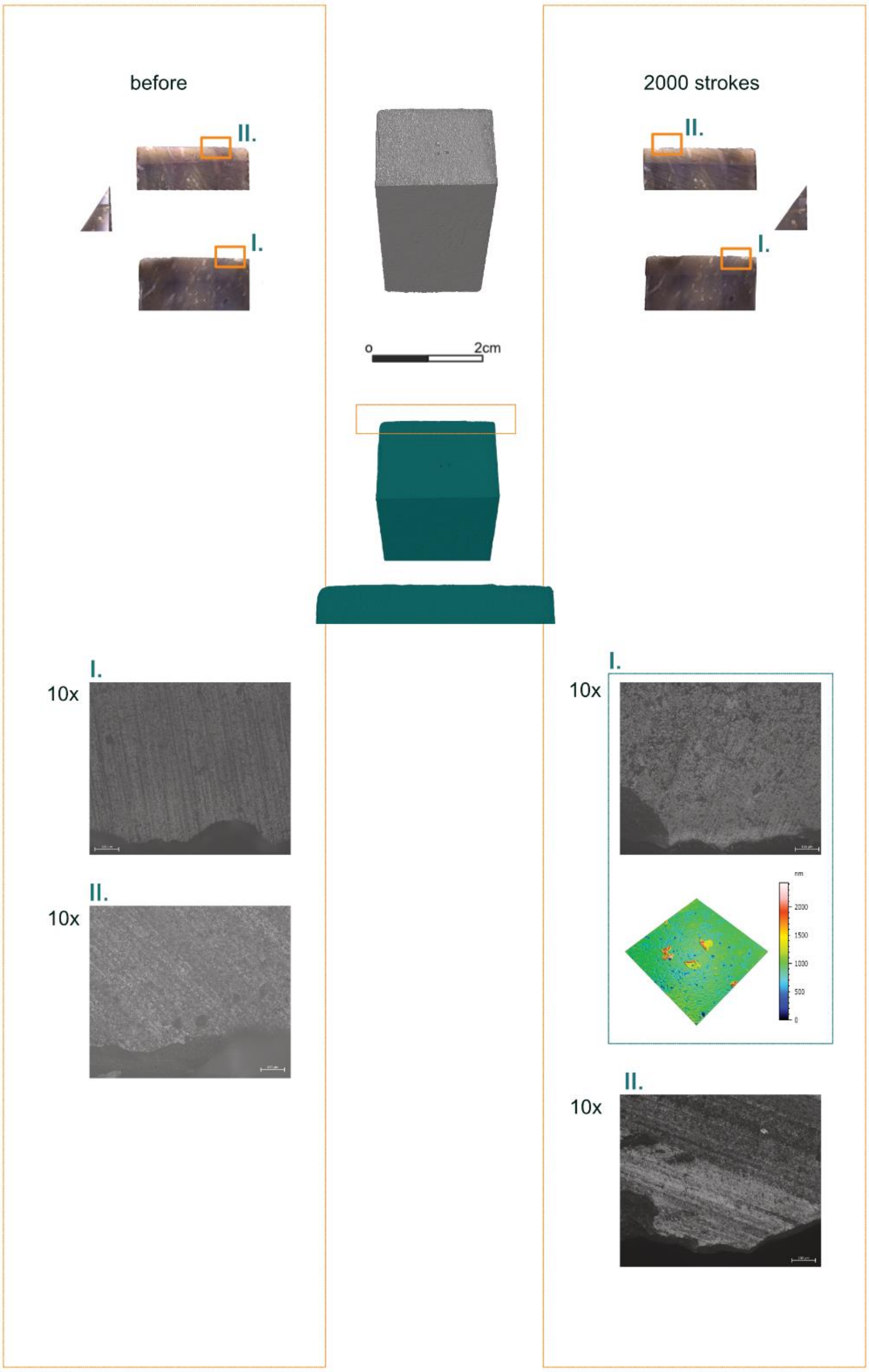


Fig. 11 Tool function experiment, flint sample FLT8-9. The topmost image displays the sample in original size before and after 2000 strokes. The 3D model of the sample is shown in the middle (grey) and as a close-up of the edge (turquoise). The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x. The micro-surface displays the processed result of the confocal data acquisition with the 50x objective.

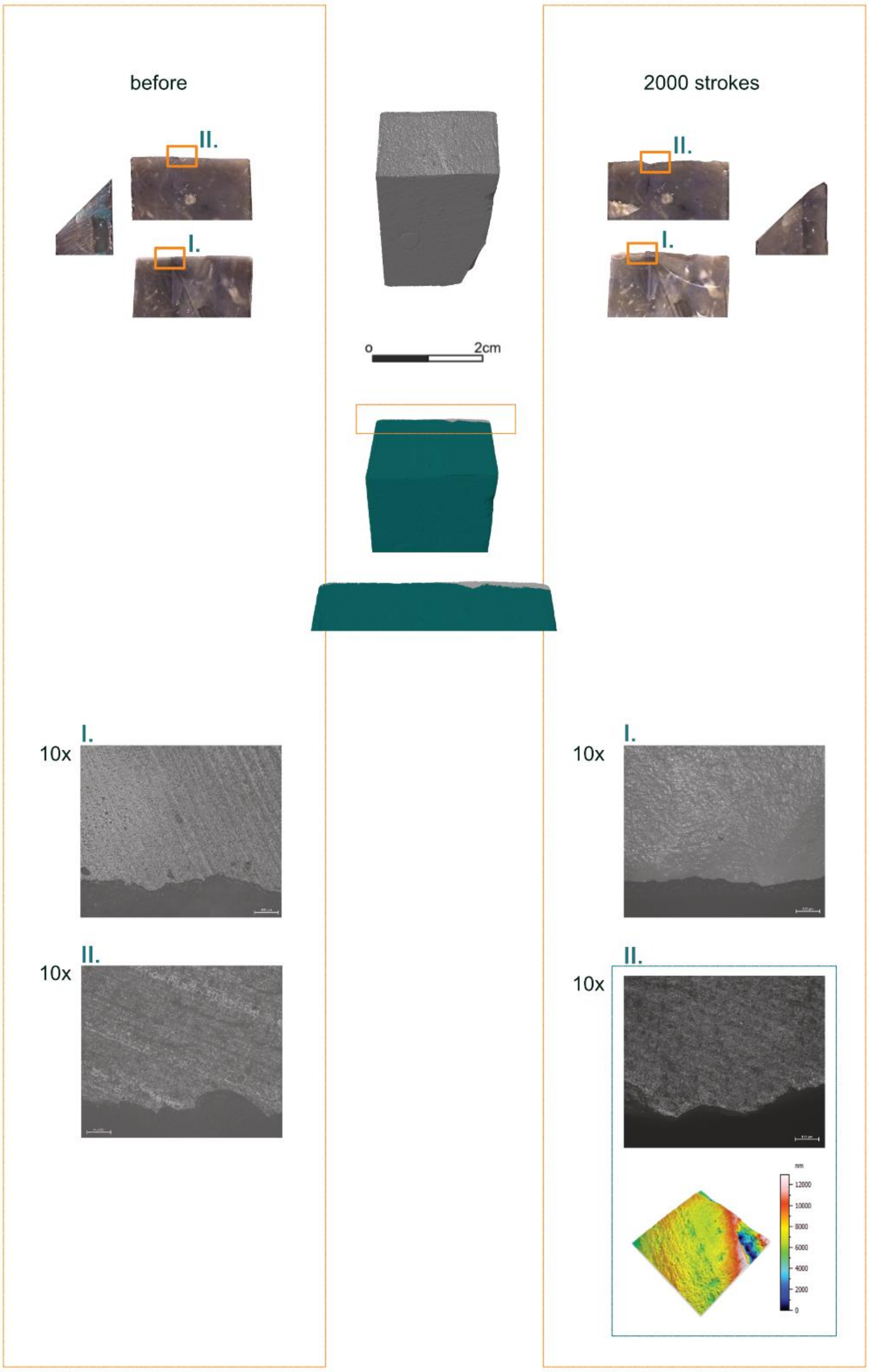


Fig. 12 Tool function experiment, flint sample FLT8-10. The topmost image displays the sample in original size before and after 2000 strokes. The 3D model of the sample is shown in the middle (grey) and as a close-up of the edge (turquoise). The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x. The micro-surface displays the processed result of the confocal data acquisition with the 50x objective.

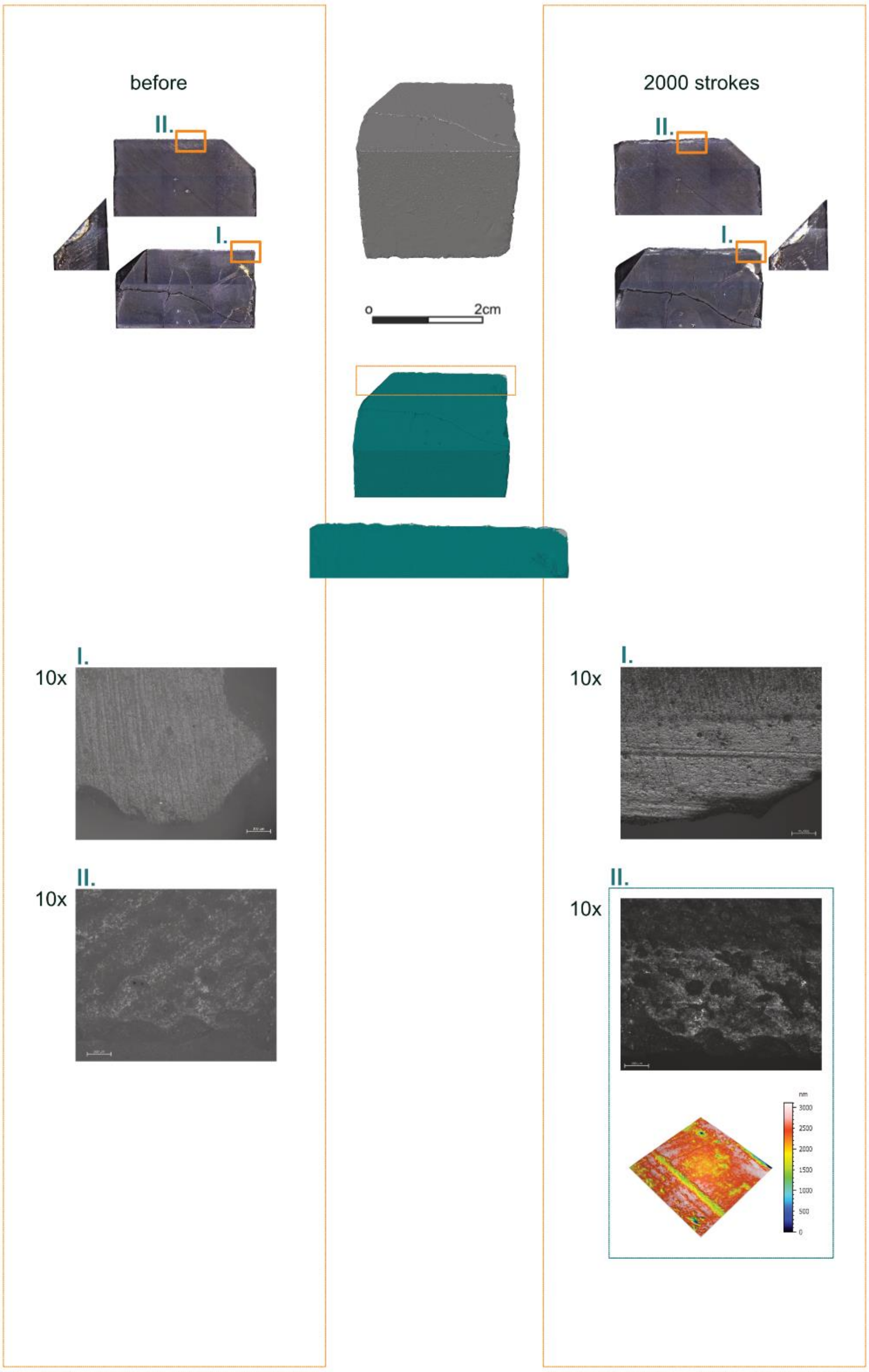


Fig. 13 Tool function experiment, lydite sample LYDIT5-2. The topmost image displays the sample in original size before and after 2000 strokes. The 3D model of the sample is shown in the middle (grey) and as a close-up of the edge (turquoise). The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x. The micro-surface displays the processed result of the confocal data acquisition with the 50x objective.

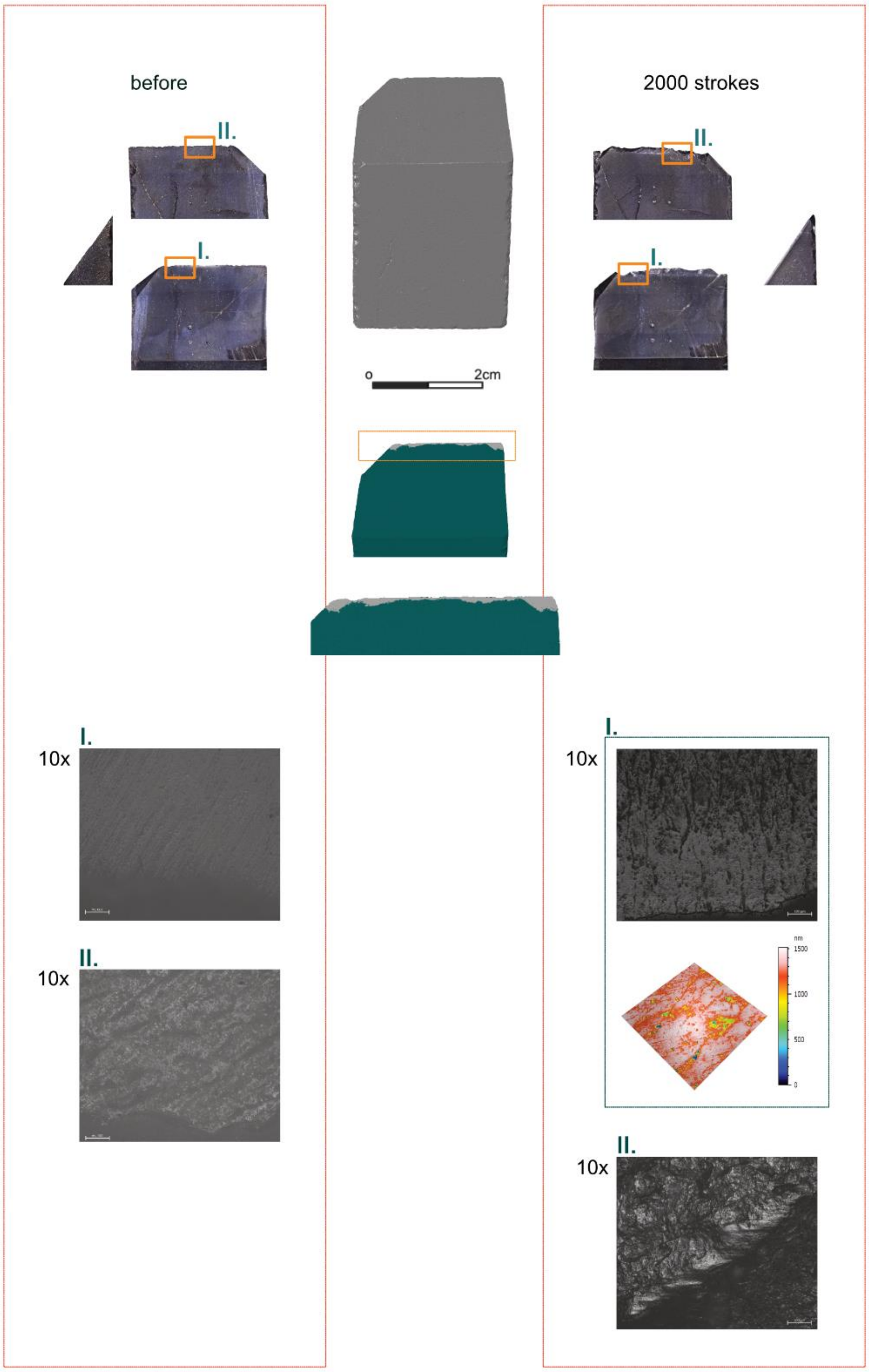


Fig. 14 Tool function experiment, lydite sample LYDIT5-7. The topmost image displays the sample in original size before and after 2000 strokes. The 3D model of the sample is shown in the middle (grey) and as a close-up of the edge (turquoise). The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x. The micro-surface displays the processed result of the confocal data acquisition with the 50x objective.

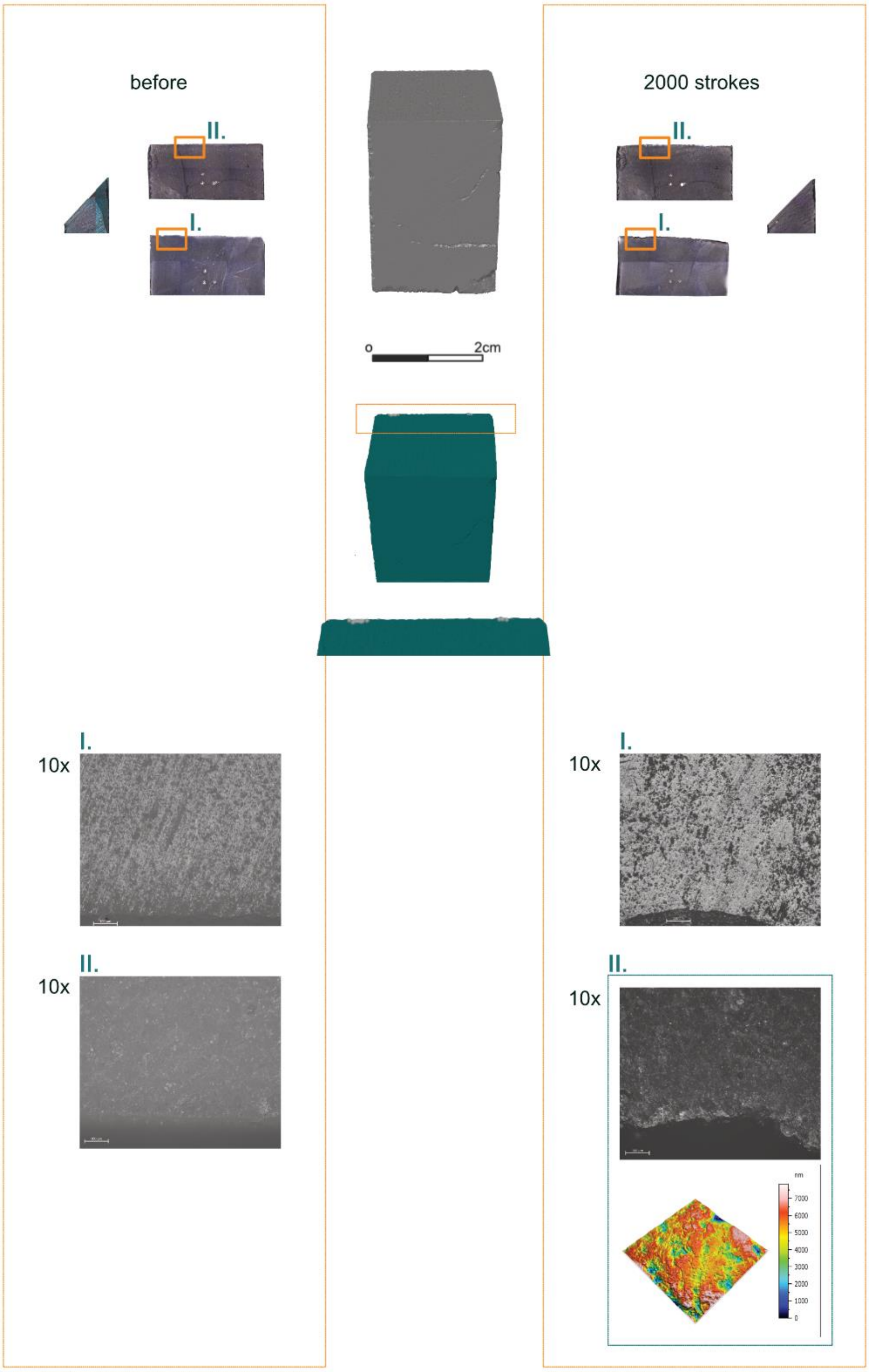


Fig. 15 Tool function experiment, lydite sample LYDIT5-8. The topmost image displays the sample in original size before and after 2000 strokes. The 3D model of the sample is shown in the middle (grey) and as a close-up of the edge (turquoise). The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x. The micro-surface displays the processed result of the confocal data acquisition with the 50x objective.

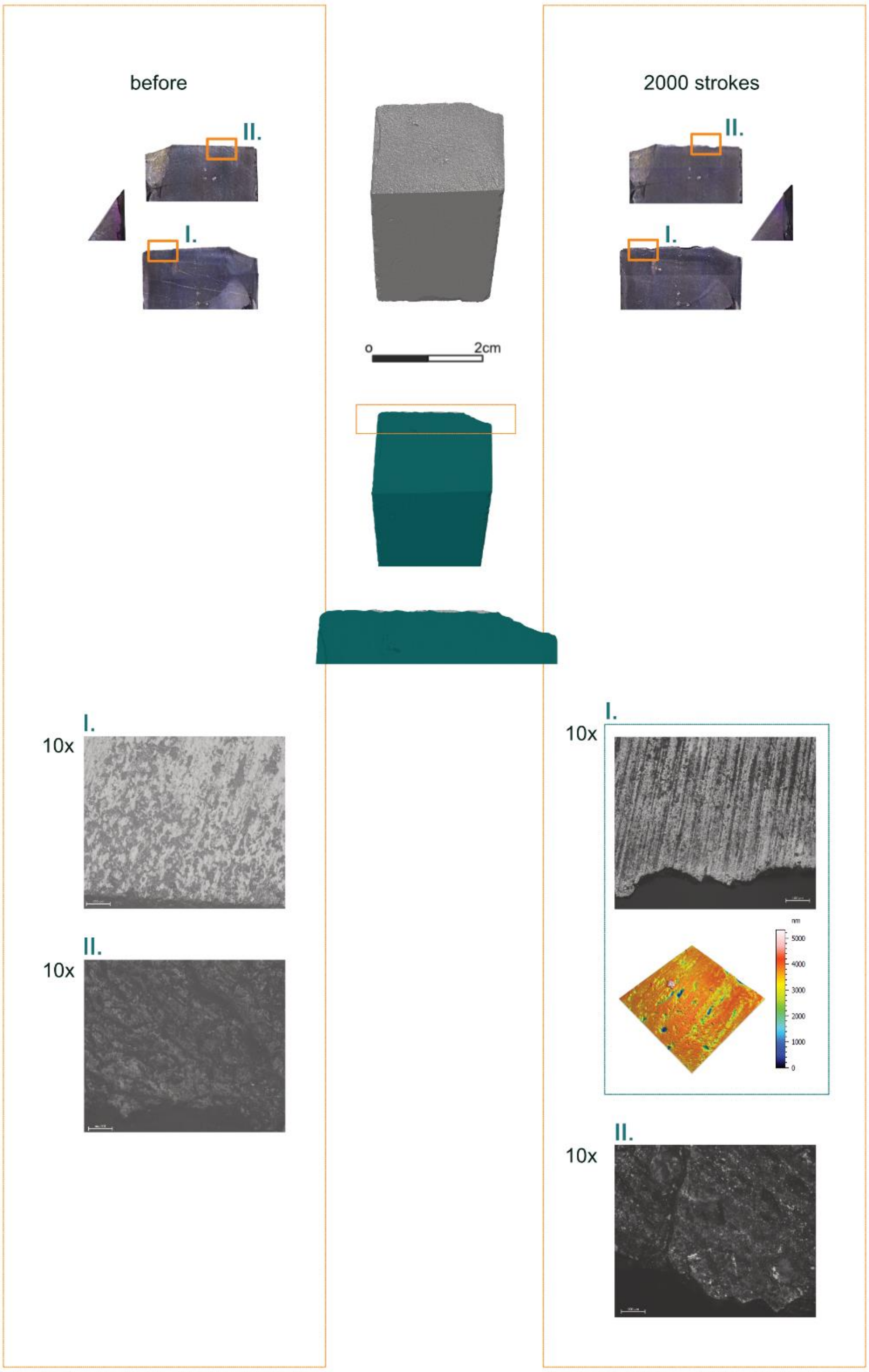


Fig. 16 Tool function experiment, lydite sample LYDIT5-12. The topmost image displays the sample in original size before and after 2000 strokes. The 3D model of the sample is shown in the middle (grey) and as a close-up of the edge (turquoise). The other illustrations are magnifications acquired with a 1.6x objective and a 34-x zoom. The use-wear traces are acquired at magnification of 10x. The micro-surface displays the processed result of the confocal data acquisition with the 50x objective.

Appendix V.

R Markdown scripts.

Techno-typological analysis: script to use in E4 to create a database

[E4]
Filename=techno-typological_DB.mdb
Sound=Yes
Delaytime=1
Table=tablename
BackColor=33023

[SITE NAME]
Type=Menu
Prompt=Enter the SITE NAME:
Menu=Balver_Höhle,Buhlen,Ramioul
Length=21

[ID]
Type=Text
Prompt=Enter the ARTEFACT ID:
Length=20

[LOAN]
Type=Menu
Prompt=Enter where the artefact is a LOAN of:
Menu= LWL-Musem_Herne,Sauerland-Museum_Arnsberg,LWL-Archäologie_Münster,Braunschweigisches_Landesmuseum,Ausstellung_Hessisches_Landesmuseum_Kassel,Depot_Hessisches_Landesmuseum_Kassel,Museum_Korbach,Prehistomuseum_Flémalle
Length=65

[EXCAVATION YEAR]
Type=Menu
Prompt=Select the EXCAVATION YEAR:
Menu= 1870s,1910th,1920s,1939,1952,1959,1960s,1978,undeterminable
Length=14

[ARTEFACT LABELING]
Type=Text
Prompt=Enter the ARTEFACT LABELING:
Length=20

[STRATIGRAPHY]
Type=Menu
Prompt=Is the artefact stratified?
Menu=YES,No,N/A
Length=3

[LEVEL]
Type=Text
Prompt=Enter the LEVEL:
Length=20
Condition1=STRATIGRAPHY YES

[ARTEFACT DRAWING]
Type=Menu
Prompt=Enter information about the ARTEFACT DRWAING:

Menu=YES_by_Bosinski,YES_by_Jöris,YES_by_Rutkowski,YES_by_unknown,NO,needed
Length=16

[RAW MATERIAL TYPE]
Type=Menu
Prompt=Select RAW MATERIAL TYPE:
Menu=baltic_flint,silicified_schist,other
Length=17

[TECHNOLOGICAL_CLASS]
Type=Menu
Prompt=Select the artefact TECHNOLOGICAL CLASS:
Menu=Keilmesser,Pradnik_scraper,Pradnik_spall,scraper,core,flake,handaxe,hammerstone,undeterminable
Length=24

[ARTEFACT STATE]
Type=Menu
Prompt=Select the ARTEFACT STATE:
Menu=complete,semifinished_product,proximal_fragment,distal_fragment,medial_fragment,Keilmesser_point
Length=20

[BLANK]
Type=Menu
Prompt=Select BLANK:
Menu=core,flake,undeterminable
Length=14

[MORPHOTYPE]
Type=Menu
Prompt=Select MORPHOTYPE:
Menu=Klausennische,Pradnik,Bockstein,Buhlen,Balve,Königsaue,Lichtenberg,undeterminable
Length=14
Condition1=TECHNOLOGICAL_CLASS Keilmesser Pradnik_scraper

[CORTEX]
Type=Menu
Prompt=Select if there is CORTEX:
Menu=YES,NO,N/A
Length=3

[CORTEX PERCENTAGE]
Type=Menu
Prompt=Select CORTEX PERCENTAGE:
Menu=<25,25-50,50-75,>75,TOTAL,N/A
Length=5
Condition1=CORTEX YES

[CORTEX LOCATION]
Type=Menu
Prompt=Select CORTEX LOCATION:
Menu=back,medial_ventral,medial_dorsa,proximal_ventral,proximal_dorsal,ventral_and_dorsal,total
Length=18
Condition1=CORTEX YES

[MORPHOLOGY BACK]

Type=Menu
Prompt=Select the MORPHOLOGY of the BACK:
Menu=cortex/unworked,cortex/partly_retouched,partly_retouched,retouched,clear_blunting,other,N/A
Length=23
Condition1=TECHNOLOGICAL_CLASS Keilmesser Pradnik_scraper

[RETOUCHED_ACTIVE_EDGE]
Type=Menu
Prompt=Select if the artefact is RETOUCHED along the ACTIVE EDGE:
Menu=YES,NO,N/A
Length=3

[RETOUCH TYPE ACTIVE EDGE]
Type=Menu
Prompt=Select the RETOUCH TYPE ACTIVE EDGE:
Menu=bifacial,semi-bifacial,unifacial,partly_retouched,unretouched,N/A
Length=16
Condition1=RETOUCHED_ACTIVE_EDGE YES

[TIP MORPHOLOGY]
Type=Menu
Prompt=Select TIP MORPHOLOGY:
Menu=pointed,rounded,broken,undeterminable
Length=14

[APPLICATION_PRADNIK_METHOD]
Type=Menu
Prompt=Select APPLICATION PRADNIK METHOD:
Menu=YES,NO,undeterminable
Length=14
Condition1=TECHNOLOGICAL_CLASS Keilmesser Pradnik_scraper

[FREQUENCY APPLICATION PRADNIK METHOD]
Type=Menu
Prompt=Select FREQUENCY APPLICATION PRADNIK METHOD:
Menu=one,multiple,N/A
Length=8
Condition1=APPLICATION_PRADNIK_METHOD YES

[TYPE LATERAL SHARPENING SPALL]
Type=Menu
Prompt=Select TYPE LATERAL SHARPENING SPALL:
Menu=primary,secondary,undeterminable
Length=14
Condition1=TECHNOLOGICAL_CLASS lateral_sharpening_spall

[TOOL LATERALISATION]
Type=Menu
Prompt=Select TOOL LATERALISATION:
Menu=dex.,sin.,undeterminable
Length=14
Condition1=TECHNOLOGICAL_CLASS Keilmesser Pradnik_scraper lateral_sharpening_spall

[LENGTH]
Type=Numeric

Prompt=Insert the artefact LENGTH mm:
Length=20

[WIDTH]
Type=Numeric
Prompt=Insert the artefact WIDTH mm:
Length=19

[THICKNESS]
Type=Numeric
Prompt=Insert the artefact THICKNESS mm:
Length=23

[WEIGHT]
Type=Numeric
Prompt=Insert the artefact WEIGHT kg:
Length=20

[PERIMETER BASIS+BACK]
Type=Numeric
Prompt=Iinsert PERIMETER BASIS+BACK mm:
Length=25

[PERIMETER DISTAL POSTERIOR PART]
Type=Numeric
Prompt=Insert PERIMETER DISTAL POSTERIOR PART mm:
Length=19

[PERIMETER ACTIVE EDGE]
Type=Numeric
Prompt=Insert PERIMETER ACTIVE EDGE mm:
Length=25

[PERIMETER TOTAL]
Type=Numeric
Prompt=Insert PERIMETER TOTAL mm:
Length=20

[THICKNESS BACK]
Type=Numeric
Prompt=Insert THICKNESS BACK mm:
Length=19

[TAPHONOMIC VISUAL INSPECTION]
Type=Menu
Prompt=Select TAPHONOMIC VISUAL INSPECTION:
Menu=Sharp_edges_and_preserved_surface, sharp_edges_and_patinated_surface, smoothed_edges_and_fresh_surfaces,smoothed_edges_and_patinated_surface,N/A
Length=36

[BURNED]
Type=Menu
Prompt=Select if the artefact is BURNED:
Menu=YES,NO,N/A
Length=3

[TOOL EDGES PRESERVATION]
Type=Menu
Prompt=Select TOOL EDGES PRESERVATION:
Menu=edges_preserved,edges_not_preserved,N/A
Length=19

[MACROSCOPICALLY_VISIBLE_USE-WEAR]
Type=Menu
Prompt=Select if there is MACROSCOPICALLY VISIBLE USE-WEAR:
Menu=YES,NO,N/A
Length=3

[DISTRIBUTION MACROSCOPICALLY VISIBLE USE-WEAR]
Type=Menu
Prompt=Select the DISTRIBUTION MACROSCOPICALLY VISIBLE USE-WEAR:
Menu=dorsal,ventral,both_sides,N/A
Length=10
Condition1=MACROSCOPICALLY_VISIBLE_USE-WEAR YES

[USE-WEAR ANALYSIS]
Type=Menu
Prompt=Select if USE-WAER ANALYSIS are needed:
Menu=YES,NO,N/A
Length=3

[3D-SCANNS]
Type=Menu
Prompt=Select if a 3D-SCANN is needed:
Menu=YES,NO,N/A
Length=3

[SCHISTOSITY]
Type=Menu
Prompt=Select if the SCHISTOSITY is recognisable:
Menu=YES,NO, N/A
Length=3

[ORIENTATION SCHISTOSITY]
Type=Menu
Prompt=Select how the SCHISTOSITY is orientated:
Menu=parallel_to_the_active_edge,contrary_to_the_active_edge,undeterminable
Length=27
Condition1=SCHISTOSITY YES

Equotip hardness measurements - 'Initial experiment'

Lisa Schunk

2021-02-14

Goal of the script

This script reads the xlsx file (measurements have been generated with the Equotip Leeb C rebound) and formats the data for a statistical analysis.
The script will:

1. Read in the original xlsx file and organise the data
2. Plot the data
3. Write an XLSX-file and save an R object ready for further analysis in R

```
dir_in <- "analysis/raw_data/"
dir_out <- "analysis/plots"
```

Raw data must be located in ~/analysis/raw_data/.
Formatted data will be saved in ~/analysis/plots. The knit directory for this script is the project directory.

Load packages

```
library(openxlsx)
Warning: package 'openxlsx' was built under R version 4.0.3
library(readr)
Warning: package 'readr' was built under R version 4.0.3
library(tools)
library(ggplot2)
Warning: package 'ggplot2' was built under R version 4.0.3
library(readxl)
library(tidyverse)
Warning: package 'tidyverse' was built under R version 4.0.3
Warning: package 'tibble' was built under R version 4.0.3
Warning: package 'dplyr' was built under R version 4.0.3
library(wesanderson)
```

Get name, path and information of the file

```
data_file <- list.files(dir_in, pattern = "\\.xlsx$", full.names = TRUE)
md5_in <- md5sum(data_file)
info_in <- data.frame(files = basename(names(md5_in)), checksum = md5_in,
                      row.names = NULL)
```

The checksum (MD5 hashes) of the imported files are:

```
                        files                         checksum
1 IE_hardness_flint+lydite.xlsx e1decfc698cd4cad8eec271bd012b5d5
```

Read in original xlsx-file

```
imp_data <- read.xlsx(xlsxFile = data_file, sheet = 1, startRow = 3,
                      colNames = TRUE,
                      rowNames = FALSE, skipEmptyRows = FALSE)
```

```
# changes the mode of 'hardness in HLC' from character to numeric
imp_data$hardness.in.HLC <- as.numeric(imp_data$hardness.in.HLC)
str(imp_data)
'data.frame':   36 obs. of  2 variables:
 $ raw.material   : chr  "flint" "flint" "flint" "flint" ...
 $ hardness.in.HLC: num  963 953 959 961 965 965 967 963 967 965 ...
flint <- imp_data[1:20,]
lydite <- imp_data[31:35,]
balve <- imp_data[36,]
```

Data analsysis - stats

```
# descriptive statistics
# flint
length(flint[["raw.material"]])
[1] 20
summary(flint[["hardness.in.HLC"]])
   Min. 1st Qu.  Median    Mean 3rd Qu.    Max. 
  953.0   960.8   963.0   962.2   965.2   969.0 
# lydite
length(lydite[["raw.material"]])
[1] 5
summary(lydite[["hardness.in.HLC"]])
   Min. 1st Qu.  Median    Mean 3rd Qu.    Max. 
  896.0   898.0   907.0   910.8   920.0   933.0 
# balve (MU-278)
length(balve[["raw.material"]])
[1] 1
summary(balve[["hardness.in.HLC"]])
   Min. 1st Qu.  Median    Mean 3rd Qu.    Max. 
    779     779     779     779     779     779 
```

Data analsysis - plot

```
# boxplot
data_plot <- ggplot (imp_data, aes(y = hardness.in.HLC, x = raw.material,
                                   fill = raw.material)) +
             theme_classic() +
             theme(legend.title = element_blank()) +
             geom_boxplot(fill = c("#ECCBAE", "#D69C4E", "#046C9A")) +
             geom_jitter() + labs(x="raw material",
                                  y="Leeb Rebound Hardness in HLC", title=" ")
```

Save data

Define output file name

```
file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "_IE_plot", ".pdf")
ggsave(filename = file_out, plot = data_plot, path = dir_out, device = "pdf")
```

The files will be saved as "~/analysis/plots.[ext]".

---

sessionInfo() and RStudio version

```
sessionInfo()
```

```
R version 4.0.2 (2020-06-22)
Platform: x86_64-w64-mingw32/x64 (64-bit)
Running under: Windows 10 x64 (build 19041)

Matrix products: default

locale:
[1] LC_COLLATE=German_Germany.1252  LC_CTYPE=German_Germany.1252
[3] LC_MONETARY=German_Germany.1252 LC_NUMERIC=C
[5] LC_TIME=German_Germany.1252

attached base packages:
[1] tools     stats     graphics  grDevices utils     datasets  methods
[8] base

other attached packages:
 [1] wesanderson_0.3.6 forcats_0.5.1     stringr_1.4.0     dplyr_1.0.3
 [5] purrr_0.3.4       tidyr_1.1.2       tibble_3.0.5      tidyverse_1.3.0
 [9] readxl_1.3.1      ggplot2_3.3.3     readr_1.4.0       openxlsx_4.2.3

loaded via a namespace (and not attached):
 [1] tidyselect_1.1.0  xfun_0.20         haven_2.3.1       colorspace_2.0-0
 [5] vctrs_0.3.6       generics_0.1.0    htmltools_0.5.1.1 yaml_2.2.1
 [9] rlang_0.4.10      pillar_1.4.7      glue_1.4.2        withr_2.4.1
[13] DBI_1.1.1         dbplyr_2.0.0      modelr_0.1.8      lifecycle_0.2.0
[17] munsell_0.5.0     gtable_0.3.0      cellranger_1.1.0  rvest_0.3.6
[21] zip_2.1.1         evaluate_0.14     labeling_0.4.2    knitr_1.31
[25] broom_0.7.4       Rcpp_1.0.6        scales_1.1.1      backports_1.2.0
[29] jsonlite_1.7.2    farver_2.0.3      fs_1.5.0          hms_1.0.0
[33] digest_0.6.27     stringi_1.5.3     grid_4.0.2        cli_2.3.0
[37] magrittr_2.0.1    crayon_1.4.0      pkgconfig_2.0.3   ellipsis_0.3.1
[41] xml2_1.3.2        reprex_1.0.0      lubridate_1.7.9.2 rstudioapi_0.13
[45] assertthat_0.2.1  rmarkdown_2.6     httr_1.4.2        R6_2.5.0
[49] compiler_4.0.2
```

RStudio version 1.3.1073.

END OF SCRIPT

Equotip hardness measurements - Tool function experiment

Lisa Schunk

2021-02-14

Goal of the script

This script reads the xlsx file (measurements have been generated with the Equotip Leeb C rebound) and formats the data for a statistical analysis.
The script will:

4. Read in the original xlsx file and organise the data
5. Plot the data
6. Write an XLSX-file and save an R object ready for further analysis in R

```
dir_in <- "analysis/raw_data_TFE/"
dir_out <- "analysis/plots"
```

Raw data must be located in ~/analysis/raw_data_TFE/.
Formatted data will be saved in ~/analysis/plots. The knit directory for this script is the project directory.

Load packages

```
library(openxlsx)
Warning: package 'openxlsx' was built under R version 4.0.3
library(tools)
library(readr)
Warning: package 'readr' was built under R version 4.0.3
library(ggplot2)
Warning: package 'ggplot2' was built under R version 4.0.3
library(readxl)
library(tidyverse)
Warning: package 'tidyverse' was built under R version 4.0.3
Warning: package 'tibble' was built under R version 4.0.3
Warning: package 'dplyr' was built under R version 4.0.3
library(wesanderson)
```

Get name, path and information of the file

```
data_file <- list.files(dir_in, pattern = "\\.xlsx$", full.names = TRUE)
md5_in <- md5sum(data_file)
info_in <- data.frame(files = basename(names(md5_in)), checksum = md5_in,
              row.names = NULL)
```

The checksum (MD5 hashes) of the imported files are:

```
            files                         checksum
1 TFE_hardness.xlsx 199e187160b2666842dcdfb6d26ee75a
```

Read in original xlsx-file

```
imp_data <- read.xlsx(xlsxFile = data_file, sheet = 1, startRow = 3, colNames = TRUE,
                  rowNames = FALSE, skipEmptyRows = FALSE)
```

```
# changes the mode of 'hardness in HLC from character to numeric
imp_data$hardness.in.HLC <- as.numeric(imp_data$hardness.in.HLC)
str(imp_data)
'data.frame':	53 obs. of  3 variables:
 $ raw.material   : chr  "flint " "flint " "flint " "flint " ...
 $ ID             : chr  "F1-1" "F1-2" "F1-3" "F1-4" ...
 $ hardness.in.HLC: num  962 957 947 944 965 ...
flint <- imp_data[1:11,]
lydite <- imp_data[15:52,]
balve <- imp_data[53,]
```

4. Data analsysis - stats

```
# descriptive statistics
# flint
length(flint[["ID"]])
[1] 11
summary(flint[["hardness.in.HLC"]])
   Min. 1st Qu.  Median    Mean 3rd Qu.    Max. 
  944.1   956.7   960.8   958.3   963.2   965.4 
# schist
length(lydite[["ID"]])
[1] 38
summary(lydite[["hardness.in.HLC"]])
   Min. 1st Qu.  Median    Mean 3rd Qu.    Max. 
  785.9   909.4   928.4   916.4   942.5   959.6 
# balve (MU-278)
length(balve[["ID"]])
[1] 1
summary(balve[["hardness.in.HLC"]])
   Min. 1st Qu.  Median    Mean 3rd Qu.    Max. 
    779     779     779     779     779     779 
```

Data analsysis - plot

```
# boxplot
data_plot <- ggplot (imp_data, aes(y = hardness.in.HLC, x = raw.material, 
                             fill = raw.material)) +
            theme_classic() +
            theme(legend.title = element_blank()) +
            geom_boxplot(fill = c("#ECCBAE", "#D69C4E", "#046C9A")) +
            geom_jitter() + labs(x="raw material", y="Leeb Rebound Hardness in HLC", title="")
```

Save data

Define output file name

```
file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "_TFE_plot", ".pdf")
ggsave(filename = file_out, plot = data_plot, path = dir_out, device = "pdf")
```

The files will be saved as "~/analysis/plots.[ext]".

---

sessionInfo() and RStudio version

```
sessionInfo()
R version 4.0.2 (2020-06-22)
Platform: x86_64-w64-mingw32/x64 (64-bit)
Running under: Windows 10 x64 (build 19041)
```

```
Matrix products: default

locale:
[1] LC_COLLATE=German_Germany.1252  LC_CTYPE=German_Germany.1252
[3] LC_MONETARY=German_Germany.1252 LC_NUMERIC=C
[5] LC_TIME=German_Germany.1252

attached base packages:
[1] tools     stats     graphics  grDevices utils     datasets  methods
[8] base

other attached packages:
 [1] wesanderson_0.3.6 forcats_0.5.1     stringr_1.4.0     dplyr_1.0.3
 [5] purrr_0.3.4       tidyr_1.1.2       tibble_3.0.5      tidyverse_1.3.0
 [9] readxl_1.3.1      ggplot2_3.3.3     readr_1.4.0       openxlsx_4.2.3

loaded via a namespace (and not attached):
 [1] tidyselect_1.1.0  xfun_0.20         haven_2.3.1       colorspace_2.0-0
 [5] vctrs_0.3.6       generics_0.1.0    htmltools_0.5.1.1 yaml_2.2.1
 [9] rlang_0.4.10      pillar_1.4.7      glue_1.4.2        withr_2.4.1
[13] DBI_1.1.1         dbplyr_2.0.0      modelr_0.1.8      lifecycle_0.2.0
[17] munsell_0.5.0     gtable_0.3.0      cellranger_1.1.0  rvest_0.3.6
[21] zip_2.1.1         evaluate_0.14     labeling_0.4.2    knitr_1.31
[25] broom_0.7.4       Rcpp_1.0.6        scales_1.1.1      backports_1.2.0
[29] jsonlite_1.7.2    farver_2.0.3      fs_1.5.0          hms_1.0.0
[33] digest_0.6.27     stringi_1.5.3     grid_4.0.2        cli_2.3.0
[37] magrittr_2.0.1    crayon_1.4.0      pkgconfig_2.0.3   ellipsis_0.3.1
[41] xml2_1.3.2        reprex_1.0.0      lubridate_1.7.9.2 rstudioapi_0.13
[45] assertthat_0.2.1  rmarkdown_2.6     httr_1.4.2        R6_2.5.0
[49] compiler_4.0.2
```

RStudio version 1.3.1073.

END OF SCRIPT

Import - Lithic analysis Buhlen

Lisa Schunk

2021-02-04

Goal of the script

This script reads the xlsx file (database techno-typological analysis) generated with E4 and formats the data for a statistical analysis.
The script will:

7. Reads in the original xlsx file
8. Changes and sort the data in order to do stats
9. Saves the data as a new xlsx file and R object

```
dir_in <-  "analysis/Buhlen/raw_data/"
dir_out <- "analysis/Buhlen/derived_data/"
```

Raw data must be located in "analysis/Buhlen/raw_data/".
Formatted data will be saved in "analysis/Buhlen/derived_data/". The knit directory for this script is the project directory.

Load packages

```
library(openxlsx)
Warning: package 'openxlsx' was built under R version 4.0.3
library(readxl)
library(R.utils)
library(tools)
library(data.table)
Warning: package 'data.table' was built under R version 4.0.3
library(chron)
library(dplyr)
Warning: package 'dplyr' was built under R version 4.0.3
```

Get name, path and information of the file

```
data_file <- list.files(dir_in, pattern = "\\.xlsx$", full.names = TRUE)
md5_in <- md5sum(data_file)
info_in <- data.frame(files = basename(names(md5_in)), checksum = md5_in,
                      row.names = NULL)
```

The checksum (MD5 hashes) of the imported files are:

```
        files                         checksum
1 Buhlen.xlsx 033dbad42d8f4bf646179adc12b13919
```

Read in original xlsx-file

```
imp_data <- read.xlsx(xlsxFile = data_file, sheet = 1, startRow = 1, colNames = TRUE,
                      rowNames = FALSE, skipEmptyRows = FALSE)
#select the columns to keep
keep_col <- c(1:2, 9:19, 21:35, 37:38, 40:43)
```

```
data_final <- imp_data[,keep_col]

data_final$length <- as.numeric(data_final$length)
data_final$width <- as.numeric(data_final$width)
data_final$thickness <- as.numeric(data_final$thickness)
data_final$weight <- as.numeric(data_final$weight)
data_final$perimeter.basis.back <- as.numeric(data_final$perimeter.basis.back)
data_final$perimeter.arch <- as.numeric(data_final$perimeter.arch)
Error in `$<-.data.frame`(`*tmp*`, perimeter.arch, value = numeric(0)): replacement has 0 rows, data has 199
data_final$perimeter.active.edge <- as.numeric(data_final$perimeter.active.edge)
data_final$perimeter.total <- as.numeric(data_final$perimeter.total)
data_final$thickness.back <- as.numeric(data_final$thickness.back)

str(data_final)
'data.frame':   199 obs. of  34 variables:
 $ site                               : chr  "Buhlen" "Buhlen" "Buhlen" "Buhlen" ...
 $ ID                                 : chr  "BU-002" "BU-003" "BU-004" "BU-005" ...
 $ raw.material                       : chr  "silicified_schist" "silicified_schist" "silicified_schist" "silicified_schist" ...
 $ technological.class                : chr  "Keilmesser" "Keilmesser" "Keilmesser" "Keilmesser" ...
 $ artefact.state                     : chr  "complete" "complete" "complete" "complete" ...
 $ blank                              : chr  "core" "core" "core" "core" ...
 $ morpho.type                        : chr  "Bockstein" "Buhlen" "Pradnik" "Balve" ...
 $ cortex                             : chr  "YES" "YES" "YES" "YES" ...
 $ cortex.percentage                  : chr  "25-50" "<25" "<25" "50-75" ...
 $ cortex.location                    : chr  "back" "base" "back" "ventral_and_dorsal" ...
 $ morphology.back                    : chr  "cortex/unworked" "cortex/partly_retouched" "cortex/unworked"
"cortex/unworked" ...
 $ retouch.active.edge                : chr  "YES" "YES" "YES" "YES" ...
 $ retouch.type.edge                  : chr  "bifacial" "bifacial" "bifacial" "bifacial" ...
 $ tip.morphology                     : chr  "rounded" "rounded" "rounded" "pointed" ...
 $ application.Pradnik.method         : chr  "NO" "YES" "YES" "NO" ...
 $ frequency.application.Pradnik.method: chr  NA "one" "one" NA ...
 $ type.lateral.sharpening.spall      : chr  NA NA NA NA ...
 $ tool.lateralisation                : chr  "dex." "dex." "dex." "dex." ...
 $ length                             : num  48 58 56.3 69 53.7 ...
 $ width                              : num  35 31 38.8 46 36.2 ...
 $ thickness                          : num  14 18 16 14 17 18 19 31 13 12 ...
 $ weight                             : num  0.0259 0.0337 0.0391 0.0561 0.0367 0.0258 0.0387 0.0733 0.0224 0.0204 ...
 $ perimeter.basis.back               : num  8.4 8.2 7.5 8.4 8.2 7.6 7.7 9.4 8.1 8.8 ...
 $ perimeter.distal.posterior.part    : num  0 1.6 2.1 2.2 1 1.5 3.9 2.5 2.4 1 ...
 $ perimeter.active.edge              : num  5.6 4.7 6.5 8.2 4.4 4.2 5.7 7 5.1 4.7 ...
 $ perimeter.total                    : num  0 11 0 0 0 0 0 0 0 0 ...
 $ thickness.back                     : num  14 11 14 12 17.3 ...
 $ taphonomic.visual.inspection       : chr  "Sharp_edges_and_preserved_surface" "Sharp_edges_and_preserved_surface"
"Sharp_edges_and_preserved_surface" "Sharp_edges_and_preserved_surface" ...
 $ tool.edges.preservation            : chr  "edges_preserved" "edges_preserved" "edges_preserved" "edges_preserved" ...
 $ macroscopically.visible.use-wear   : chr  "NO" "NO" "NO" "NO" ...
 $ use-wear.analysis                  : chr  "NO" "YES" "YES" "NO" ...
 $ 3D-scan                            : chr  "YES" "YES" "YES" "YES" ...
 $ schistosity                        : chr  "N/A" "NO" "NO" "YES" ...
 $ orientation.schistosity            : chr  NA NA NA "parallel_to_the_active_edge" ...
```

Data analsysis - sorting

Dimension

```
# keeps only columns relevant for dimensions and sorts them based on
# their technological class
keep_col <- c(1:2, 4:5,19:21)
dimensions <- data_final[, keep_col] %>% arrange(technological.class)
```

```r
KM_dimensions <- dimensions[2:131, ] %>% arrange(artefact.state)
KM.point_dimensions <- KM_dimensions[113:127, ]
KM.only_dimensions <- KM_dimensions[-(113:127), ]
KM.complete_dimensions <- KM_dimensions[1:111, ]
PS_dimensions <- dimensions[174:197, ] %>% arrange(artefact.state)
LSS_dimensions <- dimensions[132:173, ] %>% arrange(artefact.state)
S_dimensions <- dimensions[198:199, ] %>% arrange(artefact.state)
```

Perimeter

```r
# keeps only columns relevant for perimeter measurements and sorts them
# based on their technological class
keep_col <- c(1:2, 4:5,7,23:26)
perimeter <- data_final[, keep_col] %>% arrange(technological.class)

KM_perimeter <- perimeter[2:131, ] %>% arrange(artefact.state)
PS_perimeter <- perimeter[174:197, ] %>% arrange(artefact.state)
```

Weight

```r
# keeps only columns relevant for weight measurements and sorts them based
# on their technological class
keep_col <- c(1:2, 4:5, 22)
weight <- data_final[, keep_col] %>% arrange(technological.class)

KM_weight <- weight[2:131, ] %>% arrange(artefact.state)
PS_weight <- weight[174:197, ] %>% arrange(artefact.state)
LSS_weight <- weight[132:173, ] %>% arrange(artefact.state)
S_weight <- weight[198:199, ] %>% arrange(artefact.state)
```

Raw material

```r
# keeps only columns relevant for raw material classification and sorts them
# based on their technological class
keep_col <- c(1:2, 4:5, 3)
raw_material <- data_final[, keep_col] %>% arrange(technological.class)

KM_raw_material <- raw_material[2:131, ] %>% arrange(artefact.state)
PS_raw_material <- raw_material[174:197, ] %>% arrange(artefact.state)
LSS_raw_material <- raw_material[132:173, ] %>% arrange(artefact.state)
S_raw_material <- raw_material[198:199, ] %>% arrange(artefact.state)
```

Cortex + blanks

```r
# keeps only columns relevant for cortex and blank classification and sorts them
# based on their technological class
keep_col <- c(1:2, 4:5, 6, 8:10)
cortex_blanks <- data_final[, keep_col] %>% arrange(technological.class)

KM_cortex_blanks <- cortex_blanks[2:131, ] %>% arrange(artefact.state)
PS_cortex_blanks <- cortex_blanks[174:197, ] %>% arrange(artefact.state)
```

Back

```r
# keeps only columns relevant for back modifications and sorts them based
# on their technological class
keep_col <- c(1:2, 4:5, 11, 27)
back <- data_final[, keep_col] %>% arrange(technological.class)

KM_back <- back[2:131, ] %>% arrange(artefact.state)
PS_back <- back[174:197, ] %>% arrange(artefact.state)
```

Edge retouch

```
# keeps only columns relevant for edge retouch classification and sorts them
# based on their technological class
keep_col <- c(1:2, 4:5, 12:13, 29)
edge_retouch <- data_final[, keep_col] %>% arrange(technological.class)

KM_edge_retouch <- edge_retouch[2:131, ] %>% arrange(artefact.state)
PS_edge_retouch <- edge_retouch[174:197, ] %>% arrange(artefact.state)
LSS_edge_retouch <- edge_retouch[132:173, ] %>% arrange(artefact.state)
S_edge_retouch <- edge_retouch[198:199, ] %>% arrange(artefact.state)
```

Morpho type

```
# keeps only columns relevant for morpho type classification and sorts them
# based on their technological class
keep_col <- c(1:2, 4:5, 7, 19:21)
morpho.type <- data_final[, keep_col] %>% arrange(technological.class)

KM_morpho.type <- morpho.type[2:131, ] %>% arrange(artefact.state)
PS_morpho.type <- morpho.type[174:197, ] %>% arrange(artefact.state)
```

Application 'Pradnik method'

```
# keeps only columns relevant for 'morpho type 'Pradnik method' classification
# and sorts them based on their technological class
keep_col <- c(1:2, 4:5, 15:16)
Pradnik.method <- data_final[, keep_col] %>% arrange(technological.class)

KM_Pradnik.method <- Pradnik.method[2:131, ] %>% arrange(artefact.state)
PS_Pradnik.method <- Pradnik.method[174:197, ] %>% arrange(artefact.state)
```

Lateralisation

```
# keeps only columns relevant for lateralisation and sorts them based on their
# technological class
keep_col <- c(1:2, 4:5, 18)
lateralisation <- data_final[, keep_col] %>% arrange(technological.class)

KM_lateralisation <- lateralisation[2:131, ] %>% arrange(artefact.state)
PS_lateralisation <- lateralisation[174:197, ] %>% arrange(artefact.state)
```

Type lateral sharpening spall

```
# keeps only columns relevant for lateral sharpening spall classification and sorts
# them based on their technological class
keep_col <- c(1:2, 4:5, 17:18)
lss_type <- data_final[, keep_col] %>% arrange(technological.class)

LSS_type <- lss_type[132:173, ] %>% arrange(artefact.state)
```

Save data

Format name of output file

```
file_out <- "Buhlen_lithic_analysis"
```

The files will be saved as "~/Buhlen_lithic_analysis.[ext]".

Write to XLSX

```
write.xlsx(list(data = data_final, dimensions = dimensions, KM_dimensions = KM_dimensions,
           KM.point_dimensions =
           KM.point_dimensions, KM.only_dimensions = KM.only_dimensions,
```

```
        KM.complete_dimensions = KM.complete_dimensions, PS_dimensions =
        PS_dimensions, LSS_dimensions = LSS_dimensions, S_dimensions =
        S_dimensions, KM_perimeter = KM_perimeter, PS_perimeter = PS_perimeter,
        KM_weight = KM_weight, PS_weight = PS_weight,LSS_weight = LSS_weight,
        S_weight = S_weight, KM_raw_material = KM_raw_material,PS_raw_material =
        PS_raw_material, LSS_raw_material = LSS_raw_material, S_raw_material =
        S_raw_material, KM_cortex_blanks = KM_cortex_blanks, PS_cortex_blanks =
        PS_cortex_blanks, KM_back = KM_back, PS_back = PS_back, KM_edge_retouch
        = KM_edge_retouch, PS_edge_retouch = PS_edge_retouch, LSS_edge_retouch =
        LSS_edge_retouch, S_edge_retouch = S_edge_retouch, KM_morpho.type =
        KM_morpho.type, PS_morpho.type = PS_morpho.type, KM_Pradnik.method =
        KM_Pradnik.method, PS_Pradnik.method = PS_Pradnik.method,
        KM_lateralisation = KM_lateralisation, PS_lateralisation =
        PS_lateralisation, LSS_type = LSS_type),
        file = paste0(dir_out, file_out, ".xlsx"))
```

Save R object

```
saveObject(data_final, file = paste0(dir_out, file_out, ".Rbin"))
```

RStudio version 1.3.1056.

END OF SCRIPT

Summary stats - Lithic analysis Buhlen

Lisa Schunk

2021-02-04

Goal of the script

This script computes standard descriptive statistics for each group.
The groups are based on:

10. Tool type
11. state of the tool (Complete, distal/proximal fragment, medial fragment)

It computes the following statistics:

12. n (sample size = length): number of measurements
13. smallest value (min)
14. largest value (max)
15. mean
16. median
17. standard deviation (sd)

```
dir_in <- "analysis/Buhlen/derived_data/"
dir_out <- "analysis/Buhlen/summary_stats/"
```

Raw data must be located in ~/analysis/Buhlen/derived_data/.
Formatted data will be saved in ~/analysis/Buhlen/summary_stats/. The knit directory for this script is the project directory.

Load packages

```
library(openxlsx)
Warning: package 'openxlsx' was built under R version 4.0.3
library(R.utils)
library(tools)
library(doBy)
Warning: package 'doBy' was built under R version 4.0.3
```

Get names, path and information of the file

```
data_file <- list.files(dir_in, pattern = "\\.xlsx$", full.names = TRUE)
md5_in <- md5sum(data_file)
info_in <- data.frame(file = basename(names(md5_in)), checksum = md5_in, row.names = NULL)
```

The checksum (MD5 hashes) of the imported file is

```
                      file                         checksum
1 Buhlen_lithic_analysis.xlsx 0347f13eabf7deb6596b8931034a771e
```

Load data into R object

```
imp_data <- loadObject(paste0(dir_in, "Buhlen_lithic_analysis.Rbin"))
```

The imported file is: "~/analysis/Buhlen/derived_data/Buhlen_lithic_analysis.xlsx"

Define numeric variables

```
# changes the order of columns
imp_data <- imp_data[c(1:22, 27,23:26, 28:34)]
num.var <-19:23
```

The following variables will be used:

```
[19] length
[20] width
[21] thickness
[22] weight
[23] thickness.back
```

Compute summary statistics

Create function to compute the statistics at once

```
nminmaxmeanmedsd <- function(x){
    y <- x[!is.na(x)]
    n_test <- length(y)
    min_test <- min(y)
    max_test <- max(y)
    mean_test <- mean(y)
    med_test <- median(y)
    sd_test <- sd(y)
    out <- c(n_test, min_test, max_test, mean_test, med_test, sd_test)
    names(out) <- c("n", "min", "max", "mean", "median", "sd")
    return(out)
}
```

Compute the summary statistics

Dimensions

```
# Dimensions Keilmesser, Keilmesser-points, Pradnik scraper, scraper & Later sharpening spall
dimensions <- summaryBy(length + width + thickness ~ technological.class + artefact.state,
                data = imp_data, FUN = nminmaxmeanmedsd)
str(dimensions)
'data.frame':   11 obs. of  20 variables:
 $ technological.class: chr  "hammerstone" "Keilmesser" "Keilmesser" "Keilmesser" ...
 $ artefact.state     : chr  "complete" "complete" "distal_fragment" "Keilmesser_tip" ...
 $ length.n           : num  1 111 1 15 2 1 36 3 3 24 ...
 $ length.min         : num  90 30 22 13 25 82.6 21 35 26 27 ...
 $ length.max         : num  90 114 22 46 54 ...
 $ length.mean        : num  90 53 22 28.1 39.5 ...
 $ length.median      : num  90 50 22 28 39.5 ...
 $ length.sd          : num  NA 15.56 NA 8.65 20.51 ...
 $ width.n            : num  1 111 1 15 2 1 36 3 3 24 ...
 $ width.min          : num  62 14 44 19 38 ...
 $ width.max          : num  62 71.9 44 42 54 ...
 $ width.mean         : num  62 32.9 44 30 46 ...
 $ width.median       : num  62 32 44 30 46 ...
 $ width.sd           : num  NA 8.57 NA 6.63 11.31 ...
```

```
 $ thickness.n        : num  1 111 1 15 2 1 36 3 3 24 ...
 $ thickness.min      : num  52 7 12 8 10 ...
 $ thickness.max      : num  52 31 12 20 26 ...
 $ thickness.mean     : num  52 16.1 12 12.6 18 ...
 $ thickness.median   : num  52 15 12 13 18 ...
 $ thickness.sd       : num  NA 4.56 NA 3.18 11.31 ...
```

Save data

Format name of output file

```
file_out <- "Buhlen_lithic_analysis_stats"
```

The file will be saved as "~/analysis/Buhlen/summary_stats/.[ext]".

Write to XLSX

```
write.xlsx(list(dimensions = dimensions),
           file = paste0(dir_out, file_out, ".xlsx"))
```

Save R object

```
saveObject(list(dimensions = dimensions),
           file = paste0(dir_out, file_out, ".Rbin"))
```

–

sessionInfo() and RStudio version

```
sessionInfo()
R version 4.0.2 (2020-06-22)
Platform: x86_64-w64-mingw32/x64 (64-bit)
Running under: Windows 10 x64 (build 19041)

Matrix products: default

locale:
[1] LC_COLLATE=German_Germany.1252  LC_CTYPE=German_Germany.1252
[3] LC_MONETARY=German_Germany.1252 LC_NUMERIC=C
[5] LC_TIME=German_Germany.1252

attached base packages:
[1] tools     stats     graphics  grDevices utils     datasets  methods
[8] base

other attached packages:
[1] doBy_4.6.8        R.utils_2.10.1    R.oo_1.24.0       R.methodsS3_1.8.1
[5] openxlsx_4.2.3

loaded via a namespace (and not attached):
 [1] zip_2.1.1         Rcpp_1.0.6        compiler_4.0.2    pillar_1.4.7
 [5] digest_0.6.27     lattice_0.20-41   evaluate_0.14     lifecycle_0.2.0
 [9] tibble_3.0.5      gtable_0.3.0      pkgconfig_2.0.3   rlang_0.4.10
[13] Matrix_1.2-18     DBI_1.1.1         yaml_2.2.1        xfun_0.20
[17] dplyr_1.0.3       stringr_1.4.0     knitr_1.31        generics_0.1.0
[21] vctrs_0.3.6       grid_4.0.2        tidyselect_1.1.0  glue_1.4.2
[25] R6_2.5.0          rmarkdown_2.6     tidyr_1.1.2       purrr_0.3.4
[29] ggplot2_3.3.3     magrittr_2.0.1    backports_1.2.0   scales_1.1.1
[33] ellipsis_0.3.1    htmltools_0.5.1.1 MASS_7.3-53       assertthat_0.2.1
[37] colorspace_2.0-0  Deriv_4.1.2       stringi_1.5.3     munsell_0.5.0
[41] broom_0.7.4       crayon_1.4.0
```

RStudio version 1.3.1056.

END OF SCRIPT

Plots - Lithic analysis Buhlen

Lisa Schunk

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Goal of the script

This script reads the xlsx file (derived data) containing all the information gained through a lithic analysis.
The script will:

18. Read the xlsx file
19. Plot all relevant variables in various combinations
20. Save the plot as PDFs

```
dir_in <-  "analysis/Buhlen/derived_data/"
dir_out <- "analysis/Buhlen/plots/"
```

Raw data must be located in "analysis/Buhlen/derived_data/".
Formatted data will be saved in "analysis/Buhlen/plots/". The knit directory for this script is the project directory.

Load packages

```
library(openxlsx)
Warning: package 'openxlsx' was built under R version 4.0.3
library(readxl)
library(R.utils)
library(tools)
library(chron)
library(ggplot2)
Warning: package 'ggplot2' was built under R version 4.0.3
library(wesanderson)
library(dplyr)
Warning: package 'dplyr' was built under R version 4.0.3
library(ggsci)
```

Get name, path and information of the file

```
data_file <- list.files(dir_in, pattern = "\\.xlsx$", full.names = TRUE)
md5_in <- md5sum(data_file)
info_in <- data.frame(files = basename(names(md5_in)), checksum = md5_in,
                      row.names = NULL)
```

The checksum (MD5 hashes) of the imported files are:

```
                    files                         checksum
1 Buhlen_lithic_analysis.xlsx 0347f13eabf7deb6596b8931034a771e
```

Load data into R object

```
imp_data <- read.xlsx(xlsxFile = data_file, sheet = 1, startRow = 1, colNames = TRUE,
                      rowNames = FALSE, skipEmptyRows = FALSE)
```

Data analsysis - plots

Histogram

Histogram dimensions - Keilmesser

```
# Load data sheet Keilmesser
KM_dim <- read.xlsx(xlsxFile = data_file, sheet = 3)
KM_dim <- KM_dim [ , ] %>% arrange(artefact.state)
KM.tip_dim <- KM_dim[-c(112,128:130), ]


# Keilmesser length
# Calculates the mean value for the plot and ascribes the N value
mean_length <- mean(KM.tip_dim$length, na.rm = TRUE)
n <- doBy::summaryBy(length ~ artefact.state, data = KM.tip_dim, FUN = length)
tag <- gsub(pattern = "_", replacement = " ", paste0(n[[1]], " (n = ", n[[2]], ")"))

# Histogram Keilmesser length
KM.length <- ggplot(KM.tip_dim, aes(x = length, fill = artefact.state)) +
          geom_histogram(binwidth = 1) +
          labs(x = "length [mm]", y = "n", title = "", fill = "artefact state",
          size = 12) +
          theme_classic() +
          geom_vline(aes(xintercept = mean_length), linetype = "dashed",
          size = 1) +
          geom_text(aes(y = mean_length, x = 42, label = round(mean_length, 1)),
          nudge_y = -42) +
          scale_fill_manual(values = wes_palette(n = 2, name = "FantasticFox1",
          type = "continuous"), labels = tag)

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "KM.length", ".pdf")
ggsave(filename = file_out, plot = KM.length, path = dir_out, device = "pdf",
        width = 170, height = 250, units = "mm")


# Keilmesser width
# Calculates the mean value for the plot and ascribes the N value
mean_width <- mean(KM.tip_dim$width, na.rm = TRUE)
n <- doBy::summaryBy(width ~ artefact.state, data = KM.tip_dim, FUN = length)
tag <- gsub(pattern = "_", replacement = " ", paste0(n[[1]], " (n = ", n[[2]], ")"))

# Histogram Keilmesser width
KM.width <- ggplot(KM.tip_dim, aes(x = width, fill = artefact.state)) +
         geom_histogram(binwidth = 1) +
         labs(x = "width [mm]", y = "n", title = "", fill = "artefact state",
         size = 12) +
         theme_classic() +
         geom_vline(aes(xintercept = mean_width), linetype = "dashed",
         size = 1) +
         geom_text(aes(y = mean_length, x = 28, label = round(mean_width, 2)),
         nudge_y = -40) +
         scale_fill_manual(values = wes_palette(n = 2, name = "FantasticFox1",          type = "continuous"), labels =
tag)

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "KM.width", ".pdf")
ggsave(filename = file_out, plot = KM.width, path = dir_out, device = "pdf",
        width = 170, height = 250, units = "mm")
```

```r
# Keilmesser thickness
# Calculates the mean value for the plot and ascribes the N value
mean_thickness <- mean(KM.tip_dim$thickness, na.rm = TRUE)
n <- doBy::summaryBy(thickness ~ artefact.state, data = KM.tip_dim, FUN = length)
tag <- gsub(pattern = "_", replacement = " ", paste0(n[[1]], " (n = ", n[[2]], ")"))

# Histogram Keilmesser thickness
KM.thickness  <- ggplot(KM.tip_dim, aes(y = thickness, fill = artefact.state)) +
                geom_histogram(binwidth = 1) +
                labs(y = "thickness [mm]", x = "n", title = "", fill =
                "artefact state",
                size = 12) +
                theme_classic() +
                geom_hline(aes(yintercept = mean_thickness), linetype = "dashed",
                size = 1) +
                geom_text(aes(y = mean_thickness, x = 16,
                label = round(mean_thickness,
                1)), nudge_y = 1) +
                scale_fill_manual(values = wes_palette(n = 2,
                name = "FantasticFox1", type = "continuous"), labels = tag)

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "KM.thickness", ".pdf")
ggsave(filename = file_out, plot = KM.thickness, path = dir_out, device = "pdf",
         width = 250, height = 170, units = "mm")


# Keilmesser Back
# Load data sheet Keilmesser thickness back
KM_back <- read.xlsx(xlsxFile = data_file, sheet = 22)
KM_back <- KM_back[-c(112:130), ]

# Calculates the mean value for the plot and ascribes the N value
mean_KM_back <- mean(KM_back$thickness.back, na.rm = TRUE)
n <- doBy::summaryBy(thickness.back ~ artefact.state, data = KM_back, FUN = length)
tag <- gsub(pattern = "_", replacement = " ", paste0(n[[1]],
       " (n = ", n[[2]], ")"))

# Histogram Keilmesser thickness back
KM.back  <- ggplot(KM_back, aes(y = thickness.back, fill = artefact.state)) +
           geom_histogram(binwidth = 1) +
           labs(x = "thickness [mm]", y = "n", title = "",
           fill = "artefact state", size = 12) +
           theme_classic() +
           geom_hline(aes(yintercept = mean_KM_back), linetype = "dashed",
           size = 1) +
           geom_text(aes(y = mean_KM_back, x = 17.5,
           label = round(mean_KM_back, 1)),
           nudge_y = 0.7) +
           scale_fill_manual(values = wes_palette(n = 2, name = "FantasticFox1",
           type = "continuous"), labels = tag)

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "KM.back", ".pdf")
ggsave(filename = file_out, plot = KM.back, path = dir_out, device = "pdf", width = 250,
        height = 170, units = "mm")
```

Histogram dimensions - Pradnik scraper

```r
# Load data sheet Pradnik scraper
PS_dim <- read.xlsx(xlsxFile = data_file, sheet = 7)

# Pradnik scraper length
```

```r
# Calculates the mean value for the plot and ascribes the N value
mean_PS_length <- mean(PS_dim$length, na.rm = TRUE)
n <- doBy::summaryBy(length ~ artefact.state, data = PS_dim, FUN = length)
tag <- gsub(pattern = "_", replacement = " ", paste0(n[[1]], " (n = ", n[[2]], ")"))

# Histogram Pradnik scraper length
PS.length <- ggplot(PS_dim, aes(x = length, fill = artefact.state)) +
            geom_histogram(binwidth = 1) +
            labs(x = "length [mm]", y = "n", title = "", fill = "artefact state",
            size = 12) +
            theme_classic() +
            geom_vline(aes(xintercept = mean_PS_length), linetype = "dashed",
            size = 1) +
            geom_text(aes(y = mean_PS_length, x = 50,
            label = round(mean_PS_length, 1)),
            nudge_y = -41) +
            scale_fill_manual(values = wes_palette(n = 1, name = "Chevalier1"),
            labels = tag)

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "PS.length", ".pdf")
ggsave(filename = file_out, plot = PS.length, path = dir_out, device = "pdf",
         width = 170, height = 250, units = "mm")


# Pradnik scraper width
# Calculates the mean value for the plot and ascribes the N value
mean_PS_width <- mean(PS_dim$width, na.rm = TRUE)
n <- doBy::summaryBy(width ~ artefact.state, data = PS_dim, FUN = length)
tag <- gsub(pattern = "_", replacement = " ", paste0(n[[1]], " (n = ", n[[2]],
                                                     ")"))

# Histogram Pradnik scraper width
PS.width <- ggplot(PS_dim, aes(x = width, fill = artefact.state)) +
           geom_histogram(binwidth = 1) +
           labs(x = "width [mm]", y = "n", title = "", fill = "artefact state",
           size = 12) +
           theme_classic() +
           geom_vline(aes(xintercept = mean_PS_width), linetype="dashed",
           size = 1) +
           geom_text(aes(y = mean_PS_width, x = 26, label =
           round(mean_PS_width, 1)),
           nudge_y = -24) +
           scale_fill_manual(values = wes_palette(n = 1, name = "Chevalier1"),
           labels = tag)

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "PS.width", ".pdf")
ggsave(filename = file_out, plot = PS.width, path = dir_out, device = "pdf",
         width = 170, height = 250, units = "mm")


# Pradnik scraper thickness
# Calculates the mean value for the plot and ascribes the N value
mean_PS_thickness <- mean(PS_dim$thickness, na.rm = TRUE)
n <- doBy::summaryBy(thickness ~ artefact.state, data = PS_dim, FUN = length)
tag <- gsub(pattern = "_", replacement = " ", paste0(n[[1]], " (n = ", n[[2]], ")"))

# Histogram Pradnik scraper thickness
PS.thickness <- ggplot(PS_dim, aes(y = thickness, fill = artefact.state)) +
              geom_histogram(binwidth = 0.8) +
              labs(y = "thickness [mm]", x = "n", title = "",
```

```
             fill = "artefact state",
             size = 12) +
             theme_classic() +
             geom_hline(aes(yintercept = mean_PS_thickness),
             linetype = "dashed",
             size = 1) +
             geom_text(aes(y = mean_PS_thickness, x = 5.8, label =
             round(mean_PS_thickness, 1)), nudge_y = -0.4) +
             scale_fill_manual(values = wes_palette(n = 1,
             name = "Chevalier1"), labels = tag)

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "PS.thickness", ".pdf")
ggsave(filename = file_out, plot = PS.thickness, path = dir_out, device = "pdf",
        width = 250, height = 170, units = "mm")




# Back Pradnik scraper thickness
# Load data sheet Pradnik scraper thickness back
PS_back <- read.xlsx(xlsxFile = data_file, sheet = 23)

# Calculates the mean value for the plot and ascribes the N value
mean_PS_back <- mean(PS_back$thickness.back, na.rm = TRUE)
n <- doBy::summaryBy(thickness.back ~ artefact.state, data = PS_back, FUN = length)
tag <- gsub(pattern = "_", replacement = " ", paste0(n[[1]],
                                   " (n = ", n[[2]], ")"))

# Histogram Pradnik scraper thickness back
PS.back  <- ggplot(PS_back, aes(y = thickness.back, fill = artefact.state)) +
           geom_histogram(binwidth = 0.8) +
           labs(y = "thickness [mm]", x = "n", title = "",
           fill = "artefact state",
           size = 12) +
           theme_classic() +
           geom_hline(aes(yintercept = mean_PS_back), linetype = "dashed",
           size = 1) +
           geom_text(aes(y = mean_PS_back, x = 4.8, label =
           round(mean_PS_back, 1)), nudge_y = 0.6) +
           scale_fill_manual(values = wes_palette(n = 1, name = "Chevalier1"),
           labels = tag)

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "PS.back", ".pdf")
ggsave(filename = file_out, plot = PS.back, path = dir_out, device = "pdf",
        width = 250, height = 170, units = "mm")
```

Histogram dimension - Lateral sharpening spall

```
# Load data sheet lateral sharpening spall
LSS_dim <- read.xlsx(xlsxFile = data_file, sheet = 8)
LSS_dim <- LSS_dim [-c(37:42), ]

# Lateral sharpening spall length
# Calculates the mean value for the plot and ascribes the N value
mean_LSS_length <- mean(LSS_dim$length, na.rm = TRUE)
n <- doBy::summaryBy(length ~ artefact.state, data = LSS_dim, FUN = length)
tag <- gsub(pattern = "_", replacement = " ", paste0(n[[1]], " (n = ", n[[2]], ")"))

# Histogram lateral sharpening spall length
LSS.length <- ggplot(LSS_dim, aes(x = length, fill = artefact.state)) +
            geom_histogram(binwidth = 1) +
            labs(x = "length [mm]", y = "n", title = "",
```

```r
             fill = "artefact state",
             size = 12) +
             theme_classic() +
             geom_vline(aes(xintercept = mean_LSS_length), linetype = "dashed",
             size = 1) +
             geom_text(aes(y = mean_LSS_length, x = 31,
             label = round(mean_LSS_length, 1)), nudge_y = -30.7) +
             scale_fill_manual(values = wes_palette(n = 1, name = "Royal1"),
             labels = tag)

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "LSS.length", ".pdf")
ggsave(filename = file_out, plot = LSS.length, path = dir_out, device = "pdf",
          width = 170, height = 250, units = "mm")



# Lateral sharpening spall width
# Calculates the mean value for the plot and ascribes the N value
mean_LSS_width <- mean(LSS_dim$width, na.rm = TRUE)
n <- doBy::summaryBy(width ~ artefact.state, data = LSS_dim, FUN = length)
tag <- gsub(pattern = "_", replacement = " ", paste0(n[[1]], " (n = ", n[[2]], ")"))

# Histogram lateral sharpening spall width
LSS.width <- ggplot(LSS_dim, aes(x = width, fill = artefact.state)) +
            geom_histogram(binwidth = 1) +
            labs(x = "width [mm]", y = "n", title = "", fill = "artefact state",
            size = 12) +
            theme_classic() +
            geom_vline(aes(xintercept = mean_LSS_width), linetype = "dashed",
            size = 1) +
            geom_text(aes(y = mean_LSS_width, x = 21, label =
            round(mean_LSS_width, 1)),
            nudge_y = -11.97) +
            scale_fill_manual(values = wes_palette(n = 1, name = "Royal1"),
            labels = tag)

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "LSS.width", ".pdf")
ggsave(filename = file_out, plot = LSS.width, path = dir_out, device = "pdf",
          width = 170, height = 250, units = "mm")



# Lateral sharpening spall thickness
# Calculates the mean value for the plot and ascribes the N value
mean_LSS_thickness <- mean(LSS_dim$thickness, na.rm = TRUE)
n <- doBy::summaryBy(thickness ~ artefact.state, data = LSS_dim, FUN = length)
tag <- gsub(pattern = "_", replacement = " ", paste0(n[[1]],
                                        " (n = ", n[[2]], ")"))

# Histogram lateral sharpening spall thickness
LSS.thickness <- ggplot(LSS_dim, aes(y = thickness, fill = artefact.state)) +
                geom_histogram(binwidth = 0.8) +
                labs(y = "thickness[mm]", x = "n", title = "",
                fill = "artefact state",
                size = 12) +
                theme_classic() +
                geom_hline(aes(yintercept = mean_LSS_thickness),
                linetype = "dashed", size = 1) +
                geom_text(aes(y = mean_LSS_thickness, x = 9.8,
                label = round(mean_LSS_thickness, 2)), nudge_y = 0.3) +
                scale_fill_manual(values = wes_palette(n = 1, name = "Royal1"),
                labels = tag)
```

```
file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "LSS.thickness", ".pdf")
ggsave(filename = file_out, plot = LSS.thickness, path = dir_out, device = "pdf",
       width = 250, height = 170, units = "mm")
```

Scatterplot

Length-width ratio

```
# Load data sheet Keilmesser
KM_dim <- read.xlsx(xlsxFile = data_file, sheet = 3)
KM_dim_comp.tip <- KM_dim[c(1:111, 113:127), ]

# Keilmesser length VS width
# Ascribes the N value
n <- doBy::summaryBy(length + width ~ artefact.state, data = KM_dim_comp.tip,
                    FUN = length)
tag <- gsub(pattern = "_", replacement = " ", paste0(n[[1]],
                   " (n = ", n[[2]], ")"))

# Scatterplot Keilmesser (complete + point) length VS width
KM.length_width <- ggplot(KM_dim_comp.tip, aes(y = length, x = width, fill =
                  artefact.state)) +
                  geom_point(size = 3, shape = 21) +
                  labs(y = "length [mm]", x = "width [mm]", title = "",
                  fill = "artefact state", size = 12) +
                  xlim(0, 80) + ylim(0, 120) +
                  theme_classic() +
                  scale_fill_manual(values = wes_palette(n = 2,
                  name = "FantasticFox1",
                  type = "continuous"), labels = tag)

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "KM.length_width",
                  ".pdf")
ggsave(filename = file_out, plot = KM.length_width, path = dir_out,
       device = "pdf", width = 170, height = 250, units = "mm")


# Pradnik scraper length VS width
# Ascribes the N value
n <- doBy::summaryBy(length + width ~ artefact.state, data = PS_dim, FUN = length)
tag <- gsub(pattern = "_", replacement = " ", paste0(n[[1]],
                                  " (n = ", n[[2]], ")"))

# Scatterplot Pradnik scraper length VS width
PS.length_width <- ggplot(PS_dim, aes(y = length, x = width,
                  fill = artefact.state)) +
                  geom_point(size = 3, shape = 21) +
                  labs(y = "length [mm]", x = "width [mm]", title = "",
                  fill = "artefact state", size = 12) +
                  xlim(0, 60) + ylim(0, 85) +
                  theme_classic() +
                  scale_fill_manual(values = wes_palette(n = 6,
                  name = "Chevalier1",
                  type = "continuous"), labels = tag)

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "PS.length_width",
                  ".pdf")
ggsave(filename = file_out, plot = PS.length_width, path = dir_out,
       device = "pdf", width = 170, height = 250, units = "mm")
```

```r
# Lateral sharpening spall length VS width
# Defines only the rows with complete LSS
LSS.comp_dim <- LSS_dim[1:36,]

# Lateral sharpening spall length VS width
# Ascribes the N value
n <- doBy::summaryBy(length + width ~ artefact.state, data = LSS.comp_dim,
         FUN = length)
tag <- gsub(pattern = "_", replacement = " ", paste0(n[[1]],
          " (n = ", n[[2]], ")"))

# Scatterplot lateral sharpening spall length VS width
LSS.length_width <- ggplot(LSS.comp_dim, aes(y = length, x = width,
                  fill = artefact.state)) +
                  geom_point(size = 3, shape = 21) +
                  labs(y = "length [mm]", x = "width [mm]", title = "",
                  fill = "artefact state", size = 12) +
                  xlim(0, 40) + ylim(0, 60) +
                  theme_classic() +
                  scale_fill_manual(values = wes_palette(n = 2, name = "Royal1",
                  type = "continuous"), labels = tag)


file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "LSS.length_width",
                  ".pdf")
ggsave(filename = file_out, plot = LSS.length_width, path = dir_out,
        device = "pdf", width = 170, height = 250, units = "mm")


# Keilmesser (complete) + Pradnik scraper length VS width
# Load data sheet dimensions
dim <- read.xlsx(xlsxFile = data_file, sheet = 2)
# Defines only the relevant rows
KM.PS_dim <- dim[c(2:131, 174:197), ]  %>% arrange(artefact.state)
KM.PS_dim <- KM.PS_dim[1:135,]

# Keilmesser (complete) + Pradnik scraper length VS width
# Ascribes the N value
n <- doBy::summaryBy(length + width ~ technological.class, data = KM.PS_dim,
                   FUN = length)
tag <- gsub(pattern = "_", replacement = " ", paste0(n[[1]],
                  " (n = ", n[[2]], ")"))

# Scatterplot Keilmesser (complete) + Pradnik scraper length VS width
KM.PS.length_width <- ggplot(KM.PS_dim, aes(y = length, x = width,
                    fill = technological.class)) +
                    geom_point(size = 3, shape = 21) +
                    labs(y = "length [mm]", x = "width [mm]", title = "",
                    fill = "artefact category", size = 12) +
                    xlim(0, 80) + ylim(0, 120) +
                    theme_classic() +
                    scale_fill_manual(values = wes_palette(n = 3, name =
                    "GrandBudapest1", type = "continuous"), labels = tag)

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "KM.PS.length_width",
                  ".pdf")
ggsave(filename = file_out, plot = KM.PS.length_width, path = dir_out,
        device = "pdf", width = 170, height = 250, units = "mm")
```

```r
# Keilmesser (complete): length-width combined with morpho type
# Load data sheet Keilmesser morpho type
KM_morpho.type <- read.xlsx(xlsxFile = data_file, sheet = 28)

# Ascribes the N value
n <- doBy::summaryBy(length + width ~ morpho.type, data = KM_morpho.type,
                     FUN = length)
tag <- gsub(pattern = "_", replacement = " ", paste0(n[[1]],
                     " (n = ", n[[2]], ")"))



# Scatterplot Keilmesser (complete): length-width combined with morpho type
KM.width_length_morpho <- ggplot(KM_morpho.type, aes(y = length, x = width,
                          fill = morpho.type)) +
                          geom_point(size = 2, shape = 21) +
                          labs(y = "length [mm]", x = "width [mm]", title = "",
                          fill = "Keilmesser shape", size = 12) +
                          xlim(0, 80) + ylim(0, 120) +
                          theme_classic() +
                          scale_fill_manual(values = wes_palette(n = 7,name =
                          "FantasticFox1", type = "continuous"), labels = tag)

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "KM.width_length_morpho",
                   ".pdf")
ggsave(filename = file_out, plot = KM.width_length_morpho, path = dir_out,
       device = "pdf", width = 170, height = 250, units = "mm")
```

Barplot

Morphotype

```r
# Keilmesser morpho type
# Load data sheet Keilmesser morpho type
KM_morpho.type <- read.xlsx(xlsxFile = data_file, sheet = 28)
# Defines only the rows with complete Keilmesser
KM_morpho.type <- KM_morpho.type[1:111, ]

# Barplot Keilmesser morpho type
KM.morpho.type <- ggplot(data = KM_morpho.type) + aes(x = morpho.type,
                  fill = morpho.type) +
                  geom_bar(stat = "count", width = 0.6, fill = c("#899DA4",
                  "#A46F65",
                  "#BF4226", "#D76848", "#F5E0BB", "#E8B37B", "#DC863B")) +
                  theme_classic() +
                  theme(legend.position = "none") +
                  labs(x = " ", y = "n")

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "KM.morpho.type", ".pdf")
ggsave(filename = file_out, plot = KM.morpho.type, path = dir_out, device = "pdf",
        width = 190, height = 210, units = "mm")
```

Barplot

Edge retouch

```r
# Keilmesser edge retouch
# Load data sheet Keilmesser edge retouch
KM_edge <- read.xlsx(xlsxFile = data_file, sheet = 24)
# Defines only the rows with complete Keilmesser and Keilmesser tips
KM_edge <- KM_edge[-c(112, 128:130),]
```

```
# Barplot Keilmesser edge retouch
KM.edge <- ggplot(data = KM_edge) + aes(x = retouch.type.edge,
          fill = retouch.type.edge) + geom_bar(stat = "count", width = 0.5,
          fill = c ("#798E87", "#972D15", "#29211F")) +
          theme_classic() +
          theme(legend.position = "none") +
          labs(x = " ", y = "n")

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "KM.edge", ".pdf")
ggsave(filename = file_out, plot = KM.edge, path = dir_out, device = "pdf",
         width = 170, height = 200, units = "mm")



# Pradnik scraper edge retouch
# Load data sheet Pradnik scraper edge retouch
PS_edge <- read.xlsx(xlsxFile = data_file, sheet = 25)

# Barplot Pradnik scraper edge retouch
PS.edge <- ggplot(data = PS_edge) + aes(x = retouch.type.edge,
          fill = retouch.type.edge) + geom_bar(stat = "count", width = 0.5,
          fill = c ("#798E87", "#972D15",
          "#29211F")) +
          theme_classic() +
          theme(legend.position = "none") +
          labs(x = " ", y = "n")

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "PS.edge", ".pdf")
ggsave(filename = file_out, plot = PS.edge, path = dir_out, device = "pdf",
         width = 170, height = 200, units = "mm")
```

Barplot

Raw material

```
# Keilmesser raw material
# Load data sheet Keilmesser raw material
KM_raw_material <- read.xlsx(xlsxFile = data_file, sheet = 16)

# Barplot Keilmesser raw material
KM.raw_material <- ggplot(data = KM_raw_material) + aes(x = raw.material,
                  fill = raw.material) +
                  geom_bar(stat = "count", width = 0.22, fill = c("#D69C4E",
                  "#ECCBAE", "#046C9A")) +
                  theme_classic() +
                  theme(legend.position = "none") +
                  labs(x = " ", y = "n") +
                  scale_x_discrete(labels=c("Baltic flint", "other",
                  "silicified schist"))

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "KM.raw_material",
                 ".pdf")
ggsave(filename = file_out, plot = KM.raw_material, path = dir_out,
        device = "pdf")


# Pradnik scraper raw material
# Load data sheet Pradnik scraper raw material
PS_raw_material <- read.xlsx(xlsxFile = data_file, sheet = 17)
```

```r
# Barplot Pradnik scraper raw material
PS.raw_material <- ggplot(data = PS_raw_material) + aes(x = raw.material,
                  fill = raw.material) +
                  geom_bar(stat = "count", width = 0.08, fill = c("#046C9A")) +
                  theme_classic() +
                  theme(legend.position = "none") +
                  labs(x = "  ", y = "n") +
                  scale_x_discrete(labels= "silicified schist")

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "PS.raw_material",
                  ".pdf")
ggsave(filename = file_out, plot = PS.raw_material, path = dir_out, device = "pdf")


# All artefact categories raw material
# Load data sheet all artefact categories raw material
all_raw_material <- read.xlsx(xlsxFile = data_file, sheet = 1)

# Barplot Pradnik scraper raw material
all.raw_material <- ggplot(data = all_raw_material) + aes(x = raw.material,
                  fill = raw.material) +
                  geom_bar(stat = "count", width = 0.24, fill = c("#D69C4E",
                  "#ECCBAE", "#046C9A")) +
                  theme_classic() +
                  theme(legend.position = "none") +
                  labs(x = "  ", y = "n") +
                  scale_x_discrete(labels=c("Baltic flint", "other",
                  "silicified schist"))

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "all.raw_material",
                  ".pdf")
ggsave(filename = file_out, plot = all.raw_material, path = dir_out,
        device = "pdf")
```

Barplot

Morphology back

```r
# Keilmesser morphology back
# Load data sheet Keilmesser morphology back
KM_back <- read.xlsx(xlsxFile = data_file, sheet = 22)

# Barplot Keilmesser morphology back
KM.back_morpho <- ggplot(data = KM_back) + aes(x = morphology.back,
                  fill = morphology.back) +
                  geom_bar(stat = "count", width = 0.5, fill =
                  c("#518BA0","#497C80", "#D69C4E",
                  "#729394","#B9C7AD")) +
                  theme_classic() +
                  theme(legend.position = "none") +
                  labs(x = "  ", y = "n") +
                  scale_x_discrete(labels=c("cortex + partly retouched",
                  "cortex/unworked", "N/A", "partly retouched", "retouched"))

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "KM.back_morpho", ".pdf")
ggsave(filename = file_out, plot = KM.back_morpho, path = dir_out, device = "pdf",
         width = 250, height = 170, units = "mm")


# Pradnik scraper morphology back
# Load data sheet Pradnik scraper morphology back
```

```r
PS_back <- read.xlsx(xlsxFile = data_file, sheet = 23)

# Barplot Pradnik scraper morphology back
PS.back_morpho <- ggplot(data = PS_back) + aes(x = morphology.back,
                 fill = morphology.back) +
                 geom_bar(stat = "count", width = 0.5, fill = c("#518BA0",
                 "#497C80", "#729394","#B9C7AD")) +
                 theme_classic() +
                 theme(legend.position = "none") +
                 labs(x = " ", y = "n") +
                 scale_x_discrete(labels=c("cortex + partly retouched",
                 "cortex/unworked", "partly retouched", "retouched"))

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "PS.back_morpho", ".pdf")
ggsave(filename = file_out, plot = PS.back_morpho, path = dir_out, device = "pdf",
         width = 250, height = 170, units = "mm")


# Keilmesser blanks
# Load data sheet Keilmesser blanks
KM_cortex_blanks <- read.xlsx(xlsxFile = data_file, sheet = 20)

# Ascribes the N value
n <- doBy::summaryBy(blank ~ cortex, data = KM_cortex_blanks, FUN = length)
tag <- gsub(pattern = "_", replacement = " ", paste0(n[[1]],
                                    " (n = ", n[[2]], ")"))

# Barplot Keilmesser blanks
KM.cortex_blanks <- ggplot(data = KM_cortex_blanks) + aes(x = blank,
                   fill = cortex) +
                   geom_bar(stat = "count", width = 0.4) +
                   theme_classic() +
                   labs(x = " ", y = "n") +
                   scale_x_discrete(labels=c("core", "flake", "N/A")) +
                   scale_fill_manual(values = wes_palette(n = 7, name =
                   "Darjeeling2",
                   type = "continuous"), labels = tag)

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "KM.cortex_blanks",
                  ".pdf")
ggsave(filename = file_out, plot = KM.cortex_blanks, path = dir_out,
        device = "pdf")


# Pradnik scraper blanks
# Load data sheet Pradnik scraper blanks
PS_cortex_blanks <- read.xlsx(xlsxFile = data_file, sheet = 21)

# Ascribes the N value
n <- doBy::summaryBy(blank ~ cortex, data = PS_cortex_blanks, FUN = length)
tag <- gsub(pattern = "_", replacement = " ", paste0(n[[1]],
                                     " (n = ", n[[2]], ")"))

# Barplot Pradnik scraper blanks
PS.cortex_blanks <- ggplot(data = PS_cortex_blanks) +
                   aes(x = blank, fill = cortex) +
                   geom_bar(stat = "count", width = 0.16) +
                   theme_classic() +
                   labs(x = " ", y = "n") +
                   scale_x_discrete(labels= "flake") +
```

```
                scale_fill_manual(values = wes_palette(n = 7,
                name = "Darjeeling2", type = "continuous"), labels = tag)

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "PS.cortex_blanks",
                ".pdf")
ggsave(filename = file_out, plot = PS.cortex_blanks, path = dir_out,
       device = "pdf")
```

Barplot

Pradnik method

```
# Keilmesser application Pradnik method
# Load data sheet Keilmesser Pradnik method
KM_Pradnik.method <- read.xlsx(xlsxFile = data_file, sheet = 30)

# Barplot Keilmesser Pradnik method
KM.PM <- ggplot(data = KM_Pradnik.method) + aes(x = application.Pradnik.method,
       fill = application.Pradnik.method) +
       geom_bar(stat = "count", width = 0.3) +
       theme_classic() +
       labs(x = " ", y = "n") +
       theme(legend.position = "none") +
       scale_x_discrete(labels=c("no", "N/A", "yes")) +
       scale_fill_manual(values = wes_palette(n = 5, name = "GrandBudapest1",
       type = "continuous"))

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "KM.PM", ".pdf")
ggsave(filename = file_out, plot = KM.PM, path = dir_out, device = "pdf")
```

Barplot

Lateralisation

```
# Keilmesser lateralisation
# Load data sheet Keilmesser lateralisation
KM_lateralisation <- read.xlsx(xlsxFile = data_file, sheet = 32)

# Barplot Keilmesser lateralisation
KM.lat <- ggplot(data = KM_lateralisation) + aes(x = tool.lateralisation,
        fill = tool.lateralisation) +
        geom_bar(stat = "count", width = 0.3) +
        theme_classic() +
        labs(x = " ", y = "n") +
        theme(legend.position = "none") +
        scale_fill_manual(values = wes_palette(n = 9, name = "Royal1",
        type = "continuous"))

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "KM.lat", ".pdf")
ggsave(filename = file_out, plot = KM.lat, path = dir_out, device = "pdf")



# Pradnik scraper lateralisation
# Load data sheet Pradnik scraper lateralisation
PS_lateralisation <- read.xlsx(xlsxFile = data_file, sheet = 33)
# Barplot Keilmesser lateralisation
PS.lat <- ggplot(data = PS_lateralisation) + aes(x = tool.lateralisation,
        fill = tool.lateralisation) +
        geom_bar(stat = "count", width = 0.3) +
        theme_classic() +
        labs(x = " ", y = "n") +
```

```
        theme(legend.position = "none") +
        scale_fill_manual(values = wes_palette(n = 9, name = "Royal1",
        type = "continuous"))

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "PS.lat", ".pdf")
ggsave(filename = file_out, plot = PS.lat, path = dir_out, device = "pdf")
```

Barplot

Barplot lateral resharpening spall type

```
# Lateral resharpening spall type
# Load data sheet lateral resharpening spall type
LSS_type <- read.xlsx(xlsxFile = data_file, sheet = 34)

# Ascribes the N value
n <- doBy::summaryBy(type.lateral.sharpening.spall ~ tool.lateralisation,
    data = LSS_type, FUN = length)
tag <- gsub(pattern = "_", replacement = " ", paste0(n[[1]],
                                     " (n = ", n[[2]], ")"))

# Barplot lateral resharpening spall type
LSS.type <- ggplot(data = LSS_type) + aes(x = type.lateral.sharpening.spall,
          fill = tool.lateralisation) +
          geom_bar(stat = "count", width = 0.3) +
          theme_classic() +
          labs(x = " ", y = "n") +
          labs(fill = "tool lateralisation") +
          scale_x_discrete(labels=c("primary", "secondary", "N/A")) +
          scale_fill_manual(values = wes_palette(n = 9, name = "Royal1",
          type = "continuous"), labels = tag)

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "LSS.type", ".pdf")
ggsave(filename = file_out, plot = LSS.type, path = dir_out, device = "pdf")
```

Ternary plot

Perimeter

```
library(ggtern)
# Perimeter Keilmesser
# Load data sheet Keilmesser perimeter
KM_perimeter <- read.xlsx(xlsxFile = data_file, sheet = 10)
# Defines only the rows with complete Keilmesser
KM_perimeter <- KM_perimeter[1:111, ]

# Ternary diagram Keilmesser perimeter
KM.perimeter  <- ggtern(data = KM_perimeter, aes(x = perimeter.distal.posterior.part,
              y = perimeter.active.edge, z = perimeter.basis.back)) +
              geom_point(aes(colour = morpho.type)) +
              theme_bw() +
              scale_colour_startrek() +
              theme_hidetitles() +
              theme_showarrows() +
              xlab("distal.posterior.part") +
              ylab("active edge") +
              zlab("basis + back") +
              labs(colour = "Keilmesser shape") +
              tern_limits(labels=c(0, 20, 40, 60, 80, 100)) +
              theme_rotate(degrees = 330)
```

```r
file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "KM.perimeter", ".pdf")
ggsave(filename = file_out, plot = KM.perimeter, path = dir_out, device = "pdf")
```

---

sessionInfo() and RStudio version

```r
sessionInfo()
R version 4.0.2 (2020-06-22)
Platform: x86_64-w64-mingw32/x64 (64-bit)
Running under: Windows 10 x64 (build 19041)

Matrix products: default

locale:
[1] LC_COLLATE=German_Germany.1252  LC_CTYPE=German_Germany.1252
[3] LC_MONETARY=German_Germany.1252 LC_NUMERIC=C
[5] LC_TIME=German_Germany.1252

attached base packages:
[1] tools     stats     graphics  grDevices utils     datasets  methods
[8] base

other attached packages:
 [1] ggtern_3.3.0      ggsci_2.9         dplyr_1.0.3       wesanderson_0.3.6
 [5] ggplot2_3.3.3     chron_2.3-56      R.utils_2.10.1    R.oo_1.24.0
 [9] R.methodsS3_1.8.1 readxl_1.3.1      openxlsx_4.2.3

loaded via a namespace (and not attached):
 [1] tidyselect_1.1.0   xfun_0.20          purrr_0.3.4        lattice_0.20-41
 [5] latex2exp_0.4.0    colorspace_2.0-0   vctrs_0.3.6        generics_0.1.0
 [9] doBy_4.6.8         htmltools_0.5.1.1  compositions_2.0-1 yaml_2.2.1
[13] rlang_0.4.10       pillar_1.4.7       glue_1.4.2         withr_2.4.1
[17] DBI_1.1.1          plyr_1.8.6         lifecycle_0.2.0    robustbase_0.93-7
[21] stringr_1.4.0      munsell_0.5.0      gtable_0.3.0       cellranger_1.1.0
[25] zip_2.1.1          evaluate_0.14      labeling_0.4.2     knitr_1.31
[29] DEoptimR_1.0-8     proto_1.0.0        broom_0.7.4        Rcpp_1.0.6
[33] scales_1.1.1       backports_1.2.0    farver_2.0.3       gridExtra_2.3
[37] Deriv_4.1.2        tensorA_0.36.2     digest_0.6.27      stringi_1.5.3
[41] grid_4.0.2         magrittr_2.0.1     tibble_3.0.5       crayon_1.4.0
[45] tidyr_1.1.2        pkgconfig_2.0.3    bayesm_3.1-4       ellipsis_0.3.1
[49] MASS_7.3-53        Matrix_1.2-18      assertthat_0.2.1   rmarkdown_2.6
[53] R6_2.5.0           compiler_4.0.2
```

RStudio version 1.3.1056.

END OF SCRIPT

Import - Lithic analysis Balver Höhle

Lisa Schunk

2021-02-04

Goal of the script

This script reads the xlsx file (database techno-typological analysis) generated with E4 and formats the data for a statistical analysis.
The script will:

21. Reads in the original xlsx file
22. Changes and sort the data in order to do stats
23. Saves the data as a new xlsx file and R object

```
dir_in <-  "analysis/Balve/raw_data/"
dir_out <- "analysis/Balve/derived_data/"
```

Raw data must be located in “analysis/Balve/raw_data/”.
Formatted data will be saved in “analysis/Balve/derived_data/”. The knit directory for this script is the project directory.

Load packages

```
library(openxlsx)
Warning: package 'openxlsx' was built under R version 4.0.3
library(readxl)
library(R.utils)
library(tools)
library(data.table)
Warning: package 'data.table' was built under R version 4.0.3
library(chron)
library(dplyr)
Warning: package 'dplyr' was built under R version 4.0.3
```

Get name, path and information of the file

```
data_file <- list.files(dir_in, pattern = "\\.xlsx$", full.names = TRUE)
md5_in <- md5sum(data_file)
info_in <- data.frame(files = basename(names(md5_in)), checksum = md5_in,
                      row.names = NULL)
```

The checksum (MD5 hashes) of the imported files are:

```
            files                         checksum
1 Balver_Höhle.xlsx 0fcdc965c57b8f87c33fd0f8407a0ea9
```

Read in original xlsx-file

```
imp_data <- read.xlsx(xlsxFile = data_file, sheet = 1, startRow = 1, colNames = TRUE,
                      rowNames = FALSE, skipEmptyRows = FALSE)
#select the columns to keep
keep_col <- c(1:2, 9:19, 21:35, 37:38, 40:43)
data_final <- imp_data[,keep_col]
```

```
data_final$length <- as.numeric(data_final$length)
data_final$width <- as.numeric(data_final$width)
data_final$thickness <- as.numeric(data_final$thickness)
data_final$weight <- as.numeric(data_final$weight)
Warning: NAs introduced by coercion
data_final$perimeter.basis.back <- as.numeric(data_final$perimeter.basis.back)
data_final$perimeter.arch <- as.numeric(data_final$perimeter.arch)
Error in `$<-.data.frame`(`*tmp*`, perimeter.arch, value = numeric(0)): replacement has 0 rows, data has 347
data_final$perimeter.active.edge <- as.numeric(data_final$perimeter.active.edge)
data_final$perimeter.total <- as.numeric(data_final$perimeter.total)
data_final$thickness.back <- as.numeric(data_final$thickness.back)

str(data_final)
'data.frame':   347 obs. of  34 variables:
 $ site                               : chr  "Balver_Höhle" "Balver_Höhle" "Balver_Höhle" "Balver_Höhle" ...
 $ ID                                 : chr  "HE-012" "HE-013" "HE-014" "HE-015" ...
 $ raw.material                       : chr  "baltic_flint" "silicified_schist" "silicified_schist" "silicified_schist" ...
 $ technological.class                : chr  "Keilmesser" "Keilmesser" "Keilmesser" "Keilmesser" ...
 $ artefact.state                     : chr  "complete" "semifinished_product" "complete" "complete" ...
 $ blank                              : chr  "core" "core" "flake" "core" ...
 $ morpho.type                        : chr  "Bockstein" "Bockstein" "Balve" "Pradnik" ...
 $ cortex                             : chr  "YES" "YES" "YES" "N/A" ...
 $ cortex.percentage                  : chr  "N/A" "N/A" "N/A" NA ...
 $ cortex.location                    : chr  "back" "back" "back" NA ...
 $ morphology.back                    : chr  "cortex/unworked" "cortex/unworked" "cortex/unworked" "partly_retouched" ...
 $ retouch.active.edge                : chr  "YES" "YES" "YES" "YES" ...
 $ retouch.type.edge                  : chr  "bifacial" "bifacial" "bifacial" "bifacial" ...
 $ tip.morphology                     : chr  "undeterminable" "undeterminable" "undeterminable" "undeterminable" ...
 $ application.Pradnik.method         : chr  "YES" "NO" "NO" "NO" ...
 $ frequency.application.Pradnik.method: chr  "N/A" NA NA NA ...
 $ type.lateral.sharpening.spall      : chr  NA NA NA NA ...
 $ tool.lateralisation                : chr  "sin." "sin." "dex." "sin." ...
 $ length                             : num  72.5 142.8 52.4 48.3 58.9 ...
 $ width                              : num  41.6 69.7 38.2 34 30.5 ...
 $ thickness                          : num  17.8 24.2 20.9 11.6 19.7 ...
 $ weight                             : num  0.058 0.129 0.035 0.022 0.037 ...
 $ perimeter.basis.back               : num  10.6 18.7 5.7 4.1 9.6 7.6 6.3 8.5 4.6 10.8 ...
 $ perimeter.distal.posterior.part    : chr  "1" "4" "4" " 4.6" ...
 $ perimeter.active.edge              : num  6.7 11.4 4.7 4.4 4.4 6.4 5.9 5.4 5.9 5.4 ...
 $ perimeter.total                    : num  18.3 34.1 14.1 13.1 15.3 ...
 $ thickness.back                     : num  17.16 22.07 19.03 7.06 20.03 ...
 $ taphonomic.visual.inspection       : chr  "N/A" "N/A" "N/A" "N/A" ...
 $ tool.edges.preservation            : chr  "N/A" "N/A" "N/A" "N/A" ...
 $ macroscopically.visible.use-wear   : chr  "N/A" "N/A" "N/A" "N/A" ...
 $ use-wear.analysis                  : chr  "N/A" "N/A" "N/A" "N/A" ...
 $ 3D-scan                            : chr  "N/A" "N/A" "N/A" "N/A" ...
 $ schistosity                        : chr  "N/A" "N/A" "N/A" "N/A" ...
 $ orientation.schistosity            : chr  NA NA NA NA ...
```

Data analsysis - sorting

Dimension

```
# keeps only columns relevant for dimensions and sorts them based on
# their technological class
keep_col <- c(1:2, 4:5,19:21)
dimensions <- data_final[, keep_col] %>% arrange(technological.class)

KM_dimensions <- dimensions[1:191, ] %>% arrange(artefact.state)
```

```
KM.point_dimensions <- KM_dimensions[159:179,]
KM.only_dimensions <- KM_dimensions[1:158,]
KM.complete_dimensions <- KM_dimensions[1:179,]
PS_dimensions <- dimensions[309:335,] %>% arrange(artefact.state)
LSS_dimensions <- dimensions[192:308,] %>% arrange(artefact.state)
S_dimensions <- dimensions[336:347,] %>% arrange(artefact.state)
```

Perimeter

```
# keeps only columns relevant for perimeter measurements and sorts them
# based on their technological class
keep_col <- c(1:2, 4:5,7,23:26)
perimeter <- data_final[, keep_col] %>% arrange(technological.class)

KM_perimeter <- perimeter[1:191, ] %>% arrange(artefact.state)
PS_perimeter <- perimeter[309:335,] %>% arrange(artefact.state)
```

Weight

```
# keeps only columns relevant for weight measurements and sorts them based
# on their technological class
keep_col <- c(1:2, 4:5, 22)
weight <- data_final[, keep_col] %>% arrange(technological.class)

KM_weight <- weight[1:191, ] %>% arrange(artefact.state)
PS_weight <- weight[309:335,] %>% arrange(artefact.state)
LSS_weight <- weight[192:308,] %>% arrange(artefact.state)
S_weight <- weight[336:347,] %>% arrange(artefact.state)
```

Raw material

```
# keeps only columns relevant for raw material classification and sorts them
# based on their technological class
keep_col <- c(1:2, 4:5, 3)
raw_material <- data_final[, keep_col] %>% arrange(technological.class)

KM_raw_material <- raw_material[1:191, ] %>% arrange(artefact.state)
PS_raw_material <- raw_material[309:335,] %>% arrange(artefact.state)
LSS_raw_material <- raw_material[192:308,] %>% arrange(artefact.state)
S_raw_material <- raw_material[336:347,] %>% arrange(artefact.state)
```

Cortex + blanks

```
# keeps only columns relevant for cortex and blank classification and sorts them
# based on their technological class
keep_col <- c(1:2, 4:5, 6, 8:10)
cortex_blanks <- data_final[, keep_col] %>% arrange(technological.class)

KM_cortex_blanks <- cortex_blanks[1:191, ] %>% arrange(artefact.state)
PS_cortex_blanks <- cortex_blanks[309:335,] %>% arrange(artefact.state)
```

Back

```
# keeps only columns relevant for back modifications and sorts them based
# on their technological class
keep_col <- c(1:2, 4:5, 11, 27)
back <- data_final[, keep_col] %>% arrange(technological.class)

KM_back <- back[1:191, ] %>% arrange(artefact.state)
PS_back <- back[309:335,] %>% arrange(artefact.state)
```

Edge retouch

```
# keeps only columns relevant for edge retouch classification and sorts them
# based on their technological class
```

```
keep_col <- c(1:2, 4:5, 12:13, 29)
edge_retouch <- data_final[, keep_col] %>% arrange(technological.class)

KM_edge_retouch <- edge_retouch[1:191, ] %>% arrange(artefact.state)
PS_edge_retouch <- edge_retouch[309:335,] %>% arrange(artefact.state)
LSS_edge_retouch <- edge_retouch[192:308,] %>% arrange(artefact.state)
S_edge_retouch <- edge_retouch[336:347,] %>% arrange(artefact.state)
```

Morpho type

```
# keeps only columns relevant for morpho type classification and sorts them
# based on their technological class
keep_col <- c(1:2, 4:5, 7, 19:21)
morpho.type <- data_final[, keep_col] %>% arrange(technological.class)

KM_morpho.type <- morpho.type[1:191, ] %>% arrange(artefact.state)
PS_morpho.type <- morpho.type[309:335,] %>% arrange(artefact.state)
```

Application 'Pradnik method'

```
# keeps only columns relevant for 'morpho type 'Pradnik method' classification
# and sorts them based on their technological class
keep_col <- c(1:2, 4:5, 15:16)
Pradnik.method <- data_final[, keep_col] %>% arrange(technological.class)

KM_Pradnik.method <- Pradnik.method[1:191, ] %>% arrange(artefact.state)
PS_Pradnik.method <- Pradnik.method[309:335,] %>% arrange(artefact.state)
```

Lateralisation

```
# keeps only columns relevant for lateralisation and sorts them based on their
# technological class
keep_col <- c(1:2, 4:5, 18)
lateralisation <- data_final[, keep_col] %>% arrange(technological.class)

KM_lateralisation <- lateralisation[1:191, ] %>% arrange(artefact.state)
PS_lateralisation <- lateralisation[309:335,] %>% arrange(artefact.state)
```

Type lateral sharpening spall

```
# keeps only columns relevant for lateral sharpening spall classification and sorts
# them based on their technological class
keep_col <- c(1:2, 4:5, 17:18)
lss_type <- data_final[, keep_col] %>% arrange(technological.class)

LSS_type <- lss_type[192:308, ] %>% arrange(artefact.state)
```

Save data

Format name of output file

```
file_out <- "Balve_lithic_analysis"
```

The files will be saved as "~/Balve_lithic_analysis.[ext]".

Write to XLSX

```
write.xlsx(list(data = data_final, dimensions = dimensions, KM_dimensions = KM_dimensions, KM.point_dimensions =
           KM.point_dimensions, KM.only_dimensions = KM.only_dimensions,
           KM.complete_dimensions = KM.complete_dimensions, PS_dimensions =
           PS_dimensions, LSS_dimensions = LSS_dimensions, S_dimensions =
           S_dimensions, KM_perimeter = KM_perimeter, PS_perimeter = PS_perimeter,
           KM_weight = KM_weight, PS_weight = PS_weight,LSS_weight = LSS_weight,
```

```
                    S_weight = S_weight, KM_raw_material = KM_raw_material,PS_raw_material =
                    PS_raw_material, LSS_raw_material = LSS_raw_material, S_raw_material =
                    S_raw_material, KM_cortex_blanks = KM_cortex_blanks, PS_cortex_blanks =
                    PS_cortex_blanks, KM_back = KM_back, PS_back = PS_back, KM_edge_retouch =
                    KM_edge_retouch, PS_edge_retouch = PS_edge_retouch, LSS_edge_retouch =
                    LSS_edge_retouch, S_edge_retouch = S_edge_retouch, KM_morpho.type =
                    KM_morpho.type, PS_morpho.type = PS_morpho.type, KM_Pradnik.method =
                    KM_Pradnik.method, PS_Pradnik.method = PS_Pradnik.method,
                    KM_lateralisation = KM_lateralisation, PS_lateralisation =
                    PS_lateralisation, LSS_type = LSS_type),
                    file = paste0(dir_out, file_out, ".xlsx"))
```

Save R object

```
saveObject(data_final, file = paste0(dir_out, file_out, ".Rbin"))
```

---

sessionInfo() and RStudio version

```
sessionInfo()
R version 4.0.2 (2020-06-22)
Platform: x86_64-w64-mingw32/x64 (64-bit)
Running under: Windows 10 x64 (build 19041)

Matrix products: default

locale:
[1] LC_COLLATE=German_Germany.1252  LC_CTYPE=German_Germany.1252
[3] LC_MONETARY=German_Germany.1252 LC_NUMERIC=C
[5] LC_TIME=German_Germany.1252

attached base packages:
[1] tools     stats     graphics  grDevices utils     datasets  methods
[8] base

other attached packages:
[1] dplyr_1.0.3       chron_2.3-56      data.table_1.13.6 R.utils_2.10.1
[5] R.oo_1.24.0       R.methodsS3_1.8.1 readxl_1.3.1      openxlsx_4.2.3

loaded via a namespace (and not attached):
 [1] Rcpp_1.0.6        knitr_1.31        magrittr_2.0.1    tidyselect_1.1.0
 [5] R6_2.5.0          rlang_0.4.10      stringr_1.4.0     xfun_0.20
 [9] DBI_1.1.1         ellipsis_0.3.1    htmltools_0.5.1.1 assertthat_0.2.1
[13] yaml_2.2.1        digest_0.6.27     tibble_3.0.6      lifecycle_0.2.0
[17] crayon_1.4.0      zip_2.1.1         purrr_0.3.4       vctrs_0.3.6
[21] glue_1.4.2        evaluate_0.14     rmarkdown_2.6     stringi_1.5.3
[25] pillar_1.4.7      compiler_4.0.2    cellranger_1.1.0  generics_0.1.0
[29] pkgconfig_2.0.3
```

RStudio version 1.3.1056.

END OF SCRIPT

Summary stats - Lithic analysis Balver Höhle

Lisa Schunk

2021-02-04

Goal of the script

This script computes standard descriptive statistics for each group.
The groups are based on:

24. Tool type
25. state of the tool (Complete, distal/proximal fragment, medial fragment)

It computes the following statistics:

26. n (sample size = length): number of measurements
27. smallest value (min)
28. largest value (max)
29. mean
30. median
31. standard deviation (sd)

```
dir_in <- "analysis/Balve/derived_data/"
dir_out <- "analysis/Balve/summary_stats/"
```

Raw data must be located in ~/analysis/Balve/derived_data/.
Formatted data will be saved in ~/analysis/Balve/summary_stats/. The knit directory for this script is the project directory.

Load packages

```
library(openxlsx)
Warning: package 'openxlsx' was built under R version 4.0.3
library(R.utils)
library(tools)
library(doBy)
Warning: package 'doBy' was built under R version 4.0.3
```

Get names, path and information of the file

```
data_file <- list.files(dir_in, pattern = "\\.xlsx$", full.names = TRUE)
md5_in <- md5sum(data_file)
info_in <- data.frame(file = basename(names(md5_in)), checksum = md5_in, row.names = NULL)
```

The checksum (MD5 hashes) of the imported file is

```
                       file                         checksum
1 Balve_lithic_analysis.xlsx a4d7b432556150ee5eb0e3ea35ac69d1
```

Load data into R object

```
imp_data <- loadObject(paste0(dir_in, "Balve_lithic_analysis.Rbin"))
```

The imported file is: "~/analysis/Balve/derived_data/Balve_lithic_analysis.xlsx"

Define numeric variables

```
# changes the order of columns
imp_data <- imp_data[c(1:22, 27,23:26, 28:34)]
num.var <-19:23
```

The following variables will be used:

```
[19] length
[20] width
[21] thickness
[22] weight
[23] thickness.back
```

Compute summary statistics

Create function to compute the statistics at once

```
nminmaxmeanmedsd <- function(x){
  y <- x[!is.na(x)]
  n_test <- length(y)
  min_test <- min(y)
  max_test <- max(y)
  mean_test <- mean(y)
  med_test <- median(y)
  sd_test <- sd(y)
  out <- c(n_test, min_test, max_test, mean_test, med_test, sd_test)
  names(out) <- c("n", "min", "max", "mean", "median", "sd")
  return(out)
}
```

Compute the summary statistics

Dimensions

```
# Dimensions Keilmesser, Keilmesser-points, Pradnik scraper, scraper & Later sharpening spall
dimensions <- summaryBy(length + width + thickness ~ technological.class + artefact.state,
                        data = imp_data, FUN = nminmaxmeanmedsd)
str(dimensions)
'data.frame':   8 obs. of  20 variables:
 $ technological.class: chr  "Keilmesser" "Keilmesser" "Keilmesser" "lateral_sharpening_spall" ...
 $ artefact.state     : chr  "complete" "Keilmesser_tip" "semifinished_product" "complete" ...
 $ length.n           : num  158 21 12 110 4 3 27 12
 $ length.min         : num  29.7 18 42.7 12.4 20.5 ...
 $ length.max         : num  135.6 91.9 154.7 55.8 52.9 ...
 $ length.mean        : num  56.4 45.2 84.6 29.3 33.4 ...
 $ length.median      : num  52.6 43.2 72.6 27.6 30.2 ...
 $ length.sd          : num  16.59 16.58 35.21 9.18 14.31 ...
 $ width.n            : num  158 21 12 110 4 3 27 12
 $ width.min          : num  18.7 22.9 37.9 7 16.7 ...
 $ width.max          : num  81.4 53.2 91.7 29.9 20.6 ...
 $ width.mean         : num  34.1 35.6 54 17.4 18.3 ...
 $ width.median       : num  33.1 35.6 43.9 17 18 ...
 $ width.sd           : num  8.91 8.99 19.54 5.17 1.81 ...
```

```
 $ thickness.n        : num  158 21 12 110 4 3 27 12
 $ thickness.min      : num  7.35 9.53 13.6 2.14 5.66 ...
 $ thickness.max      : num  29.25 23.6 26.08 10.96 7.69 ...
 $ thickness.mean     : num  16.28 15.47 18.92 6.02 6.37 ...
 $ thickness.median   : num  15.67 15.31 18.34 5.87 6.07 ...
 $ thickness.sd       : num  4.208 3.418 4.157 2.012 0.899 ...
```

Save data

Format name of output file

```
file_out <- "Balve_lithic_analysis_stats"
```

The file will be saved as "~/analysis/Balve/summary_stats/.[ext]".

Write to XLSX

```
write.xlsx(list(dimensions = dimensions),
           file = paste0(dir_out, file_out, ".xlsx"))
```

Save R object

```
saveObject(list(dimensions = dimensions),
           file = paste0(dir_out, file_out, ".Rbin"))
```

sessionInfo() and RStudio version

```
sessionInfo()
R version 4.0.2 (2020-06-22)
Platform: x86_64-w64-mingw32/x64 (64-bit)
Running under: Windows 10 x64 (build 19041)

Matrix products: default

locale:
[1] LC_COLLATE=German_Germany.1252  LC_CTYPE=German_Germany.1252
[3] LC_MONETARY=German_Germany.1252 LC_NUMERIC=C
[5] LC_TIME=German_Germany.1252

attached base packages:
[1] tools     stats     graphics  grDevices utils     datasets  methods
[8] base

other attached packages:
[1] doBy_4.6.8        R.utils_2.10.1    R.oo_1.24.0       R.methodsS3_1.8.1
[5] openxlsx_4.2.3

loaded via a namespace (and not attached):
 [1] zip_2.1.1         Rcpp_1.0.6        compiler_4.0.2    pillar_1.4.7
 [5] digest_0.6.27     lattice_0.20-41   evaluate_0.14     lifecycle_0.2.0
 [9] tibble_3.0.6      gtable_0.3.0      pkgconfig_2.0.3   rlang_0.4.10
[13] Matrix_1.2-18     DBI_1.1.1         yaml_2.2.1        xfun_0.20
[17] dplyr_1.0.3       stringr_1.4.0     knitr_1.31        generics_0.1.0
[21] vctrs_0.3.6       grid_4.0.2        tidyselect_1.1.0  glue_1.4.2
[25] R6_2.5.0          rmarkdown_2.6     tidyr_1.1.2       purrr_0.3.4
[29] ggplot2_3.3.3     magrittr_2.0.1    backports_1.2.1   scales_1.1.1
[33] ellipsis_0.3.1    htmltools_0.5.1.1 MASS_7.3-51.6     assertthat_0.2.1
[37] colorspace_2.0-0  Deriv_4.1.2       stringi_1.5.3     munsell_0.5.0
[41] broom_0.7.4       crayon_1.4.0
```

RStudio version 1.3.1056.

END OF SCRIPT

Plots - Lithic analysis Balver Höhle

Lisa Schunk

2021-02-14

Goal of the script

This script reads the xlsx file (derived data) containing all the information gained through a lithic analysis.
The script will:

32. Read the xlsx file
33. Plot all relevant variables in various combinations
34. Save the plot as PDFs

```
dir_in <-  "analysis/Balve/derived_data/"
dir_out <- "analysis/Balve/plots/"
```

Raw data must be located in “analysis/Balve/derived_data/”.
Formatted data will be saved in “analysis/Balve/plots/”. The knit directory for this script is the project directory.

Load packages

```
library(openxlsx)
Warning: package 'openxlsx' was built under R version 4.0.3
library(readxl)
library(R.utils)
library(tools)
library(chron)
library(ggplot2)
Warning: package 'ggplot2' was built under R version 4.0.3
library(wesanderson)
library(dplyr)
Warning: package 'dplyr' was built under R version 4.0.3
library(ggsci)
```

Get name, path and information of the file

```
data_file <- list.files(dir_in, pattern = "\\.xlsx$", full.names = TRUE)
md5_in <- md5sum(data_file)
info_in <- data.frame(files = basename(names(md5_in)), checksum = md5_in,
                      row.names = NULL)
```

The checksum (MD5 hashes) of the imported files are:

```
                      files                         checksum
1 Balve_lithic_analysis.xlsx a4d7b432556150ee5eb0e3ea35ac69d1
```

Load data into R object

```
imp_data <- read.xlsx(xlsxFile = data_file, sheet = 1, startRow = 1,
                      colNames = TRUE,
                      rowNames = FALSE, skipEmptyRows = FALSE)
```

Data analsysis - plots

Histogram

Histogram dimensions - Keilmesser

```
# Load data sheet Keilmesser
KM_dim <- read.xlsx(xlsxFile = data_file, sheet = 3)
KM_dim <- KM_dim [ , ] %>% arrange(artefact.state)
KM.tip_dim <- KM_dim[-c(180:191), ]

# Keilmesser length
# Calculates the mean value for the plot and ascribes the N value
mean_length <- mean(KM.tip_dim$length, na.rm = TRUE)
n <- doBy::summaryBy(length ~ artefact.state, data = KM.tip_dim, FUN = length)
tag <- gsub(pattern = "_", replacement = " ", paste0(n[[1]], " (n = ", n[[2]],
                 ")"))

# Histogram Keilmesser length
KM.length <- ggplot(KM.tip_dim, aes(x = length, fill = artefact.state)) +
             geom_histogram(binwidth = 1) +
             labs(x = "length [mm]", y = "n", title = "",
             fill = "artefact state", size = 12) +
             theme_classic() +
             geom_vline(aes(xintercept = mean_length), linetype="dashed",
             size = 1) +
             geom_text(aes(y = mean_length, x = 70, label = round(mean_length,
                         1)), nudge_y = -48) +
             scale_fill_manual(values = wes_palette(n = 2, name =
             "FantasticFox1", type = "continuous"), labels = tag)

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "KM.length", ".pdf")
ggsave(filename = file_out, plot = KM.length, path = dir_out, device = "pdf",
          width = 170, height = 250, units = "mm")


# Keilmesser width
# Calculates the mean value for the plot and ascribes the N value
mean_width <- mean(KM.tip_dim$width, na.rm = TRUE)
n <- doBy::summaryBy(width ~ artefact.state, data = KM.tip_dim, FUN = length)
tag <- gsub(pattern = "_", replacement = " ", paste0(n[[1]], " (n = ", n[[2]],
                          ")"))

# Histogram Keilmesser width
KM.width <- ggplot(KM.tip_dim, aes(x = width, fill = artefact.state)) +
            geom_histogram(binwidth = 1) +
            labs(x = "width [mm]", y = "n", title = "", fill = "artefact state",
            size = 12) +
            theme_classic() +
            geom_vline(aes(xintercept = mean_width), linetype = "dashed",
            size = 1) +
            geom_text(aes(y = mean_length, x = 45, label = round(mean_width, 1)),
            nudge_y = -45) +
            scale_fill_manual(values = wes_palette(n = 2, name = "FantasticFox1",
            type = "continuous"), labels = tag)

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "KM.width", ".pdf")
ggsave(filename = file_out, plot = KM.width, path = dir_out, device = "pdf",
          width = 170, height = 250, units = "mm")
```

```r
# Keilmesser thickness
# Calculates the mean value for the plot and ascribes the N value
mean_thickness <- mean(KM.tip_dim$thickness, na.rm = TRUE)
n <- doBy::summaryBy(thickness ~ artefact.state, data = KM.tip_dim, FUN = length)
tag <- gsub(pattern = "_", replacement = " ", paste0(n[[1]], " (n = ", n[[2]],
                                              ")"))

# Histogram Keilmesser thickness
KM.thickness  <- ggplot(KM.tip_dim, aes(y = thickness, fill = artefact.state)) +
                geom_histogram(binwidth = 1) +
                labs(y = "thickness [mm]", x = "n", title = "",
                fill = "artefact state", size = 12) +
                theme_classic() +
                geom_hline(aes(yintercept = mean_thickness),
                linetype = "dashed", size = 1) +
                geom_text(aes(y = mean_thickness, x = 20,
                label = round(mean_thickness, 1)), nudge_y = 1) +
                scale_fill_manual(values = wes_palette(n = 2,
                name = "FantasticFox1", type = "continuous"), labels = tag)

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "KM.thickness", ".pdf")
ggsave(filename = file_out, plot = KM.thickness, path = dir_out, device = "pdf",
        width = 250, height = 170, units = "mm")



# Keilmesser Back
# Load data sheet Keilmesser thickness back
KM_back <- read.xlsx(xlsxFile = data_file, sheet = 22)
KM_back <- KM_back[-c(159:191), ]

# Calculates the mean value for the plot and ascribes the N value
mean_KM_back <- mean(KM_back$thickness.back, na.rm = TRUE)
n <- doBy::summaryBy(thickness.back ~ artefact.state, data = KM_back,
                    FUN = length)
tag <- gsub(pattern = "_", replacement = " ", paste0(n[[1]],
                                     " (n = ", n[[2]], ")"))

# Histogram Keilmesser thickness back
KM.back  <- ggplot(KM_back, aes(y = thickness.back, fill = artefact.state)) +
                geom_histogram(binwidth = 1) +
                labs(x = "thickness [mm]", y = "n", title = "",
                fill = "artefact state", size = 12) +
                theme_classic() +
                geom_hline(aes(yintercept = mean_KM_back), linetype = "dashed",
                size = 1) +
                geom_text(aes(y = mean_KM_back, x = 16,
                label = round(mean_KM_back, 1)), nudge_y = -0.7) +
                scale_fill_manual(values = wes_palette(n = 2,
                name = "FantasticFox1", type = "continuous"), labels = tag)

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "KM.back", ".pdf")
ggsave(filename = file_out, plot = KM.back, path = dir_out, device = "pdf",
        width = 250, height = 170, units = "mm")
```

Histogram dimensions - Pradnik scraper

```r
# Load data sheet Pradnik scraper
PS_dim <- read.xlsx(xlsxFile = data_file, sheet = 7)

# Pradnik scraper length
```

```r
# Calculates the mean value for the plot and ascribes the N value
mean_PS_length <- mean(PS_dim$length, na.rm = TRUE)
n <- doBy::summaryBy(length ~ artefact.state, data = PS_dim, FUN = length)
tag <- gsub(pattern = "_", replacement = " ", paste0(n[[1]],
                                   " (n = ", n[[2]], ")"))

# Histogram Pradnik scraper length
PS.length <- ggplot(PS_dim, aes(x = length, fill = artefact.state)) +
            geom_histogram(binwidth = 1) +
            labs(x = "length [mm]", y = "n", title = "",
            fill = "artefact state", size = 12) +
            theme_classic() +
            geom_vline(aes(xintercept = mean_PS_length), linetype = "dashed",
            size = 1) +
            geom_text(aes(y = mean_PS_length, x = 55,
            label = round(mean_PS_length, 1)), nudge_y = -47) +
            scale_fill_manual(values = wes_palette(n = 1, name = "Chevalier1"),
            labels = tag)

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "PS.length", ".pdf")
ggsave(filename = file_out, plot = PS.length, path = dir_out, device = "pdf",
         width = 170, height = 250, units = "mm")


# Pradnik scraper width
# Calculates the mean value for the plot and ascribes the N value
mean_PS_width <- mean(PS_dim$width, na.rm = TRUE)
n <- doBy::summaryBy(width ~ artefact.state, data = PS_dim, FUN = length)
tag <- gsub(pattern = "_", replacement = " ", paste0(n[[1]],
                                   " (n = ", n[[2]], ")"))

# Histogram Pradnik scraper width
PS.width <- ggplot(PS_dim, aes(x = width, fill = artefact.state)) +
           geom_histogram(binwidth = 1) +
           labs(x = "width [mm]", y = "n", title = "", fill = "artefact state",
           size = 12) +
           theme_classic() +
           geom_vline(aes(xintercept = mean_PS_width), linetype="dashed",
           size = 1) +
           geom_text(aes(y = mean_PS_width, x = 30, label = round(mean_PS_width,
           1)), nudge_y = -30) +
           scale_fill_manual(values = wes_palette(n = 1, name = "Chevalier1"), labels = tag)

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "PS.width", ".pdf")
ggsave(filename = file_out, plot = PS.width, path = dir_out, device = "pdf",
         width = 170, height = 250, units = "mm")


# Pradnik scraper thickness
# Calculates the mean value for the plot and ascribes the N value
mean_PS_thickness <- mean(PS_dim$thickness, na.rm = TRUE)
n <- doBy::summaryBy(thickness ~ artefact.state, data = PS_dim, FUN = length)
tag <- gsub(pattern = "_", replacement = " ", paste0(n[[1]],
                                   " (n = ", n[[2]], ")"))

# Histogram Pradnik scraper thickness
PS.thickness <- ggplot(PS_dim, aes(y = thickness, fill = artefact.state)) +
               geom_histogram(binwidth = 1) +
               labs(y = "thickness [mm]", x = "n", title = "",
               fill = "artefact state", size = 12) +
```

```
            theme_classic() +
            geom_hline(aes(yintercept = mean_PS_thickness),
            linetype = "dashed", size = 1) +
            geom_text(aes(y = mean_PS_thickness, x = 5.9,
            label = round(mean_PS_thickness, 1)), nudge_y = -1) +
            scale_fill_manual(values = wes_palette(n = 1, name =
            "Chevalier1"), labels = tag)

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "PS.thickness", ".pdf")
ggsave(filename = file_out, plot = PS.thickness, path = dir_out, device = "pdf",
       width = 250, height = 170, units = "mm")


# Back Pradnik scraper thickness
# Load data sheet Pradnik scraper thickness back
PS_back <- read.xlsx(xlsxFile = data_file, sheet = 23)

# Calculates the mean value for the plot and ascribes the N value
mean_PS_back <- mean(PS_back$thickness.back, na.rm = TRUE)
n <- doBy::summaryBy(thickness.back ~ artefact.state, data = PS_back,
                FUN = length)
tag <- gsub(pattern = "_", replacement = " ", paste0(n[[1]], " (n = ", n[[2]],
                                            ")"))

# Histogram Pradnik scraper thickness back
PS.back  <- ggplot(PS_back, aes(y = thickness.back, fill = artefact.state)) +
            geom_histogram(binwidth = 0.8) +
            labs(y = "thickness [mm]", x = "n", title = "",
            fill = "artefact state", size = 12) +
            theme_classic() +
            geom_hline(aes(yintercept = mean_PS_back), linetype = "dashed",
            size = 1) +
            geom_text(aes(y = mean_PS_back, x = 2.9,
            label = round(mean_PS_back, 1)), nudge_y = -0.8) +
            scale_fill_manual(values = wes_palette(n = 1, name =
            "Chevalier1"), labels = tag)

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "PS.back", ".pdf")
ggsave(filename = file_out, plot = PS.back, path = dir_out, device = "pdf",
       width = 250, height = 170, units = "mm")
Warning: Removed 1 rows containing non-finite values (stat_bin).
```

Histogram dimension - Lateral sharpening spall

```
# Load data sheet lateral sharpening spall
LSS_dim <- read.xlsx(xlsxFile = data_file, sheet = 8)
LSS_dim <- LSS_dim [-c(111:117), ]

# Lateral sharpening spall length
# Calculates the mean value for the plot and ascribes the N value
mean_LSS_length <- mean(LSS_dim$length, na.rm = TRUE)
n <- doBy::summaryBy(length ~ artefact.state, data = LSS_dim, FUN = length)
tag <- gsub(pattern = "_", replacement = " ", paste0(n[[1]], " (N = ", n[[2]],
                                            ")"))
# Histogram lateral sharpening spall length
LSS.length <- ggplot(LSS_dim, aes(x = length, fill = artefact.state)) +
          geom_histogram(binwidth = 1) +
          labs(x = "length [mm]", y = "N", title = "",
          fill = "artefact state", size = 12) +
          theme_classic() +
          geom_vline(aes(xintercept = mean_LSS_length), linetype = "dashed",
```

```r
              size = 1) +
              geom_text(aes(y = mean_LSS_length, x = 33,
              label = round(mean_LSS_length, 1)), nudge_y = -20) +
              scale_fill_manual(values = wes_palette(n = 1, name = "Royal1"),
              labels = tag)

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "LSS.length", ".pdf")
ggsave(filename = file_out, plot = LSS.length, path = dir_out, device = "pdf",
          width = 170, height = 250, units = "mm")



# Lateral sharpening spall width
# Calculates the mean value for the plot and ascribes the N value
mean_LSS_width <- mean(LSS_dim$width, na.rm = TRUE)
n <- doBy::summaryBy(width ~ artefact.state, data = LSS_dim, FUN = length)
tag <- gsub(pattern = "_", replacement = " ", paste0(n[[1]], " (n = ", n[[2]],
                                                     ")"))

# Histogram lateral sharpening spall width
LSS.width <- ggplot(LSS_dim, aes(x = width, fill = artefact.state)) +
             geom_histogram(binwidth = 1) +
             labs(x = "width [mm]", y = "n", title = "", fill = "artefact state",
             size = 12) +
             theme_classic() +
             geom_vline(aes(xintercept = mean_LSS_width), linetype = "dashed",
             size = 1) +
             geom_text(aes(y = mean_LSS_width, x = 19,
             label = round(mean_LSS_width, 1)), nudge_y = -7) +
             scale_fill_manual(values = wes_palette(n = 1, name = "Royal1"),
                               labels = tag)

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "LSS.width", ".pdf")
ggsave(filename = file_out, plot = LSS.width, path = dir_out, device = "pdf",
          width = 170, height = 250, units = "mm")



# Lateral sharpening spall thickness
# Calculates the mean value for the plot and ascribes the N value
mean_LSS_thickness <- mean(LSS_dim$thickness, na.rm = TRUE)
n <- doBy::summaryBy(thickness ~ artefact.state, data = LSS_dim, FUN = length)
tag <- gsub(pattern = "_", replacement = " ", paste0(n[[1]], " (n = ", n[[2]],
                                                     ")"))

# Histogram lateral sharpening spall thickness
LSS.thickness <- ggplot(LSS_dim, aes(y = thickness, fill = artefact.state)) +
                 geom_histogram(binwidth = 0.8) +
                 labs(y = "thickness[mm]", x = "n", title = "",
                 fill = "artefact state", size = 12) +
                 theme_classic() +
                 geom_hline(aes(yintercept = mean_LSS_thickness),
                 linetype = "dashed", size = 1) +
                 geom_text(aes(y = mean_LSS_thickness, x = 23.1,
                 label = round(mean_LSS_thickness, 2)), nudge_y = -0.3) +
                 scale_fill_manual(values = wes_palette(n = 1, name = "Royal1"),
                 labels = tag)

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "LSS.thickness",
                   ".pdf")
ggsave(filename = file_out, plot = LSS.thickness, path = dir_out,
         device = "pdf", width = 250, height = 170, units = "mm")
```

Scatterplot

Length-width ratio

```
# Load data sheet Keilmesser
KM_comp_dim <- read.xlsx(xlsxFile = data_file, sheet = 6)

# Keilmesser length VS width
# Ascribes the N value
n <- doBy::summaryBy(length + width ~ artefact.state, data = KM_comp_dim,
                    FUN = length)
tag <- gsub(pattern = "_", replacement = " ", paste0(n[[1]], " (n = ", n[[2]],
                                                   ")"))

# Scatterplot Keilmesser (complete + point) length VS width
KM.length_width <- ggplot(KM_comp_dim, aes(y = length, x = width,
                                          fill = artefact.state)) +
                  geom_point(size = 3, shape = 21) +
                  labs(y = "length [mm]", x = "width [mm]", title = "",
                  fill = "artefact state", size = 12) +
                  xlim(0, 90) + ylim(0, 160) +
                  theme_classic() +
                  scale_fill_manual(values = wes_palette(n = 2,
                  name = "FantasticFox1", type = "continuous"), labels = tag)

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "KM.length_width",
                  ".pdf")
ggsave(filename = file_out, plot = KM.length_width, path = dir_out,
        device = "pdf", width = 170, height = 250, units = "mm")


# Pradnik scraper length VS width
# Ascribes the N value
n <- doBy::summaryBy(length + width ~ artefact.state, data = PS_dim, FUN = length)
tag <- gsub(pattern = "_", replacement = " ", paste0(n[[1]], " (n = ", n[[2]],
                                                   ")"))

# Scatterplot Pradnik scraper length VS width
PS.length_width <- ggplot(PS_dim, aes(y = length, x = width,
                                     fill = artefact.state)) +
                  geom_point(size = 3, shape = 21) +
                  labs(y = "length [mm]", x = "width [mm]", title = "",
                  fill = "artefact state", size = 12) +
                  xlim(0, 70) + ylim(0, 80) +
                  theme_classic() +
                  scale_fill_manual(values = wes_palette(n = 6,
                  name = "Chevalier1", type = "continuous"), labels = tag)

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "PS.length_width",
                  ".pdf")
ggsave(filename = file_out, plot = PS.length_width, path = dir_out,
       device = "pdf", width = 170, height = 250, units = "mm")


# Lateral sharpening spall length VS width
# Defines only the rows with complete LSS
LSS.comp_dim <- LSS_dim[1:110,]

# Lateral sharpening spall length VS width
# Ascribes the N value
```

```r
n <- doBy::summaryBy(length + width ~ artefact.state, data = LSS.comp_dim,
                     FUN = length)
tag <- gsub(pattern = "_", replacement = " ", paste0(n[[1]], " (n = ", n[[2]],
                                                     ")"))

# Scatterplot lateral sharpening spall length VS width
LSS.length_width <- ggplot(LSS.comp_dim, aes(y = length, x = width,
                                             fill = artefact.state)) +
                    geom_point(size = 3, shape = 21) +
                    labs(y = "length [mm]", x = "width [mm]", title = "",
                    fill = "artefact state", size = 12) +
                    xlim(0, 45) + ylim(0, 65) +
                    theme_classic() +
                    scale_fill_manual(values = wes_palette(n = 2,
                    name = "Royal1", type = "continuous"), labels = tag)

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "LSS.length_width",
                   ".pdf")
ggsave(filename = file_out, plot = LSS.length_width, path = dir_out,
        device = "pdf", width = 170, height = 250, units = "mm")


# Keilmesser (complete) + Pradnik scraper length VS width
# Load data sheet dimensions
dim <- read.xlsx(xlsxFile = data_file, sheet = 2)
# Defines only the relevant rows
KM.PS_dim <- dim[c(1:191, 309:335), ]  %>% arrange(artefact.state)
KM.PS_dim <- KM.PS_dim[1:185,]

# Keilmesser (complete) + Pradnik scraper length VS width
# Ascribes the N value
n <- doBy::summaryBy(length + width ~ technological.class, data = KM.PS_dim,
                     FUN = length)
tag <- gsub(pattern = "_", replacement = " ", paste0(n[[1]], " (n = ", n[[2]],
                                                             ")"))

# Scatterplot Keilmesser (complete) + Pradnik scraper length VS width
KM.PS.length_width <- ggplot(KM.PS_dim, aes(y = length, x = width,
                                            fill = technological.class)) +
                      geom_point(size = 3, shape = 21) +
                      labs(y = "length [mm]", x = "width [mm]", title = "",
                      fill = "artefact category", size = 12) +
                      xlim(0, 100) + ylim(0, 150) +
                      theme_classic() +
                      scale_fill_manual(values = wes_palette(n = 3, name =
                      "GrandBudapest1", type = "continuous"), labels = tag)

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "KM.PS.length_width",
                   ".pdf")
ggsave(filename = file_out, plot = KM.PS.length_width, path = dir_out,
       device = "pdf", width = 170, height = 250, units = "mm")

# Keilmesser (complete): length-width combined with morpho type
# Load data sheet Keilmesser morpho type
KM_morpho.type <- read.xlsx(xlsxFile = data_file, sheet = 28)

# Ascribes the N value
n <- doBy::summaryBy(length + width ~ morpho.type, data = KM_morpho.type,
                     FUN = length)
tag <- gsub(pattern = "_", replacement = " ", paste0(n[[1]], " (n = ", n[[2]],
```

```
                                    ")"))


# Scatterplot Keilmesser (complete): length-width combined with morpho type
KM.width_length_morpho <- ggplot(KM_morpho.type, aes(y = length, x = width,
                                    fill = morpho.type)) +
                geom_point(size = 2, shape = 21) +
                labs(y = "length [mm]", x = "width [mm]", title = " ",
                fill = "Keilmesser shape", size = 12) +
                xlim(0, 100) + ylim(0, 150) +
                theme_classic() +
                scale_fill_manual(values = wes_palette(n = 7,name =
                "FantasticFox1", type = "continuous"), labels = tag)

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "KM.width_length_morpho", ".pdf")
ggsave(filename = file_out, plot = KM.width_length_morpho, path = dir_out,
       device = "pdf", width = 170, height = 250, units = "mm")
Warning: Removed 1 rows containing missing values (geom_point).
```

Barplot

Morphotype

```
# Keilmesser morpho type
# Load data sheet Keilmesser morpho type
KM_morpho.type <- read.xlsx(xlsxFile = data_file, sheet = 28)
# Defines only the rows with complete Keilmesser
KM_morpho.type <- KM_morpho.type[1:158,]

# Barplot Keilmesser morpho type
KM.morpho.type <- ggplot(data = KM_morpho.type) + aes(x = morpho.type,
                                    fill = morpho.type) +
   geom_bar(stat = "count", width = 0.5, fill = c("#899DA4", "#A46F65",
              "#BF4226", "#D76848", "#EBB99A", "#E8B37B")) +
   theme_classic() +
   theme(legend.position = "none") +
   labs(x = " ", y = "n")

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "KM.morpho.type",
              ".pdf")
ggsave(filename = file_out, plot = KM.morpho.type, path = dir_out,
       device = "pdf", width = 170, height = 200, units = "mm")
```

Barplot

Edge retouch

```
# Keilmesser edge retouch
# Load data sheet Keilmesser edge retouch
KM_edge <- read.xlsx(xlsxFile = data_file, sheet = 24)
# Defines only the rows with complete Keilmesser and Keilmesser tips
KM_edge <- KM_edge[-c(180:191),]

# Barplot Keilmesser edge retouch
KM.edge <- ggplot(data = KM_edge) + aes(x = retouch.type.edge,
                            fill = retouch.type.edge) +
   geom_bar(stat = "count", width = 0.5, fill = c ("#798E87", "#C27D38",
   "#972D15", "#29211F")) +
   theme_classic() +
   theme(legend.position = "none") +
   labs(x = " ", y = "n")
```

```r
file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "KM.edge", ".pdf")
ggsave(filename = file_out, plot = KM.edge, path = dir_out, device = "pdf",
       width = 170, height = 200, units = "mm")


# Pradnik scraper edge retouch
# Load data sheet Pradnik scraper edge retouch
PS_edge <- read.xlsx(xlsxFile = data_file, sheet = 25)
# Defines only the rows with complete Keilmesser and Keilmesser tips
PS_edge <- PS_edge[-c(3:5),]

# Barplot Pradnik scraper edge retouch
PS.edge <- ggplot(data = PS_edge) + aes(x = retouch.type.edge,
                                    fill = retouch.type.edge) +
  geom_bar(stat = "count", width = 0.5, fill = c ("#798E87", "#C27D38",
  "#972D15", "#29211F")) +
  theme_classic() +
  theme(legend.position = "none") +
  labs(x = " ", y = "n")

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "PS.edge", ".pdf")
ggsave(filename = file_out, plot = PS.edge, path = dir_out, device = "pdf",
       width = 170, height = 200, units = "mm")
```

Barplot

Raw material

```r
# Keilmesser raw material
# Load data sheet Keilmesser raw material
KM_raw_material <- read.xlsx(xlsxFile = data_file, sheet = 16)

# Barplot Keilmesser raw material
KM.raw_material <- ggplot(data = KM_raw_material) + aes(x = raw.material,
                                                  fill = raw.material) +
  geom_bar(stat = "count", width = 0.22, fill = c("#D69C4E", "#046C9A")) +
  theme_classic() +
  theme(legend.position = "none") +
  labs(x = " ", y = "n") +
  scale_x_discrete(labels=c("Baltic flint", "silicified schist"))

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "KM.raw_material",
                   ".pdf")
ggsave(filename = file_out, plot = KM.raw_material, path = dir_out,
       device = "pdf")


# Pradnik scraper raw material
# Load data sheet Pradnik scraper raw material
PS_raw_material <- read.xlsx(xlsxFile = data_file, sheet = 17)

# Barplot Pradnik scraper raw material
PS.raw_material <- ggplot(data = PS_raw_material) + aes(x = raw.material,
                                                  fill = raw.material) +
  geom_bar(stat = "count", width = 0.08, fill = c("#046C9A")) +
  theme_classic() +
  theme(legend.position = "none") +
  labs(x = " ", y = "n") +
  scale_x_discrete(labels=c("silicified schist"))
```

```
file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "PS.raw_material",
                   ".pdf")
ggsave(filename = file_out, plot = PS.raw_material, path = dir_out,
        device = "pdf")



# All tool types raw material
# Load data sheet all tool types raw material
all_raw_material <- read.xlsx(xlsxFile = data_file, sheet = 1)

# Barplot Pradnik scraper raw material
all.raw_material <- ggplot(data = all_raw_material) + aes(x = raw.material,
                                                          fill = raw.material) +
     geom_bar(stat = "count", width = 0.24, fill = c("#D69C4E", "#046C9A")) +
     theme_classic() +
     theme(legend.position = "none") +
     labs(x = "  ", y = "n") +
     scale_x_discrete(labels=c("Baltic flint", "silicified schist"))

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "all.raw_material",
                     ".pdf")
ggsave(filename = file_out, plot = all.raw_material, path = dir_out,
        device = "pdf")
```

Barplot

Morphology back

```
# Keilmesser morphology back
# Load data sheet Keilmesser morphology back
KM_back <- read.xlsx(xlsxFile = data_file, sheet = 22)

# Barplot Keilmesser morphology back
KM.back_morpho <- ggplot(data = KM_back) + aes(x = morphology.back,
                                               fill = morphology.back) +
     geom_bar(stat = "count", width = 0.5, fill = c("#518BA0", "#497C80",
     "#D69C4E", "#729394","#B9C7AD")) +
     theme_classic() +
     theme(legend.position = "none") +
     labs(x = "  ", y = "n") +
     scale_x_discrete(labels=c("cortex + partly retouched", "cortex/unworked",
                              "N/A", "partly retouched", "retouched"))

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "KM.back_morpho",
                   ".pdf")
ggsave(filename = file_out, plot = KM.back_morpho, path = dir_out,
        device = "pdf",width = 250, height = 170, units = "mm")



# Pradnik scraper morphology back
# Load data sheet Pradnik scraper morphology back
PS_back <- read.xlsx(xlsxFile = data_file, sheet = 23)

# Barplot Pradnik scraper morphology back
PS.back_morpho <- ggplot(data = PS_back) + aes(x = morphology.back,
                                               fill = morphology.back) +
     geom_bar(stat = "count", width = 0.4, fill = c("#518BA0", "#497C80",
                                                   "#D69C4E", "#729394")) +
     theme_classic() +
     theme(legend.position = "none") +
```

```
    labs(x = " ", y = "n") +
    scale_x_discrete(labels=c("cortex + partly retouched", "cortex/unworked",
                              "N/A", "partly retouched", "retouched")) +
    scale_fill_manual(values = wes_palette(n = 7, name = "Darjeeling2",
                                           type = "continuous"))

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "PS.back_morpho",
                   ".pdf")
ggsave(filename = file_out, plot = PS.back_morpho, path = dir_out,
       device = "pdf",width = 250, height = 170, units = "mm")



# Keilmesser blanks
# Load data sheet Keilmesser blanks

KM_cortex_blanks <- read.xlsx(xlsxFile = data_file, sheet = 20)
# Ascribes the N value
n <- doBy::summaryBy(blank ~ cortex, data = KM_cortex_blanks, FUN = length)
tag <- gsub(pattern = "_", replacement = " ", paste0(n[[1]], " (n = ", n[[2]],
                                                    ")"))

# Barplot Keilmesser blanks
KM.cortex_blanks <- ggplot(data = KM_cortex_blanks) + aes(x = blank,
                                                    fill = cortex) +
    geom_bar(stat = "count", width = 0.4) +
    theme_classic() +
    labs(x = " ", y = "n") +
    scale_x_discrete(labels=c("core", "flake", "N/A")) +
    scale_fill_manual(values = wes_palette(n = 7, name = "Darjeeling2",
                                           type = "continuous"), labels = tag)

file_out <- paste0(file_path_sans_ext(info_in[["file"]]),
                   "KM.cortex_blanks", ".pdf")
ggsave(filename = file_out, plot = KM.cortex_blanks, path = dir_out,
       device = "pdf")



# Pradnik scraper blanks
# Load data sheet Pradnik scraper blanks
PS_cortex_blanks <- read.xlsx(xlsxFile = data_file, sheet = 21)

# Ascribes the N value
n <- doBy::summaryBy(blank ~ cortex, data = PS_cortex_blanks, FUN = length)
tag <- gsub(pattern = "_", replacement = " ", paste0(n[[1]],
                                                    " (n = ", n[[2]], ")"))

# Barplot Pradnik scraper blanks
PS.cortex_blanks <- ggplot(data = PS_cortex_blanks) + aes(x = blank,
                                                    fill = cortex) +
    geom_bar(stat = "count", width = 0.3) +
    theme_classic() +
    labs(x = " ", y = "n") +
    scale_x_discrete(labels=c("core", "flake", "N/A")) +
    scale_fill_manual(values = wes_palette(n = 7, name = "Darjeeling2",
                                           type = "continuous"), labels = tag)

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "PS.cortex_blanks", ".pdf")
ggsave(filename = file_out, plot = PS.cortex_blanks, path = dir_out, device = "pdf")
```

Barplot

Pradnik method

```
# Keilmesser application Pradnik method
# Load data sheet Keilmesser Pradnik method
KM_Pradnik.method <- read.xlsx(xlsxFile = data_file, sheet = 30)

# Barplot Keilmesser Pradnik method
KM.PM <- ggplot(data = KM_Pradnik.method) + aes(x = application.Pradnik.method,
                                   fill = application.Pradnik.method) +
    geom_bar(stat = "count", width = 0.3) +
    theme_classic() +
    labs(x = " ", y = "n") +
    theme(legend.position = "none") +
    scale_x_discrete(labels=c("no", "N/A", "yes")) +
    scale_fill_manual(values = wes_palette(n = 5, name = "GrandBudapest1",
                                 type = "continuous"))

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "KM.PM", ".pdf")
ggsave(filename = file_out, plot = KM.PM, path = dir_out, device = "pdf")
```

Barplot

Lateralisation

```
# Keilmesser lateralisation
# Load data sheet Keilmesser lateralisation
KM_lateralisation <- read.xlsx(xlsxFile = data_file, sheet = 32)
 # Barplot Keilmesser lateralisation
KM.lat <- ggplot(data = KM_lateralisation) + aes(x = tool.lateralisation,
        fill = tool.lateralisation) +
        geom_bar(stat = "count", width = 0.3) +
        theme_classic() +
        labs(x = " ", y = "n") +
        theme(legend.position = "none") +
        scale_fill_manual(values = wes_palette(n = 9, name = "Royal1",
                                  type = "continuous"))

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "KM.lat", ".pdf")
ggsave(filename = file_out, plot = KM.lat, path = dir_out, device = "pdf")


# Pradnik scraper lateralisation
# Load data sheet Pradnik scraper lateralisation
PS_lateralisation <- read.xlsx(xlsxFile = data_file, sheet = 33)

# Pradnik scraper lateralisation
# Load data sheet Pradnik scraper lateralisation
PS_lateralisation <- read.xlsx(xlsxFile = data_file, sheet = 33)
# Barplot Keilmesser lateralisation
PS.lat <- ggplot(data = PS_lateralisation) + aes(x = tool.lateralisation,
        fill = tool.lateralisation) +
        geom_bar(stat = "count", width = 0.3) +
        theme_classic() +
        labs(x = " ", y = "n") +
        theme(legend.position = "none") +
        scale_fill_manual(values = wes_palette(n = 9, name = "Royal1",
                                  type = "continuous"))
```

```
file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "PS.lat", ".pdf")
ggsave(filename = file_out, plot = PS.lat, path = dir_out, device = "pdf")
```

Barplot

Barplot lateral resharpening spall type

```
# Lateral resharpening spall type
# Load data sheet lateral resharpening spall type
LSS_type <- read.xlsx(xlsxFile = data_file, sheet = 34)

# Ascribes the N value
n <- doBy::summaryBy(type.lateral.sharpening.spall ~ tool.lateralisation,
                     data = LSS_type, FUN = length)
tag <- gsub(pattern = "_", replacement = " ", paste0(n[[1]],
                                                      " (n = ", n[[2]], ")"))

# Barplot lateral resharpening spall type
LSS.type <- ggplot(data = LSS_type) + aes(x = type.lateral.sharpening.spall,
                                          fill = tool.lateralisation) +
    geom_bar(stat = "count", width = 0.2) +
    theme_classic() +
    labs(x = " ", y = "n") +
    labs(fill = "tool lateralisation") +
    scale_x_discrete() +
    scale_fill_manual(values = wes_palette(n = 9, name = "Royal1",
    type = "continuous"), labels = tag)

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "LSS.type", ".pdf")
ggsave(filename = file_out, plot = LSS.type, path = dir_out, device = "pdf")
```

Ternary plot

Perimeter

```
library(ggtern)
# Perimeter Keilmesser
# Load data sheet Keilmesser perimeter
KM_perimeter <- read.xlsx(xlsxFile = data_file, sheet = 10)
# Defines only the rows with complete Keilmesser
KM_perimeter <- KM_perimeter[1:158,]

# Ternary diagram Keilmesser perimeter
KM.perimeter  <- ggtern(data = KM_perimeter, aes(x = perimeter.distal.posterior.part, y = perimeter.active.edge, z =
perimeter.basis.back)) +
              geom_point(aes(colour = morpho.type)) +
              theme_bw() +
              scale_colour_startrek() +
              theme_hidetitles() +
              theme_showarrows() +
              xlab("distal posterior part")+
              ylab("active edge")+
              zlab("basis + back")+
              labs(colour = "Keilmesser shape") +
              tern_limits(labels=c(0, 20, 40, 60, 80, 100)) +
              theme_rotate(degrees = 330)


file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "KM.perimeter", ".pdf")
ggsave(filename = file_out, plot = KM.perimeter, path = dir_out, device = "pdf")
```

---

sessionInfo() and RStudio version

```
sessionInfo()
R version 4.0.2 (2020-06-22)
Platform: x86_64-w64-mingw32/x64 (64-bit)
Running under: Windows 10 x64 (build 19041)

Matrix products: default

locale:
[1] LC_COLLATE=German_Germany.1252  LC_CTYPE=German_Germany.1252
[3] LC_MONETARY=German_Germany.1252 LC_NUMERIC=C
[5] LC_TIME=German_Germany.1252

attached base packages:
[1] tools     stats     graphics  grDevices utils     datasets  methods
[8] base

other attached packages:
 [1] ggtern_3.3.0      ggsci_2.9         dplyr_1.0.3       wesanderson_0.3.6
 [5] ggplot2_3.3.3     chron_2.3-56      R.utils_2.10.1    R.oo_1.24.0
 [9] R.methodsS3_1.8.1 readxl_1.3.1      openxlsx_4.2.3

loaded via a namespace (and not attached):
 [1] tidyselect_1.1.0   xfun_0.20          purrr_0.3.4        lattice_0.20-41
 [5] latex2exp_0.4.0    colorspace_2.0-0   vctrs_0.3.6        generics_0.1.0
 [9] doBy_4.6.8         htmltools_0.5.1.1  compositions_2.0-1 yaml_2.2.1
[13] rlang_0.4.10       pillar_1.4.7       glue_1.4.2         withr_2.4.1
[17] DBI_1.1.1          plyr_1.8.6         lifecycle_0.2.0    robustbase_0.93-7
[21] stringr_1.4.0      munsell_0.5.0      gtable_0.3.0       cellranger_1.1.0
[25] zip_2.1.1          evaluate_0.14      labeling_0.4.2     knitr_1.31
[29] DEoptimR_1.0-8     proto_1.0.0        broom_0.7.4        Rcpp_1.0.6
[33] scales_1.1.1       backports_1.2.0    farver_2.0.3       gridExtra_2.3
[37] Deriv_4.1.2        tensorA_0.36.2     digest_0.6.27      stringi_1.5.3
[41] grid_4.0.2         magrittr_2.0.1     tibble_3.0.5       crayon_1.4.0
[45] tidyr_1.1.2        pkgconfig_2.0.3    bayesm_3.1-4       ellipsis_0.3.1
[49] MASS_7.3-53        Matrix_1.2-18      assertthat_0.2.1   rmarkdown_2.6
[53] R6_2.5.0           compiler_4.0.2
```

RStudio version 1.3.1056.

END OF SCRIPT

Import - Lithic analysis Ramioul

Lisa Schunk

2021-02-04

Goal of the script

This script reads the xlsx file (database techno-typological analysis) generated with E4 and formats the data for a statistical analysis.
The script will:

35. Reads in the original xlsx file
36. Changes and sort the data in order to do stats
37. Saves the data as a new xlsx file and R object

```
dir_in <-  "analysis/Ramioul/raw_data/"
dir_out <- "analysis/Ramioul/derived_data/"
```

Raw data must be located in “analysis/Ramioul/raw_data/”.
Formatted data will be saved in “analysis/Ramioul/derived_data/”. The knit directory for this script is the project directory.

Load packages

```
library(openxlsx)
Warning: package 'openxlsx' was built under R version 4.0.3
library(readxl)
library(R.utils)
library(tools)
library(data.table)
Warning: package 'data.table' was built under R version 4.0.3
library(chron)
library(dplyr)
Warning: package 'dplyr' was built under R version 4.0.3
```

Get name, path and information of the file

```
data_file <- list.files(dir_in, pattern = "\\.xlsx$", full.names = TRUE)
md5_in <- md5sum(data_file)
info_in <- data.frame(files = basename(names(md5_in)), checksum = md5_in,
                      row.names = NULL)
```

The checksum (MD5 hashes) of the imported files are:

```
        files                         checksum
1 Ramioul.xlsx 20e268e7a32dbda976241b3124c73557
```

Read in original xlsx-file

```
imp_data <- read.xlsx(xlsxFile = data_file, sheet = 1, startRow = 1, colNames = TRUE,
                      rowNames = FALSE, skipEmptyRows = FALSE)
#select the columns to keep
keep_col <- c(1:2, 9:19, 21:35, 37:38, 40:43)
```

```
data_final <- imp_data[,keep_col]

data_final$length <- as.numeric(data_final$length)
data_final$width <- as.numeric(data_final$width)
data_final$thickness <- as.numeric(data_final$thickness)
data_final$weight <- as.numeric(data_final$weight)
data_final$perimeter.basis.back <- as.numeric(data_final$perimeter.basis.back)
data_final$perimeter.arch <- as.numeric(data_final$perimeter.arch)
Error in `$<-.data.frame`(`*tmp*`, perimeter.arch, value = numeric(0)): replacement has 0 rows, data has 20
data_final$perimeter.active.edge <- as.numeric(data_final$perimeter.active.edge)
data_final$perimeter.total <- as.numeric(data_final$perimeter.total)
data_final$thickness.back <- as.numeric(data_final$thickness.back)

str(data_final)
'data.frame':   20 obs. of  34 variables:
 $ site                                : chr  "Ramioul" "Ramioul" "Ramioul" "Ramioul" ...
 $ ID                                  : chr  "R-001" "R-002" "R-003" "R-004" ...
 $ raw.material                        : chr  "baltic_flint" "baltic_flint" "baltic_flint" "baltic_flint" ...
 $ technological.class                 : chr  "Keilmesser" "Keilmesser" "scraper" "scraper" ...
 $ artefact.state                      : chr  "complete" "complete" "complete" "complete" ...
 $ blank                               : chr  "core" "core" "core" "flake" ...
 $ morpho.type                         : chr  "Balve" "Klausennische" NA NA ...
 $ cortex                              : chr  "YES" "YES" "YES" "YES" ...
 $ cortex.percentage                   : chr  "<25" "<25" "25-50" "25-50" ...
 $ cortex.location                     : chr  "back" "back" "back" "medial_dorsa" ...
 $ morphology.back                     : chr  "cortex/partly_retouched" "cortex/unworked" NA NA ...
 $ retouch.active.edge                 : chr  "YES" "YES" "YES" "YES" ...
 $ retouch.type.edge                   : chr  "bifacial" "semi-bifacial" "semi-bifacial" "unifacial" ...
 $ tip.morphology                      : chr  "rounded" "rounded" "rounded" "undeterminable" ...
 $ application.Pradnik.method          : chr  "YES" "YES" NA NA ...
 $ frequency.application.Pradnik.method: chr  "one" "one" NA NA ...
 $ type.lateral.sharpening.spall       : num  NA NA NA NA NA NA NA NA NA NA ...
 $ tool.lateralisation                 : chr  "dex." "dex." NA NA ...
 $ length                              : num  50 44 51 42 54 53 76 75 99 52 ...
 $ width                               : num  33 27 31 24 27 31 37 43 42 35 ...
 $ thickness                           : num  16 21 20 9 16 16 21 23 25 14 ...
 $ weight                              : num  0.025 0.02 0.029 0.01 0.016 0.018 0.062 0.066 0.075 0.0017 ...
 $ perimeter.basis.back                : num  6.7 6.4 6.5 0 0 5.7 9.5 7.3 0 8.2 ...
 $ perimeter.distal.posterior.part     : num  3 2.5 3.1 0 0 3.1 1.9 4.4 0 2 ...
 $ perimeter.active.edge               : num  5 4 4.9 0 0 4.4 6.5 7.6 0 4.5 ...
 $ perimeter.total                     : num  0 0 0 0 0 0 0 0 0 0 ...
 $ thickness.back                      : num  16 21 14 0 0 6 21 17 0 5 ...
 $ taphonomic.visual.inspection        : chr  "sharp_edges_and_patinated_surface" "sharp_edges_and_patinated_surface" "sharp_edges_and_patinated_surface" "sharp_edges_and_patinated_surface" ...
 $ tool.edges.preservation             : chr  "edges_preserved" "edges_preserved" "edges_preserved" "edges_preserved" ...
 $ macroscopically.visible.use-wear    : chr  "NO" "NO" "NO" "NO" ...
 $ use-wear.analysis                   : chr  "YES" "YES" "NO" "YES" ...
 $ 3D-scan                             : chr  "YES" "YES" "YES" "YES" ...
 $ schistosity                         : chr  "N/A" "N/A" "N/A" "N/A" ...
 $ orientation.schistosity             : num  NA NA NA NA NA NA NA NA NA NA ...
```

Data analsysis - sorting

Dimension

```
# keeps only columns relevant for dimensions and sorts them based on
# their technological class
keep_col <- c(1:2, 4:5,19:21)
dimensions <- data_final[, keep_col] %>% arrange(technological.class)
```

```r
KM_dimensions <- dimensions[3:11, ]
PS_dimensions <- dimensions[12:14, ]
F_dimensions <- dimensions[1:2, ]
S_dimensions <- dimensions[15:20, ]
```

Perimeter

```r
# keeps only columns relevant for perimeter measurements and sorts them
# based on their technological class
keep_col <- c(1:2, 4:5,7,23:26)
perimeter <- data_final[, keep_col] %>% arrange(technological.class)

KM_perimeter <- perimeter[3:11, ]
PS_perimeter <- perimeter[12:14, ]
```

Weight

```r
# keeps only columns relevant for weight measurements and sorts them based
# on their technological class
keep_col <- c(1:2, 4:5, 22)
weight <- data_final[, keep_col] %>% arrange(technological.class)

KM_weight <- weight[3:11, ]
PS_weight <- weight[12:14, ]
F_weight <- weight[1:2, ]
S_weight <- weight[15:20, ]
```

Raw material

```r
# keeps only columns relevant for raw material classification and sorts them
# based on their technological class
keep_col <- c(1:2, 4:5, 3)
raw_material <- data_final[, keep_col] %>% arrange(technological.class)

KM_raw_material <- raw_material[3:11, ]
PS_raw_material <- raw_material[12:14, ]
F_raw_material <- raw_material[1:2, ]
S_raw_material <- raw_material[15:20, ]
```

Cortex + blanks

```r
# keeps only columns relevant for cortex and blank classification and sorts them
# based on their technological class
keep_col <- c(1:2, 4:5, 6, 8:10)
cortex_blanks <- data_final[, keep_col] %>% arrange(technological.class)

KM_cortex_blanks <- cortex_blanks[3:11, ]
PS_cortex_blanks <- cortex_blanks[12:14, ]
```

Back

```r
# keeps only columns relevant for back modifications and sorts them based
# on their technological class
keep_col <- c(1:2, 4:5, 11, 27)
back <- data_final[, keep_col] %>% arrange(technological.class)

KM_back <- back[3:11, ]
PS_back <- back[12:14, ]
```

Edge retouch

```r
# keeps only columns relevant for edge retouch classification and sorts them
# based on their technological class
keep_col <- c(1:2, 4:5, 12:13, 29)
edge_retouch <- data_final[, keep_col] %>% arrange(technological.class)
```

```
KM_edge_retouch <- edge_retouch[3:11, ]
PS_edge_retouch <- edge_retouch[12:14, ]
F_edge_retouch <- edge_retouch[1:2, ]
S_edge_retouch <- edge_retouch[15:20, ]
```

Morpho type

```
# keeps only columns relevant for morpho type classification and sorts them
# based on their technological class
keep_col <- c(1:2, 4:5, 7, 19:21)
morpho.type <- data_final[, keep_col] %>% arrange(technological.class)

KM_morpho.type <- morpho.type[3:11, ]
PS_morpho.type <- morpho.type[12:14, ]
```

Application 'Pradnik method'

```
# keeps only columns relevant for 'morpho type 'Pradnik method' classification
# and sorts them based on their technological class
keep_col <- c(1:2, 4:5, 15:16)
Pradnik.method <- data_final[, keep_col] %>% arrange(technological.class)

KM_Pradnik.method <- Pradnik.method[3:11, ]
PS_Pradnik.method <- Pradnik.method[12:14, ]
```

Lateralisation

```
# keeps only columns relevant for lateralisation and sorts them based on their
# technological class
keep_col <- c(1:2, 4:5, 18)
lateralisation <- data_final[, keep_col] %>% arrange(technological.class)

KM_lateralisation <- lateralisation[3:11, ]
PS_lateralisation <- lateralisation[12:14, ]
```

Save data

Format name of output file

```
file_out <- "Ramioul_lithic_analysis"
```

The files will be saved as "~/Ramioul_lithic_analysis.[ext]".

Write to XLSX

```
write.xlsx(list(data = data_final, dimensions = dimensions, KM_dimensions = KM_dimensions,
                PS_dimensions = PS_dimensions, F_dimensions = F_dimensions, S_dimensions =
                 S_dimensions, KM_perimeter = KM_perimeter, PS_perimeter = PS_perimeter,
                 KM_weight = KM_weight, PS_weight = PS_weight, F_weight = F_weight,
                 S_weight = S_weight, KM_raw_material = KM_raw_material,PS_raw_material =
                 PS_raw_material, F_raw_material = F_raw_material, S_raw_material =
                 S_raw_material, KM_cortex_blanks = KM_cortex_blanks, PS_cortex_blanks =
                 PS_cortex_blanks, KM_back = KM_back, PS_back = PS_back, KM_edge_retouch
                 = KM_edge_retouch, PS_edge_retouch = PS_edge_retouch, F_edge_retouch =
                 F_edge_retouch, S_edge_retouch = S_edge_retouch, KM_morpho.type =
                 KM_morpho.type, PS_morpho.type = PS_morpho.type, KM_Pradnik.method =
                 KM_Pradnik.method, PS_Pradnik.method = PS_Pradnik.method,
                 KM_lateralisation = KM_lateralisation, PS_lateralisation =
                 PS_lateralisation),
                 file = paste0(dir_out, file_out, ".xlsx"))
```

Save R object

```
saveObject(data_final, file = paste0(dir_out, file_out, ".Rbin"))
```

---

sessionInfo() and RStudio version

```
sessionInfo()
R version 4.0.2 (2020-06-22)
Platform: x86_64-w64-mingw32/x64 (64-bit)
Running under: Windows 10 x64 (build 19041)

Matrix products: default

locale:
[1] LC_COLLATE=German_Germany.1252  LC_CTYPE=German_Germany.1252
[3] LC_MONETARY=German_Germany.1252 LC_NUMERIC=C
[5] LC_TIME=German_Germany.1252

attached base packages:
[1] tools     stats     graphics  grDevices utils     datasets  methods
[8] base

other attached packages:
[1] dplyr_1.0.3       chron_2.3-56      data.table_1.13.6 R.utils_2.10.1
[5] R.oo_1.24.0       R.methodsS3_1.8.1 readxl_1.3.1      openxlsx_4.2.3

loaded via a namespace (and not attached):
 [1] Rcpp_1.0.6        knitr_1.31        magrittr_2.0.1    tidyselect_1.1.0
 [5] R6_2.5.0          rlang_0.4.10      stringr_1.4.0     xfun_0.20
 [9] DBI_1.1.1         ellipsis_0.3.1    htmltools_0.5.1.1 assertthat_0.2.1
[13] yaml_2.2.1        digest_0.6.27     tibble_3.0.5      lifecycle_0.2.0
[17] crayon_1.4.0      zip_2.1.1         purrr_0.3.4       vctrs_0.3.6
[21] glue_1.4.2        evaluate_0.14     rmarkdown_2.6     stringi_1.5.3
[25] pillar_1.4.7      compiler_4.0.2    cellranger_1.1.0  generics_0.1.0
[29] pkgconfig_2.0.3
```

RStudio version 1.3.1056.

END OF SCRIPT

Summary stats - Lithic analysis Ramioul

Lisa Schunk
2021-02-04

Goal of the script

This script computes standard descriptive statistics for each group.
The groups are based on:

38. Tool type
39. state of the tool (Complete, distal/proximal fragment, medial fragment)

It computes the following statistics:

40. n (sample size = length): number of measurements

41. smallest value (min)

42. largest value (max)
43. mean

44. median

45. standard deviation (sd)

```
dir_in <- "analysis/Ramioul/derived_data/"
dir_out <- "analysis/Ramioul/summary_stats/"
```

Raw data must be located in ~/analysis/Ramioul/derived_data/.
Formatted data will be saved in ~/analysis/Ramioul/summary_stats/. The knit directory for this script is the project directory.

Load packages

```
library(openxlsx)
Warning: package 'openxlsx' was built under R version 4.0.3
library(R.utils)
library(tools)
library(doBy)
Warning: package 'doBy' was built under R version 4.0.3
```

Get names, path and information of the file

```
data_file <- list.files(dir_in, pattern = "\\.xlsx$", full.names = TRUE)
md5_in <- md5sum(data_file)
info_in <- data.frame(file = basename(names(md5_in)), checksum = md5_in, row.names = NULL)
```

The checksum (MD5 hashes) of the imported file is

```
                        file                         checksum
1 Ramioul_lithic_analysis.xlsx 6dcfbbc95a1a28ab6f0b32ff043da7ca
```

Load data into R object

```
imp_data <- loadObject(paste0(dir_in, "Ramioul_lithic_analysis.Rbin"))
```

The imported file is: "~/analysis/Ramioul/derived_data/Ramioul_lithic_analysis.xlsx"

Define numeric variables

```
# changes the order of columns
imp_data <- imp_data[c(1:22, 27,23:26, 28:34)]
num.var <-19:23
```

The following variables will be used:

```
[19] length
[20] width
[21] thickness
[22] weight
[23] thickness.back
```

Compute summary statistics

Create function to compute the statistics at once

```
nminmaxmeanmedsd <- function(x){
    y <- x[!is.na(x)]
    n_test <- length(y)
    min_test <- min(y)
    max_test <- max(y)
    mean_test <- mean(y)
    med_test <- median(y)
    sd_test <- sd(y)
    out <- c(n_test, min_test, max_test, mean_test, med_test, sd_test)
    names(out) <- c("n", "min", "max", "mean", "median", "sd")
    return(out)
}
```

Compute the summary statistics

Dimensions

```
# Dimensions Keilmesser, Pradnik scraper, scraper & falke
dimensions <- summaryBy(length + width + thickness ~ technological.class + artefact.state,
                data = imp_data, FUN = nminmaxmeanmedsd)
str(dimensions)
'data.frame':   4 obs. of  20 variables:
 $ technological.class: chr  "flake" "Keilmesser" "Pradnik_scraper" "scraper"
 $ artefact.state     : chr  "complete" "complete" "complete" "complete"
 $ length.n           : num  2 9 3 6
 $ length.min         : num  54 42 45 42
 $ length.max         : num  99 117 52 107
 $ length.mean        : num  76.5 71.2 48.3 64
 $ length.median      : num  76.5 75 48 50.5
 $ length.sd          : num  31.82 26.85 3.51 27.14
 $ width.n            : num  2 9 3 6
 $ width.min          : num  27 27 35 24
 $ width.max          : num  42 57 37 46
 $ width.mean         : num  34.5 37.4 35.7 35.5
 $ width.median       : num  34.5 33 35 36.5
 $ width.sd           : num  10.61 10.44 1.15 9.31
```

```
 $ thickness.n        : num  2 9 3 6
 $ thickness.min      : num  16 14 11 9
 $ thickness.max      : num  25 23 14 20
 $ thickness.mean     : num  20.5 18.7 12 15
 $ thickness.median   : num  20.5 19 11 15
 $ thickness.sd       : num  6.36 2.92 1.73 4.69
```

Save data

Format name of output file

```
file_out <- "Ramioul_lithic_analysis_stats"
```

The file will be saved as "~/analysis/Ramioul/summary_stats/.[ext]".

Write to XLSX

```
write.xlsx(list(dimensions = dimensions),
           file = paste0(dir_out, file_out, ".xlsx"))
```

Save R object

```
saveObject(list(dimensions = dimensions),
           file = paste0(dir_out, file_out, ".Rbin"))
```

---

sessionInfo() and RStudio version

```
sessionInfo()
R version 4.0.2 (2020-06-22)
Platform: x86_64-w64-mingw32/x64 (64-bit)
Running under: Windows 10 x64 (build 19041)

Matrix products: default

locale:
[1] LC_COLLATE=German_Germany.1252  LC_CTYPE=German_Germany.1252
[3] LC_MONETARY=German_Germany.1252 LC_NUMERIC=C
[5] LC_TIME=German_Germany.1252

attached base packages:
[1] tools     stats     graphics  grDevices utils     datasets  methods
[8] base

other attached packages:
[1] doBy_4.6.8        R.utils_2.10.1    R.oo_1.24.0       R.methodsS3_1.8.1
[5] openxlsx_4.2.3

loaded via a namespace (and not attached):
 [1] zip_2.1.1         Rcpp_1.0.6        compiler_4.0.2    pillar_1.4.7
 [5] digest_0.6.27     lattice_0.20-41   evaluate_0.14     lifecycle_0.2.0
 [9] tibble_3.0.5      gtable_0.3.0      pkgconfig_2.0.3   rlang_0.4.10
[13] Matrix_1.2-18     DBI_1.1.1         yaml_2.2.1        xfun_0.20
[17] dplyr_1.0.3       stringr_1.4.0     knitr_1.31        generics_0.1.0
[21] vctrs_0.3.6       grid_4.0.2        tidyselect_1.1.0  glue_1.4.2
[25] R6_2.5.0          rmarkdown_2.6     tidyr_1.1.2       purrr_0.3.4
[29] ggplot2_3.3.3     magrittr_2.0.1    backports_1.2.0   scales_1.1.1
[33] ellipsis_0.3.1    htmltools_0.5.1.1 MASS_7.3-53       assertthat_0.2.1
[37] colorspace_2.0-0  Deriv_4.1.2       stringi_1.5.3     munsell_0.5.0
[41] broom_0.7.4       crayon_1.4.0
```

RStudio version 1.3.1056.

END OF SCRIPT

Plots - Lithic analysis Ramioul

Lisa Schunk

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Goal of the script

This script reads the xlsx file (derived data) containing all the information gained through a lithic analysis.
The script will:

46. Read the xlsx file
47. Plot all relevant variables in various combinations
48. Save the plot as PDFs

```
dir_in <- "analysis/Ramioul/derived_data/"
dir_out <- "analysis/Ramioul/plots/"
```

Raw data must be located in “analysis/Ramioul/derived_data/”.
Formatted data will be saved in “analysis/Ramioul/plots/”. The knit directory for this script is the project directory.

Load packages

```
library(openxlsx)
Warning: package 'openxlsx' was built under R version 4.0.3
library(readxl)
library(R.utils)
library(tools)
library(chron)
library(ggplot2)
Warning: package 'ggplot2' was built under R version 4.0.3
library(wesanderson)
library(dplyr)
Warning: package 'dplyr' was built under R version 4.0.3
library(ggsci)
```

Get name, path and information of the file

```
data_file <- list.files(dir_in, pattern = "\\.xlsx$", full.names = TRUE)
md5_in <- md5sum(data_file)
info_in <- data.frame(files = basename(names(md5_in)), checksum = md5_in,
                      row.names = NULL)
```

The checksum (MD5 hashes) of the imported files are:

```
                        files                         checksum
1 Ramioul_lithic_analysis.xlsx 6dcfbbc95a1a28ab6f0b32ff043da7ca
```

Load data into R object

```
imp_data <- read.xlsx(xlsxFile = data_file, sheet = 1, startRow = 1, colNames = TRUE,
                      rowNames = FALSE, skipEmptyRows = FALSE)
```

Data analsysis - plots

Histogram

Histogram dimensions - Keilmesser

```
# Load data sheet Keilmesser
KM_dim <- read.xlsx(xlsxFile = data_file, sheet = 3)

# Keilmesser length
# Calculates the mean value for the plot and ascribes the N value
mean_length <- mean(KM_dim$length, na.rm = TRUE)
n <- doBy::summaryBy(length ~ artefact.state, data = KM_dim, FUN = length)
tag <- gsub(pattern = "_", replacement = " ", paste0(n[[1]], " (n = ", n[[2]], ")"))

# Histogram Keilmesser length
KM.length <- ggplot(KM_dim, aes(x = length, fill = artefact.state)) +
           geom_histogram(binwidth = 1) +
           labs(x = "length [mm]", y = "n", title = "", fill = "artefact state",
           size = 12) +
           theme_classic() +
           geom_vline(aes(xintercept = mean_length), linetype = "dashed", size = 1) +
           geom_text(aes(y = mean_length, x = 65, label = round(mean_length, 1)),
           nudge_y = -70.24) +
           scale_fill_manual(values = wes_palette(n = 1, name = "FantasticFox1"),
           labels = tag)

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "KM.length", ".pdf")
ggsave(filename = file_out, plot = KM.length, path = dir_out, device = "pdf",
         width = 170, height = 250, units = "mm")



# Keilmesser width
# Calculates the mean value for the plot and ascribes the N value
mean_width <- mean(KM_dim$width, na.rm = TRUE)
n <- doBy::summaryBy(width ~ artefact.state, data = KM_dim, FUN = length)
tag <- gsub(pattern = "_", replacement = " ", paste0(n[[1]], " (n = ", n[[2]], ")"))

# Histogram Keilmesser width
KM.width <- ggplot(KM_dim, aes(x = width, fill = artefact.state)) +
          geom_histogram(binwidth = 0.5) +
          labs(x = "width [mm]", y = "n", title = "", fill = "artefact state",
          size = 12) +
          theme_classic() +
          geom_vline(aes(xintercept = mean_width), linetype = "dashed", size = 1) +
          geom_text(aes(y = mean_length, x = 41, label = round(mean_width, 2)),
          nudge_y = -69.25) +
          scale_fill_manual(values = wes_palette(n = 1, name = "FantasticFox1"),
          labels = tag)

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "KM.width", ".pdf")
ggsave(filename = file_out, plot = KM.width, path = dir_out, device = "pdf",
         width = 170, height = 250, units = "mm")



# Keilmesser thickness
# Calculates the mean value for the plot and ascribes the N value
mean_thickness <- mean(KM_dim$thickness, na.rm = TRUE)
n <- doBy::summaryBy(thickness ~ artefact.state, data = KM_dim, FUN = length)
tag <- gsub(pattern = "_", replacement = " ", paste0(n[[1]], " (n = ", n[[2]], ")"))
```

```
# Histogram Keilmesser thickness
KM.thickness  <- ggplot(KM_dim, aes(y = thickness, fill = artefact.state)) +
                geom_histogram(binwidth = 1) +
                labs(y = "thickness [mm]", x = "n", title = " ", fill = "artefact state",
                size = 12) +
                theme_classic() +
                geom_hline(aes(yintercept = mean_thickness), linetype = "dashed",
                size = 1) +
                geom_text(aes(y = mean_thickness, x = 1.9, label = round(mean_thickness,
                1)), nudge_y = 0.5) +
                scale_fill_manual(values = wes_palette(n = 1, name = "FantasticFox1"),
                                 labels = tag)

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "KM.thickness", ".pdf")
ggsave(filename = file_out, plot = KM.thickness, path = dir_out, device = "pdf",
         width = 250, height = 170, units = "mm")



# Keilmesser Back
# Load data sheet Keilmesser thickness back
KM_back <- read.xlsx(xlsxFile = data_file, sheet = 19)

# Calculates the mean value for the plot and ascribes the N value
mean_KM_back <- mean(KM_back$thickness.back, na.rm = TRUE)
n <- doBy::summaryBy(thickness.back ~ artefact.state, data = KM_back, FUN = length)
tag <- gsub(pattern = "_", replacement = " ", paste0(n[[1]], " (n = ", n[[2]], ")"))

# Histogram Keilmesser thickness back
KM.back  <- ggplot(KM_back, aes(y = thickness.back, fill = artefact.state)) +
                geom_histogram(binwidth = 0.6) +
                labs(x = "thickness [mm]", y = "n", title = " ", fill = "artefact state",
                size = 12) +
                theme_classic() +
                geom_hline(aes(yintercept = mean_KM_back), linetype = "dashed",
                size = 1) +
                geom_text(aes(y = mean_KM_back, x = 1.95, label = round(mean_KM_back,
                1)), nudge_y = 0.7) +
                scale_fill_manual(values = wes_palette(n = 1, name = "FantasticFox1"),
                labels = tag)

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "KM.back", ".pdf")
ggsave(filename = file_out, plot = KM.back, path = dir_out, device = "pdf", width = 250,
        height = 170, units = "mm")
```

Histogram dimensions - Pradnik scraper

```
# Load data sheet Pradnik scraper
PS_dim <- read.xlsx(xlsxFile = data_file, sheet = 4)

# Pradnik scraper length
# Calculates the mean value for the plot and ascribes the N value
mean_PS_length <- mean(PS_dim$length, na.rm = TRUE)
n <- doBy::summaryBy(length ~ artefact.state, data = PS_dim, FUN = length)
tag <- gsub(pattern = "_", replacement = " ", paste0(n[[1]], " (n = ", n[[2]], ")"))

# Histogram Pradnik scraper length
PS.length <- ggplot(PS_dim, aes(x = length, fill = artefact.state)) +
            geom_histogram(binwidth = 0.1) +
            labs(x = "length [mm]", y = "n", title = " ", fill = "artefact state",
```

```
            size = 12) +
            theme_classic() +
            geom_vline(aes(xintercept = mean_PS_length), linetype = "dashed", size = 1) +
            geom_text(aes(y = mean_PS_length, x = 49, label = round(mean_PS_length, 1)),
            nudge_y = -47.35) +
            scale_fill_manual(values = wes_palette(n = 1, name = "Chevalier1"),
                            labels = tag)

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "PS.length", ".pdf")
ggsave(filename = file_out, plot = PS.length, path = dir_out, device = "pdf",
         width = 170, height = 250, units = "mm")


# Pradnik scraper width
# Calculates the mean value for the plot and ascribes the N value
mean_PS_width <- mean(PS_dim$width, na.rm = TRUE)
n <- doBy::summaryBy(width ~ artefact.state, data = PS_dim, FUN = length)
tag <- gsub(pattern = "_", replacement = " ", paste0(n[[1]], " (n = ", n[[2]], ")"))

# Histogram Pradnik scraper width
PS.width <- ggplot(PS_dim, aes(x = width, fill = artefact.state)) +
           geom_histogram(binwidth = 0.1) +
           labs(x = "width [mm]", y = "n", title = " ", fill = "artefact state",
           size = 12) +
           theme_classic() +
           geom_vline(aes(xintercept = mean_PS_width), linetype="dashed", size = 1) +
           geom_text(aes(y = mean_PS_width, x = 36, label = round(mean_PS_width, 1)),
           nudge_y = -33.7) +
           scale_fill_manual(values = wes_palette(n = 1, name = "Chevalier1"),
           labels = tag)

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "PS.width", ".pdf")
ggsave(filename = file_out, plot = PS.width, path = dir_out, device = "pdf",
         width = 170, height = 250, units = "mm")


# Pradnik scraper thickness
# Calculates the mean value for the plot and ascribes the N value
mean_PS_thickness <- mean(PS_dim$thickness, na.rm = TRUE)
n <- doBy::summaryBy(thickness ~ artefact.state, data = PS_dim, FUN = length)
tag <- gsub(pattern = "_", replacement = " ", paste0(n[[1]], " (n = ", n[[2]], ")"))

# Histogram Pradnik scraper thickness
PS.thickness <- ggplot(PS_dim, aes(y = thickness, fill = artefact.state)) +
              geom_histogram(binwidth = 0.2) +
              labs(y = "thickness [mm]", x = "n", title = " ", fill = "artefact state",
              size = 12) +
              theme_classic() +
              geom_hline(aes(yintercept = mean_PS_thickness), linetype = "dashed",
              size = 1) +
              geom_text(aes(y = mean_PS_thickness, x = 1.9, label =
              round(mean_PS_thickness, 1)), nudge_y = 0.2) +
              scale_fill_manual(values = wes_palette(n = 1, name = "Chevalier1"),
              labels = tag)

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "PS.thickness", ".pdf")
ggsave(filename = file_out, plot = PS.thickness, path = dir_out, device = "pdf",
         width = 250, height = 170, units = "mm")
```

```r
# Back Pradnik scraper thickness
# Load data sheet Pradnik scraper thickness back
PS_back <- read.xlsx(xlsxFile = data_file, sheet = 20)

# Calculates the mean value for the plot and ascribes the N value
mean_PS_back <- mean(PS_back$thickness.back, na.rm = TRUE)
n <- doBy::summaryBy(thickness.back ~ artefact.state, data = PS_back, FUN = length)
tag <- gsub(pattern = "_", replacement = " ", paste0(n[[1]], " (n = ", n[[2]], ")"))

# Histogram Pradnik scraper thickness back
PS.back  <- ggplot(PS_back, aes(y = thickness.back, fill = artefact.state)) +
              geom_histogram(binwidth = 0.05) +
              labs(y = "thickness [mm]", x = "n", title = "", fill = "artefact state",
              size = 12) +
              theme_classic() +
              geom_hline(aes(yintercept = mean_PS_back), linetype = "dashed",
              size = 1) +
              geom_text(aes(y = mean_PS_back, x = 1.9, label = round(mean_PS_back, 1)),
              nudge_y = -0.1) +
              scale_fill_manual(values = wes_palette(n = 1, name = "Chevalier1"),
              labels = tag)

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "PS.back", ".pdf")
ggsave(filename = file_out, plot = PS.back, path = dir_out, device = "pdf",
       width = 250, height = 170, units = "mm")
```

Scatterplot

Length-width ratio

```r
# Load data sheet Keilmesser
KM_dim <- read.xlsx(xlsxFile = data_file, sheet = 3)

# Keilmesser length VS width
# Ascribes the N value
n <- doBy::summaryBy(length + width ~ artefact.state, data = KM_dim, FUN = length)
tag <- gsub(pattern = "_", replacement = " ", paste0(n[[1]], " (n = ", n[[2]], ")"))

# Scatterplot Keilmesser (complete + point) length VS width
KM.length_width <- ggplot(KM_dim, aes(y = length, x = width, fill = artefact.state)) +
               geom_point(size = 3, shape = 21) +
               labs(y = "length [mm]", x = "width [mm]", title = "",
               fill = "artefact state", size = 12) +
               xlim(0, 70) + ylim(0, 120) +
               theme_classic() +
               scale_fill_manual(values = wes_palette(n = 1, name = "FantasticFox1"),
               labels = tag)

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "KM.length_width", ".pdf")
ggsave(filename = file_out, plot = KM.length_width, path = dir_out, device = "pdf",
       width = 200, height = 290, units = "mm")


# Pradnik scraper length VS width
# Ascribes the N value
n <- doBy::summaryBy(length + width ~ artefact.state, data = PS_dim, FUN = length)
tag <- gsub(pattern = "_", replacement = " ", paste0(n[[1]], " (n = ", n[[2]], ")"))

# Scatterplot Pradnik scraper length VS width
PS.length_width <- ggplot(PS_dim, aes(y = length, x = width, fill = artefact.state)) +
```

```r
                geom_point(size = 3, shape = 21) +
                labs(y = "length [mm]", x = "width [mm]", title = " ",
                fill = "artefact state", size = 12) +
                xlim(0, 45) + ylim(0, 55) +
                theme_classic() +
                scale_fill_manual(values = wes_palette(n = 6, name = "Chevalier1",
                                  type = "continuous"), labels = tag)

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "PS.length_width", ".pdf")
ggsave(filename = file_out, plot = PS.length_width, path = dir_out, device = "pdf")


# Keilmesser (complete) + Pradnik scraper length VS width
# Load data sheet dimensions
dim <- read.xlsx(xlsxFile = data_file, sheet = 2)
# Defines only the relevant rows
KM.PS_dim <- dim[c(3:11, 12:14), ]

# Keilmesser (complete) + Pradnik scraper length VS width
# Ascribes the N value
n <- doBy::summaryBy(length + width ~ technological.class, data = KM.PS_dim, FUN = length)
tag <- gsub(pattern = "_", replacement = "  ", paste0(n[[1]], " (n = ", n[[2]], ")"))

# Scatterplot Keilmesser (complete) + Pradnik scraper length VS width
KM.PS.length_width <- ggplot(KM.PS_dim, aes(y = length, x = width,
                  fill = technological.class)) +
                  geom_point(size = 3, shape = 21) +
                  labs(y = "length [mm]", x = "width [mm]", title = " ",
                  fill = "artefact category", size = 12) +
                  xlim(0, 80) + ylim(0, 120) +
                  theme_classic() +
                  scale_fill_manual(values = wes_palette(n = 3, name =
                  "GrandBudapest1", type = "continuous"), labels = tag)

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "KM.PS.length_width", ".pdf")
ggsave(filename = file_out, plot = KM.PS.length_width, path = dir_out, device = "pdf",
       width = 170, height = 250, units = "mm")


# Keilmesser (complete): length-width combined with morpho type
# Load data sheet Keilmesser morpho type
KM_morpho.type <- read.xlsx(xlsxFile = data_file, sheet = 25)

# Ascribes the N value
n <- doBy::summaryBy(length + width ~ morpho.type, data = KM_morpho.type, FUN = length)
tag <- gsub(pattern = "_", replacement = "  ", paste0(n[[1]], " (n = ", n[[2]], ")"))


# Scatterplot Keilmesser (complete): length-width combined with morpho type
KM.width_length_morpho <- ggplot(KM_morpho.type, aes(y = length, x = width,
                                    fill = morpho.type)) +
                  geom_point(size = 2, shape = 21) +
                  labs(y = "length [mm]", x = "width [mm]", title = " ",
                  fill = "Keilmesser shape", size = 12) +
                  xlim(0, 80) + ylim(00, 120) +
                  theme_classic() +
                  scale_fill_manual(values = wes_palette(n = 3, name =
                  "FantasticFox1", type = "continuous"), labels = tag)

file_out <- paste0(file_path_sans_ext(info_in[["file"]]),
```

```
                "KM.width_length_morpho", ".pdf")
ggsave(filename = file_out, plot = KM.width_length_morpho, path = dir_out,
        device = "pdf", width = 170, height = 250, units = "mm")
```

Barplot

Morphotype

```
# Keilmesser morpho type
# Load data sheet Keilmesser morpho type
KM_morpho.type <- read.xlsx(xlsxFile = data_file, sheet = 25)

# Barplot Keilmesser morpho type
KM.morpho.type <- ggplot(data = KM_morpho.type) + aes(x = morpho.type,
               fill = morpho.type) +
               geom_bar(stat = "count", width = 0.3, fill = c("#899DA4", "#D76848",
               "#E8B37B")) +
               theme_classic() +
               theme(legend.position = "none") +
               labs(x = " ", y = "n")

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "KM.morpho.type", ".pdf")
ggsave(filename = file_out, plot = KM.morpho.type, path = dir_out, device = "pdf",
         width = 170, height = 200, units = "mm")
```

Barplot

Edge retouch

```
# Keilmesser edge retouch
# Load data sheet Keilmesser edge retouch
KM_edge <- read.xlsx(xlsxFile = data_file, sheet = 21)

# Barplot Keilmesser edge retouch
KM.edge <- ggplot(data = KM_edge) + aes(x = retouch.type.edge, fill = retouch.type.edge) +          geom_bar(stat =
"count", width = 0.5, fill = c ("#798E87", "#972D15",
          "#29211F")) +
          theme_classic() +
          theme(legend.position = "none") +
          labs(x = " ", y = "n")

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "KM.edge", ".pdf")
ggsave(filename = file_out, plot = KM.edge, path = dir_out, device = "pdf",
         width = 170, height = 200, units = "mm")




# Pradnik scraper edge retouch
# Load data sheet Pradnik scraper edge retouch
PS_edge <- read.xlsx(xlsxFile = data_file, sheet = 22)

# Barplot Pradnik scraper edge retouch
PS.edge <- ggplot(data = PS_edge) + aes(x = retouch.type.edge, fill = retouch.type.edge) +
          geom_bar(stat = "count", width = 0.5,
          fill = c ("#972D15", "#29211F")) +
          theme_classic() +
          theme(legend.position = "none") +
          labs(x = " ", y = "n")

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "PS.edge", ".pdf")
```

```
ggsave(filename = file_out, plot = PS.edge, path = dir_out, device = "pdf",
       width = 170, height = 200, units = "mm")
```

Barplot

Raw material

```
# Keilmesser raw material
# Load data sheet Keilmesser raw material
KM_raw_material <- read.xlsx(xlsxFile = data_file, sheet = 13)

# Barplot Keilmesser raw material
KM.raw_material <- ggplot(data = KM_raw_material) + aes(x = raw.material,
                 fill = raw.material) +
                 geom_bar(stat = "count", width = 0.15, fill = c("#D69C4E",
                 "#046C9A")) +
                 theme_classic() +
                 theme(legend.position = "none") +
                 labs(x = " ", y = "n") +
                 scale_x_discrete(labels=c("flint", "silicified schist"))


file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "KM.raw_material", ".pdf")
ggsave(filename = file_out, plot = KM.raw_material, path = dir_out,
       device = "pdf", width = 250, height = 170, units = "mm")


# Pradnik scraper raw material
# Load data sheet Pradnik scraper raw material
PS_raw_material <- read.xlsx(xlsxFile = data_file, sheet = 14)

# Barplot Pradnik scraper raw material
PS.raw_material <- ggplot(data = PS_raw_material) + aes(x = raw.material,
                 fill = raw.material) +
                 geom_bar(stat = "count", width = 0.08, fill = c("#D69C4E")) +
                 theme_classic() +
                 theme(legend.position = "none") +
                 labs(x = " ", y = "n") +
                 scale_x_discrete(labels= "flint")

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "PS.raw_material", ".pdf")
ggsave(filename = file_out, plot = PS.raw_material, path = dir_out, device = "pdf",
       width = 250, height = 170, units = "mm")


# All tool types raw material
# Load data sheet all tool types raw material
all_raw_material <- read.xlsx(xlsxFile = data_file, sheet = 1)

# Barplot Pradnik scraper raw material
all.raw_material <- ggplot(data = all_raw_material) + aes(x = raw.material,
                  fill = raw.material) +
                  geom_bar(stat = "count", width = 0.15, fill = c("#D69C4E",
                  "#046C9A")) +
                  theme_classic() +
                  theme(legend.position = "none") +
                  labs(x = " ", y = "n") +
                  scale_x_discrete(labels=c("flint", "silicified schist"))

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "all.raw_material", ".pdf")
```

```
ggsave(filename = file_out, plot = all.raw_material, path = dir_out, device = "pdf",
       width = 250, height = 170, units = "mm")
```

Barplot

Morphology back

```
# Keilmesser morphology back
# Load data sheet Keilmesser morphology back
KM_back <- read.xlsx(xlsxFile = data_file, sheet = 19)

# colour code
# Darjeeling2 = c("#ECCBAE", "#046C9A", "#D69C4E", "#ABDDDE", "#000000"),

# Barplot Keilmesser morphology back
KM.back_morpho <- ggplot(data = KM_back) + aes(x = morphology.back,
                 fill = morphology.back) +
                 geom_bar(stat = "count", width = 0.25, fill = c("#518BA0", "#518BA0",                    "#B9C7AD")) +
                 theme_classic() +
                 theme(legend.position = "none") +
                 labs(x = " ", y = "n") +
                 scale_x_discrete(labels=c("cortex + partly retouched",
                 "cortex/unworked", "retouched"))

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "KM.back_morpho", ".pdf")
ggsave(filename = file_out, plot = KM.back_morpho, path = dir_out, device = "pdf",
       width = 250, height = 170, units = "mm")



# Pradnik scraper morphology back
# Load data sheet Pradnik scraper morphology back
PS_back <- read.xlsx(xlsxFile = data_file, sheet = 20)

# Barplot Pradnik scraper morphology back
PS.back_morpho <- ggplot(data = PS_back) + aes(x = morphology.back,
                 fill = morphology.back) +
                 geom_bar(stat = "count", width = 0.22, fill = "#B9C7AD") +
                 theme_classic() +
                 theme(legend.position = "none") +
                 labs(x = " ", y = "n") +
                 scale_x_discrete()

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "PS.back_morpho", ".pdf")
ggsave(filename = file_out, plot = PS.back_morpho, path = dir_out, device = "pdf",
       width = 250, height = 170, units = "mm")


# Keilmesser blanks
# Load data sheet Keilmesser blanks
KM_cortex_blanks <- read.xlsx(xlsxFile = data_file, sheet = 17)

# Ascribes the N value
n <- doBy::summaryBy(blank ~ cortex, data = KM_cortex_blanks, FUN = length)
tag <- gsub(pattern = "_", replacement = " ", paste0(n[[1]], " (n = ", n[[2]], ")"))

# Barplot Keilmesser blanks
KM.cortex_blanks <- ggplot(data = KM_cortex_blanks) + aes(x = blank, fill = cortex) +
                  geom_bar(stat = "count", width = 0.38) +
                  theme_classic() +
```

```
                  labs(x = " ", y = "n") +
                  scale_x_discrete(labels=c("core", "flake", "N/A")) +
                  scale_fill_manual(values = wes_palette(n = 7, name = "Darjeeling2",
                  type = "continuous"), labels = tag)

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "KM.cortex_blanks", ".pdf")
ggsave(filename = file_out, plot = KM.cortex_blanks, path = dir_out, device = "pdf",
         width = 250, height = 170, units = "mm")



# Pradnik scraper blanks
# Load data sheet Pradnik scraper blanks
PS_cortex_blanks <- read.xlsx(xlsxFile = data_file, sheet = 18)

# Ascribes the N value
n <- doBy::summaryBy(blank ~ cortex, data = PS_cortex_blanks, FUN = length)
tag <- gsub(pattern = "_", replacement = " ", paste0(n[[1]], " (n = ", n[[2]], ")"))

# Barplot Pradnik scraper blanks
PS.cortex_blanks <- ggplot(data = PS_cortex_blanks) + aes(x = blank, fill = cortex) +
                  geom_bar(stat = "count", width = 0.15) +
                  theme_classic() +
                  labs(x = " ", y = "n") +
                  scale_x_discrete(labels= "flake") +
                  scale_fill_manual(values = wes_palette(n = 7, name = "Darjeeling2",
                  type = "continuous"), labels = tag)

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "PS.cortex_blanks", ".pdf")
ggsave(filename = file_out, plot = PS.cortex_blanks, path = dir_out, device = "pdf",
         width = 250, height = 170, units = "mm")
```

Barplot

Pradnik method

```
# Keilmesser application Pradnik method
# Load data sheet Keilmesser Pradnik method
KM_Pradnik.method <- read.xlsx(xlsxFile = data_file, sheet = 27)

# Barplot Keilmesser Pradnik method
KM.PM <- ggplot(data = KM_Pradnik.method) + aes(x = application.Pradnik.method,
        fill = application.Pradnik.method) +
        geom_bar(stat = "count", width = 0.2) +
        theme_classic() +
        labs(x = " ", y = "n") +
        theme(legend.position = "none") +
        scale_x_discrete(labels=c("no", "yes")) +
        scale_fill_manual(values = wes_palette(n = 3, name = "GrandBudapest1",
        type = "continuous"))

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "KM.PM", ".pdf")
ggsave(filename = file_out, plot = KM.PM, path = dir_out, device = "pdf",
         width = 250, height = 170, units = "mm")
```

Barplot

Lateralisation

```
# Keilmesser lateralisation
# Load data sheet Keilmesser lateralisation
KM_lateralisation <- read.xlsx(xlsxFile = data_file, sheet = 29)
```

```r
# Barplot Keilmesser lateralisation
KM.lat <- ggplot(data = KM_lateralisation) + aes(x = tool.lateralisation,
         fill = tool.lateralisation) +
         geom_bar(stat = "count", width = 0.2) +
         theme_classic() +
         labs(x = " ", y = "n") +
         theme(legend.position = "none") +
         scale_fill_manual(values = wes_palette(n = 9, name = "Royal1",
         type = "continuous"))

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "KM.lat", ".pdf")
ggsave(filename = file_out, plot = KM.lat, path = dir_out, device = "pdf")


# Pradnik scraper lateralisation
# Load data sheet Pradnik scraper lateralisation
PS_lateralisation <- read.xlsx(xlsxFile = data_file, sheet = 30)

# Barplot Keilmesser lateralisation
PS.lat <- ggplot(data = PS_lateralisation) + aes(x = tool.lateralisation,
         fill = tool.lateralisation) +
         geom_bar(stat = "count", width = 0.2) +
         theme_classic() +
         labs(x = " ", y = "n") +
         theme(legend.position = "none") +
         scale_fill_manual(values = wes_palette(n = 9, name = "Royal1",
         type = "continuous"))

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "PS.lat", ".pdf")
ggsave(filename = file_out, plot = PS.lat, path = dir_out, device = "pdf")
```

Ternary plot

Perimeter

```r
library(ggtern)
# Perimeter Keilmesser
# Load data sheet Keilmesser perimeter
KM_perimeter <- read.xlsx(xlsxFile = data_file, sheet = 7)

# Ternary diagram Keilmesser perimeter
KM.perimeter  <- ggtern(data = KM_perimeter, aes(x = perimeter.distal.posterior.part,
               y = perimeter.active.edge, z = perimeter.basis.back)) +
               geom_point(aes(colour = morpho.type)) +
               theme_bw() +
               scale_colour_startrek() +
               theme_hidetitles() +
               theme_showarrows() +
               xlab("distal posterior part")+
               ylab("active edge")+
               zlab("basis + back")+
               labs(colour = "Keilmesser shape") +
               tern_limits(labels=c(0, 20, 40, 60, 80, 100)) +
               theme_rotate(degrees = 330)


file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "KM.perimeter", ".pdf")
ggsave(filename = file_out, plot = KM.perimeter, path = dir_out, device = "pdf",
         width = 250, height = 170, units = "mm")
```

sessionInfo() and RStudio version

```
sessionInfo()
R version 4.0.2 (2020-06-22)
Platform: x86_64-w64-mingw32/x64 (64-bit)
Running under: Windows 10 x64 (build 19041)

Matrix products: default

locale:
[1] LC_COLLATE=German_Germany.1252  LC_CTYPE=German_Germany.1252
[3] LC_MONETARY=German_Germany.1252 LC_NUMERIC=C
[5] LC_TIME=German_Germany.1252

attached base packages:
[1] tools     stats     graphics  grDevices utils     datasets  methods
[8] base

other attached packages:
 [1] ggtern_3.3.0      ggsci_2.9         dplyr_1.0.3       wesanderson_0.3.6
 [5] ggplot2_3.3.3     chron_2.3-56      R.utils_2.10.1    R.oo_1.24.0
 [9] R.methodsS3_1.8.1 readxl_1.3.1      openxlsx_4.2.3

loaded via a namespace (and not attached):
 [1] tidyselect_1.1.0   xfun_0.20          purrr_0.3.4        lattice_0.20-41
 [5] latex2exp_0.4.0    colorspace_2.0-0   vctrs_0.3.6        generics_0.1.0
 [9] doBy_4.6.8         htmltools_0.5.1.1  compositions_2.0-1 yaml_2.2.1
[13] rlang_0.4.10       pillar_1.4.7       glue_1.4.2         withr_2.4.1
[17] DBI_1.1.1          plyr_1.8.6         lifecycle_0.2.0    robustbase_0.93-7
[21] stringr_1.4.0      munsell_0.5.0      gtable_0.3.0       cellranger_1.1.0
[25] zip_2.1.1          evaluate_0.14      labeling_0.4.2     knitr_1.31
[29] DEoptimR_1.0-8     proto_1.0.0        broom_0.7.4        Rcpp_1.0.6
[33] scales_1.1.1       backports_1.2.0    farver_2.0.3       gridExtra_2.3
[37] Deriv_4.1.2        tensorA_0.36.2     digest_0.6.27      stringi_1.5.3
[41] grid_4.0.2         magrittr_2.0.1     tibble_3.0.5       crayon_1.4.0
[45] tidyr_1.1.2        pkgconfig_2.0.3    bayesm_3.1-4       ellipsis_0.3.1
[49] MASS_7.3-53        Matrix_1.2-18      assertthat_0.2.1   rmarkdown_2.6
[53] R6_2.5.0           compiler_4.0.2
```

RStudio version 1.3.1056.

END OF SCRIPT

Import - Lithic analysis from three sites: Balver Höhle, Buhlen & Ramioul

Lisa Schunk

2021-02-05

Goal of the script

This script reads the three xlsx files (database techno-typological analysis) and formats the data for a statistical analysis.
The script will:

49. Read in the original xlsx files
50. Change and sort the data in order to do stats
51. Save the data as a new single xlsx file and R object

```
dir_in <- "analysis/all_sites/raw_data/"
dir_out <- "analysis/all_sites/derived_data/"
```

Raw data must be located in "analysis/all_sites/raw_data/".
Formatted data will be saved in "analysis/all_sites/derived_data/". The knit directory for this script is the project directory.

Load packages

```
library(openxlsx)
Warning: package 'openxlsx' was built under R version 4.0.3
library(readxl)
library(R.utils)
library(tools)
library(data.table)
Warning: package 'data.table' was built under R version 4.0.3
library(chron)
library(dplyr)
Warning: package 'dplyr' was built under R version 4.0.3
```

Get name, path and information of the files

```
data_files <- list.files(dir_in, pattern = "\\.xlsx$", full.names = TRUE)
md5_in <- md5sum(data_files)
info_in <- data.frame(files = basename(names(md5_in)), checksum = md5_in,
                      row.names = NULL)
```

The checksum (MD5 hashes) of the imported files are:

```
                         files                         checksum
1   Balve_lithic_analysis.xlsx 4028b66a7c29ffed5e1b7cf09551771f
2  Buhlen_lithic_analysis.xlsx 79af46bcc5dcfac4b6a812d6c8bfa6f7
3 Ramioul_lithic_analysis.xlsx cddece99809aaeed573ac6c688817894
```

Read in original xlsx-files

```
imp_data <- vector(mode = "list", length = length(data_files))
names(imp_data) <- basename(data_files)
```

```
# loop for import data due to the three different CSV files
for (i in seq_along(data_files)) {
  imp_data[[i]] <- read.xlsx(data_files[i], sheet = 1, colNames = TRUE,
                  rowNames = FALSE, skipEmptyCols = FALSE)
}
str(imp_data)
List of 3
 $ Balve_lithic_analysis.xlsx  :'data.frame':   347 obs. of  34 variables:
  ..$ site                              : chr [1:347] "Balver_Höhle" "Balver_Höhle" "Balver_Höhle" "Balver_Höhle" ...
  ..$ ID                                : chr [1:347] "HE-012" "HE-013" "HE-014" "HE-015" ...
  ..$ raw.material                      : chr [1:347] "baltic_flint" "silicified_schist" "silicified_schist" "silicified_schist" ...
  ..$ technological.class               : chr [1:347] "Keilmesser" "Keilmesser" "Keilmesser" "Keilmesser" ...
  ..$ artefact.state                    : chr [1:347] "complete" "semifinished_product" "complete" "complete" ...
  ..$ blank                             : chr [1:347] "core" "core" "flake" "core" ...
  ..$ morpho.type                       : chr [1:347] "Bockstein" "Bockstein" "Balve" "Pradnik" ...
  ..$ cortex                            : chr [1:347] "YES" "YES" "YES" "N/A" ...
  ..$ cortex.percentage                 : chr [1:347] "N/A" "N/A" "N/A" NA ...
  ..$ cortex.location                   : chr [1:347] "back" "back" "back" NA ...
  ..$ morphology.back                   : chr [1:347] "cortex/unworked" "cortex/unworked" "cortex/unworked"
"partly_retouched" ...
  ..$ retouch.active.edge               : chr [1:347] "YES" "YES" "YES" "YES" ...
  ..$ retouch.type.edge                 : chr [1:347] "bifacial" "bifacial" "bifacial" "bifacial" ...
  ..$ tip.morphology                    : chr [1:347] "undeterminable" "undeterminable" "undeterminable"
"undeterminable" ...
  ..$ application.Pradnik.method        : chr [1:347] "YES" "NO" "NO" "NO" ...
  ..$ frequency.application.Pradnik.method: chr [1:347] "N/A" NA NA NA ...
  ..$ type.lateral.sharpening.spall     : chr [1:347] NA NA NA NA ...
  ..$ tool.lateralisation               : chr [1:347] "sin." "sin." "dex." "sin." ...
  ..$ length                            : num [1:347] 72.5 142.8 52.4 48.3 58.9 ...
  ..$ width                             : num [1:347] 41.6 69.7 38.2 34 30.5 ...
  ..$ thickness                         : num [1:347] 17.8 24.2 20.9 11.6 19.7 ...
  ..$ weight                            : num [1:347] 0.058 0.129 0.035 0.022 0.037 ...
  ..$ perimeter.basis.back              : num [1:347] 10.6 18.7 5.7 4.1 9.6 7.6 6.3 8.5 4.6 10.8 ...
  ..$ perimeter.distal.posterior.part   : chr [1:347] "1" "4" "4" " 4.6" ...
  ..$ perimeter.active.edge             : num [1:347] 6.7 11.4 4.7 4.4 4.4 6.4 5.9 5.4 5.9 5.4 ...
  ..$ perimeter.total                   : num [1:347] 18.3 34.1 14.1 13.1 15.3 ...
  ..$ thickness.back                    : num [1:347] 17.16 22.07 19.03 7.06 20.03 ...
  ..$ taphonomic.visual.inspection      : chr [1:347] "N/A" "N/A" "N/A" "N/A" ...
  ..$ tool.edges.preservation           : chr [1:347] "N/A" "N/A" "N/A" "N/A" ...
  ..$ macroscopically.visible.use-wear  : chr [1:347] "N/A" "N/A" "N/A" "N/A" ...
  ..$ use-wear.analysis                 : chr [1:347] "N/A" "N/A" "N/A" "N/A" ...
  ..$ 3D-scan                           : chr [1:347] "N/A" "N/A" "N/A" "N/A" ...
  ..$ schistosity                       : chr [1:347] "N/A" "N/A" "N/A" "N/A" ...
  ..$ orientation.schistosity           : chr [1:347] NA NA NA NA ...
 $ Buhlen_lithic_analysis.xlsx :'data.frame':   199 obs. of  34 variables:
  ..$ site                              : chr [1:199] "Buhlen" "Buhlen" "Buhlen" "Buhlen" ...
  ..$ ID                                : chr [1:199] "BU-002" "BU-003" "BU-004" "BU-005" ...
  ..$ raw.material                      : chr [1:199] "silicified_schist" "silicified_schist" "silicified_schist" "silicified_schist" ...
  ..$ technological.class               : chr [1:199] "Keilmesser" "Keilmesser" "Keilmesser" "Keilmesser" ...
  ..$ artefact.state                    : chr [1:199] "complete" "complete" "complete" "complete" ...
  ..$ blank                             : chr [1:199] "core" "core" "core" "core" ...
  ..$ morpho.type                       : chr [1:199] "Bockstein" "Buhlen" "Pradnik" "Balve" ...
  ..$ cortex                            : chr [1:199] "YES" "YES" "YES" "YES" ...
  ..$ cortex.percentage                 : chr [1:199] "25-50" "<25" "<25" "50-75" ...
  ..$ cortex.location                   : chr [1:199] "back" "base" "back" "ventral_and_dorsal" ...
  ..$ morphology.back                   : chr [1:199] "cortex/unworked" "cortex/partly_retouched" "cortex/unworked"
"cortex/unworked" ...
  ..$ retouch.active.edge               : chr [1:199] "YES" "YES" "YES" "YES" ...
  ..$ retouch.type.edge                 : chr [1:199] "bifacial" "bifacial" "bifacial" "bifacial" ...
  ..$ tip.morphology                    : chr [1:199] "rounded" "rounded" "rounded" "pointed" ...
  ..$ application.Pradnik.method        : chr [1:199] "NO" "YES" "YES" "NO" ...
```

```
  ..$ frequency.application.Pradnik.method: chr [1:199] NA "one" "one" NA ...
  ..$ type.lateral.sharpening.spall       : chr [1:199] NA NA NA NA ...
  ..$ tool.lateralisation                 : chr [1:199] "dex." "dex." "dex." "dex." ...
  ..$ length                              : num [1:199] 48 58 56.3 69 53.7 ...
  ..$ width                               : num [1:199] 35 31 38.8 46 36.2 ...
  ..$ thickness                           : num [1:199] 14 18 16 14 17 18 19 31 13 12 ...
  ..$ weight                              : num [1:199] 0.0259 0.0337 0.0391 0.0561 0.0367 0.0258 0.0387 0.0733 0.0224
0.0204 ...
  ..$ perimeter.basis.back                : num [1:199] 8.4 8.2 7.5 8.4 8.2 7.6 7.7 9.4 8.1 8.8 ...
  ..$ perimeter.distal.posterior.part     : num [1:199] 0 1.6 2.1 2.2 1 1.5 3.9 2.5 2.4 1 ...
  ..$ perimeter.active.edge               : num [1:199] 5.6 4.7 6.5 8.2 4.4 4.2 5.7 7 5.1 4.7 ...
  ..$ perimeter.total                     : num [1:199] 0 11 0 0 0 0 0 0 0 0 ...
  ..$ thickness.back                      : num [1:199] 14 11 14 12 17.3 ...
  ..$ taphonomic.visual.inspection        : chr [1:199] "Sharp_edges_and_preserved_surface"
"Sharp_edges_and_preserved_surface" "Sharp_edges_and_preserved_surface" "Sharp_edges_and_preserved_surface" ...
  ..$ tool.edges.preservation             : chr [1:199] "edges_preserved" "edges_preserved" "edges_preserved"
"edges_preserved" ...
  ..$ macroscopically.visible.use-wear    : chr [1:199] "NO" "NO" "NO" "NO" ...
  ..$ use-wear.analysis                   : chr [1:199] "NO" "YES" "YES" "NO" ...
  ..$ 3D-scan                             : chr [1:199] "YES" "YES" "YES" "YES" ...
  ..$ schistosity                         : chr [1:199] "N/A" "NO" "NO" "YES" ...
  ..$ orientation.schistosity             : chr [1:199] NA NA NA "parallel_to_the_active_edge" ...
 $ Ramioul_lithic_analysis.xlsx:'data.frame':   20 obs. of  34 variables:
  ..$ site                                : chr [1:20] "Ramioul" "Ramioul" "Ramioul" "Ramioul" ...
  ..$ ID                                  : chr [1:20] "R-001" "R-002" "R-003" "R-004" ...
  ..$ raw.material                        : chr [1:20] "baltic_flint" "baltic_flint" "baltic_flint" "baltic_flint" ...
  ..$ technological.class                 : chr [1:20] "Keilmesser" "Keilmesser" "scraper" "scraper" ...
  ..$ artefact.state                      : chr [1:20] "complete" "complete" "complete" "complete" ...
  ..$ blank                               : chr [1:20] "core" "core" "core" "flake" ...
  ..$ morpho.type                         : chr [1:20] "Balve" "Klausennische" NA NA ...
  ..$ cortex                              : chr [1:20] "YES" "YES" "YES" "YES" ...
  ..$ cortex.percentage                   : chr [1:20] "<25" "<25" "25-50" "25-50" ...
  ..$ cortex.location                     : chr [1:20] "back" "back" "back" "medial_dorsa" ...
  ..$ morphology.back                     : chr [1:20] "cortex/partly_retouched" "cortex/unworked" NA NA ...
  ..$ retouch.active.edge                 : chr [1:20] "YES" "YES" "YES" "YES" ...
  ..$ retouch.type.edge                   : chr [1:20] "bifacial" "semi-bifacial" "semi-bifacial" "unifacial" ...
  ..$ tip.morphology                      : chr [1:20] "rounded" "rounded" "rounded" "undeterminable" ...
  ..$ application.Pradnik.method          : chr [1:20] "YES" "YES" NA NA ...
  ..$ frequency.application.Pradnik.method: chr [1:20] "one" "one" NA NA ...
  ..$ type.lateral.sharpening.spall       : num [1:20] NA NA NA NA NA NA NA NA NA NA ...
  ..$ tool.lateralisation                 : chr [1:20] "dex." "dex." NA NA ...
  ..$ length                              : num [1:20] 50 44 51 42 54 53 76 75 99 52 ...
  ..$ width                               : num [1:20] 33 27 31 24 27 31 37 43 42 35 ...
  ..$ thickness                           : num [1:20] 16 21 20 9 16 16 21 23 25 14 ...
  ..$ weight                              : num [1:20] 0.025 0.02 0.029 0.01 0.016 0.018 0.062 0.066 0.075 0.0017 ...
  ..$ perimeter.basis.back                : num [1:20] 6.7 6.4 6.5 0 0 5.7 9.5 7.3 0 8.2 ...
  ..$ perimeter.distal.posterior.part     : num [1:20] 3 2.5 3.1 0 0 3.1 1.9 4.4 0 2 ...
  ..$ perimeter.active.edge               : num [1:20] 5 4 4.9 0 0 4.4 6.5 7.6 0 4.5 ...
  ..$ perimeter.total                     : num [1:20] 0 0 0 0 0 0 0 0 0 0 ...
  ..$ thickness.back                      : num [1:20] 16 21 14 0 0 6 21 17 0 5 ...
  ..$ taphonomic.visual.inspection        : chr [1:20] "sharp_edges_and_patinated_surface"
"sharp_edges_and_patinated_surface" "sharp_edges_and_patinated_surface" "sharp_edges_and_patinated_surface" ...
  ..$ tool.edges.preservation             : chr [1:20] "edges_preserved" "edges_preserved" "edges_preserved"
"edges_preserved" ...
  ..$ macroscopically.visible.use-wear    : chr [1:20] "NO" "NO" "NO" "NO" ...
  ..$ use-wear.analysis                   : chr [1:20] "YES" "YES" "NO" "YES" ...
  ..$ 3D-scan                             : chr [1:20] "YES" "YES" "YES" "YES" ...
  ..$ schistosity                         : chr [1:20] "N/A" "N/A" "N/A" "N/A" ...
  ..$ orientation.schistosity             : num [1:20] NA NA NA NA NA NA NA NA NA NA ...
# check pairwise if the three lines of headers are identical among the datasets
# merges the data based on the three lines of headers while they get only
```

```
# used in the first CSV file
comp <- all(sapply(list(names(imp_data[[1]]), names(imp_data[[2]])),
                FUN = identical, names(imp_data[[3]])))
merged_data <- do.call(rbind, imp_data)

str(merged_data)
'data.frame':   566 obs. of  34 variables:
 $ site                              : chr  "Balver_Höhle" "Balver_Höhle" "Balver_Höhle" "Balver_Höhle" ...
 $ ID                                : chr  "HE-012" "HE-013" "HE-014" "HE-015" ...
 $ raw.material                      : chr  "baltic_flint" "silicified_schist" "silicified_schist" "silicified_schist" ...
 $ technological.class               : chr  "Keilmesser" "Keilmesser" "Keilmesser" "Keilmesser" ...
 $ artefact.state                    : chr  "complete" "semifinished_product" "complete" "complete" ...
 $ blank                             : chr  "core" "core" "flake" "core" ...
 $ morpho.type                       : chr  "Bockstein" "Bockstein" "Balve" "Pradnik" ...
 $ cortex                            : chr  "YES" "YES" "YES" "N/A" ...
 $ cortex.percentage                 : chr  "N/A" "N/A" "N/A" NA ...
 $ cortex.location                   : chr  "back" "back" "back" NA ...
 $ morphology.back                   : chr  "cortex/unworked" "cortex/unworked" "cortex/unworked" "partly_retouched" ...
 $ retouch.active.edge               : chr  "YES" "YES" "YES" "YES" ...
 $ retouch.type.edge                 : chr  "bifacial" "bifacial" "bifacial" "bifacial" ...
 $ tip.morphology                    : chr  "undeterminable" "undeterminable" "undeterminable" "undeterminable" ...
 $ application.Pradnik.method        : chr  "YES" "NO" "NO" "NO" ...
 $ frequency.application.Pradnik.method: chr  "N/A" NA NA NA ...
 $ type.lateral.sharpening.spall     : chr  NA NA NA NA ...
 $ tool.lateralisation               : chr  "sin." "sin." "dex." "sin." ...
 $ length                            : num  72.5 142.8 52.4 48.3 58.9 ...
 $ width                             : num  41.6 69.7 38.2 34 30.5 ...
 $ thickness                         : num  17.8 24.2 20.9 11.6 19.7 ...
 $ weight                            : num  0.058 0.129 0.035 0.022 0.037 ...
 $ perimeter.basis.back              : num  10.6 18.7 5.7 4.1 9.6 7.6 6.3 8.5 4.6 10.8 ...
 $ perimeter.distal.posterior.part   : chr  "1" "4" "4" " 4.6" ...
 $ perimeter.active.edge             : num  6.7 11.4 4.7 4.4 4.4 6.4 5.9 5.4 5.9 5.4 ...
 $ perimeter.total                   : num  18.3 34.1 14.1 13.1 15.3 ...
 $ thickness.back                    : num  17.16 22.07 19.03 7.06 20.03 ...
 $ taphonomic.visual.inspection      : chr  "N/A" "N/A" "N/A" "N/A" ...
 $ tool.edges.preservation           : chr  "N/A" "N/A" "N/A" "N/A" ...
 $ macroscopically.visible.use-wear  : chr  "N/A" "N/A" "N/A" "N/A" ...
 $ use-wear.analysis                 : chr  "N/A" "N/A" "N/A" "N/A" ...
 $ 3D-scan                           : chr  "N/A" "N/A" "N/A" "N/A" ...
 $ schistosity                       : chr  "N/A" "N/A" "N/A" "N/A" ...
 $ orientation.schistosity           : chr  NA NA NA NA ...
# adds indices as row names
row.names(merged_data) <- 1:nrow(merged_data)
```

Data analsysis - sorting

Dimension

```
# keeps only columns relevant for dimensions and sorts them based on
# their technological class
keep_col <- c(1:2, 4:5, 19:21)
dimensions <- merged_data[, keep_col] %>% arrange(technological.class)

KM_dimensions <- dimensions[4:333, ]
PS_dimensions <- dimensions[493:546, ]
LSS_dimensions <- dimensions[334:492, ]
```

Perimeter

```
# keeps only columns relevant for perimeter measurements and sorts them
# based on their technological class
```

```
keep_col <- c(1:2, 4:5,7,23:26)
perimeter <- merged_data[, keep_col] %>% arrange(technological.class)

KM_perimeter <- perimeter[4:333, ] %>% arrange(artefact.state)
PS_perimeter <- perimeter[493:546, ]
```

Raw material

```
# keeps only columns relevant for raw material classification and sorts them
# based on their technological class
keep_col <- c(1:2, 4:5, 3)
raw_material <- merged_data[, keep_col] %>% arrange(technological.class)

KM_raw_material <- raw_material[4:333, ] %>% arrange(artefact.state)
PS_raw_material <- raw_material[493:546, ] %>% arrange(artefact.state)
LSS_raw_material <- raw_material[334:492, ] %>% arrange(artefact.state)
```

Cortex + blanks

```
# keeps only columns relevant for cortex and blank classification and sorts them
# based on their technological class
keep_col <- c(1:2, 4:5, 6, 8:10)
cortex_blanks <- merged_data[, keep_col] %>% arrange(technological.class)

KM_cortex_blanks <- cortex_blanks[4:333, ] %>% arrange(artefact.state)
PS_cortex_blanks <- cortex_blanks[493:546, ] %>% arrange(artefact.state)
```

Back

```
# keeps only columns relevant for back modifications and sorts them based
# on their technological class
keep_col <- c(1:2, 4:5, 11, 27)
back <- merged_data[, keep_col] %>% arrange(technological.class)

KM_back <- back[4:333, ] %>% arrange(artefact.state)
PS_back <- back[493:546, ] %>% arrange(artefact.state)
```

Edge retouch

```
# keeps only columns relevant for edge retouch classification and sorts them
# based on their technological class
keep_col <- c(1:2, 4:5, 12:13, 29)
edge_retouch <- merged_data[, keep_col] %>% arrange(technological.class)

KM_edge_retouch <- edge_retouch[4:333, ] %>% arrange(artefact.state)
PS_edge_retouch <- edge_retouch[493:546,] %>% arrange(artefact.state)
```

Morpho type

```
# keeps only columns relevant for morpho type classification and sorts them
# based on their technological class
keep_col <- c(1:2, 4:5, 7, 19:21)
morpho.type <- merged_data[, keep_col] %>% arrange(technological.class)

KM_morpho.type <- morpho.type[4:333, ] %>% arrange(artefact.state)
PS_morpho.type <- morpho.type[493:546, ] %>% arrange(artefact.state)
```

Application ‘Pradnik method’

```
# keeps only columns relevant for 'morpho type 'Pradnik method' classification
# and sorts them based on their technological class
keep_col <- c(1:2, 4:5, 15:16)
Pradnik.method <- merged_data[, keep_col] %>% arrange(technological.class)
```

```r
KM_Pradnik.method <- Pradnik.method[4:333, ] %>% arrange(artefact.state)
PS_Pradnik.method <- Pradnik.method[493:546, ]  %>% arrange(artefact.state)
```

Lateralisation

```r
# keeps only columns relevant for lateralisation and sorts them based on their
# technological class
keep_col <- c(1:2, 4:5, 18)
lateralisation <- merged_data[, keep_col] %>% arrange(technological.class)

KM_lateralisation <- lateralisation[4:333, ] %>% arrange(artefact.state)
PS_lateralisation <- lateralisation[493:546, ] %>% arrange(artefact.state)
```

Type lateral sharpening spall

```r
# keeps only columns relevant for lateral sharpening spall classification and sorts
# them based on their technological class
keep_col <- c(1:2, 4:5, 17:18)
lss_type <- merged_data[, keep_col] %>% arrange(technological.class)

LSS_type <- lss_type[334:492, ] %>% arrange(artefact.state)
```

Save data

Format name of output file

```r
file_out <- "all_sites_analysis"
```

The files will be saved as "~/all_sites_analysis.[ext]".

Write to XLSX

```r
write.xlsx(list(data = merged_data, dimensions = dimensions, KM_dimensions =
                KM_dimensions, PS_dimensions = PS_dimensions, LSS_dimensions =
                LSS_dimensions, KM_perimeter = KM_perimeter, PS_perimeter =
                PS_perimeter, KM_raw_material = KM_raw_material,
                PS_raw_material = PS_raw_material, LSS_raw_material =
                LSS_raw_material, KM_cortex_blanks = KM_cortex_blanks,
                PS_cortex_blanks = PS_cortex_blanks,
                KM_back = KM_back, PS_back = PS_back, KM_edge_retouch =
                KM_edge_retouch, PS_edge_retouch = PS_edge_retouch,
                KM_morpho.type = KM_morpho.type,
                PS_morpho.type = PS_morpho.type, KM_Pradnik.method =
                KM_Pradnik.method, PS_Pradnik.method = PS_Pradnik.method,
                KM_lateralisation = KM_lateralisation,
                PS_lateralisation = PS_lateralisation, LSS_type = LSS_type),
                file = paste0(dir_out, file_out, ".xlsx"))
```

Save R object

```r
saveObject(merged_data, file = paste0(dir_out, file_out, ".Rbin"))
```

---

sessionInfo() and RStudio version

```r
sessionInfo()
R version 4.0.2 (2020-06-22)
Platform: x86_64-w64-mingw32/x64 (64-bit)
Running under: Windows 10 x64 (build 19041)

Matrix products: default
```

```
locale:
[1] LC_COLLATE=German_Germany.1252  LC_CTYPE=German_Germany.1252
[3] LC_MONETARY=German_Germany.1252 LC_NUMERIC=C
[5] LC_TIME=German_Germany.1252

attached base packages:
[1] tools     stats     graphics  grDevices utils     datasets  methods
[8] base

other attached packages:
[1] dplyr_1.0.3       chron_2.3-56      data.table_1.13.6 R.utils_2.10.1
[5] R.oo_1.24.0       R.methodsS3_1.8.1 readxl_1.3.1      openxlsx_4.2.3

loaded via a namespace (and not attached):
 [1] Rcpp_1.0.6        knitr_1.31        magrittr_2.0.1    tidyselect_1.1.0
 [5] R6_2.5.0          rlang_0.4.10      stringr_1.4.0     xfun_0.20
 [9] DBI_1.1.1         ellipsis_0.3.1    htmltools_0.5.1.1 assertthat_0.2.1
[13] yaml_2.2.1        digest_0.6.27     tibble_3.0.5      lifecycle_0.2.0
[17] crayon_1.4.0      zip_2.1.1         purrr_0.3.4       vctrs_0.3.6
[21] glue_1.4.2        evaluate_0.14     rmarkdown_2.6     stringi_1.5.3
[25] pillar_1.4.7      compiler_4.0.2    cellranger_1.1.0  generics_0.1.0
[29] pkgconfig_2.0.3
```

RStudio version 1.3.1073.

END OF SCRIPT

Summary stats - Lithic analysis from three sites: Balver Höhle, Buhlen & Ramioul

Lisa Schunk

2021-02-05

Goal of the script

This script computes standard descriptive statistics for each group.
The groups are based on:

52. Tool type
53. state of the tool (Complete, distal/proximal fragment, medial fragment)

It computes the following statistics:

54. n (sample size = length): number of measurements
55. smallest value (min)
56. largest value (max)
57. mean
58. median
59. standard deviation (sd)

```
dir_in <- "analysis/all_sites/derived_data/"
dir_out <- "analysis/all_sites/summary_stats/"
```

Raw data must be located in ~/analysis/all_sites/derived_data/.
Formatted data will be saved in ~/analysis/all_sites/summary_stats/. The knit directory for this script is the project directory.

Load packages

```
library(openxlsx)
Warning: package 'openxlsx' was built under R version 4.0.3
library(R.utils)
library(tools)
library(doBy)
Warning: package 'doBy' was built under R version 4.0.3
```

Get name, path and information of the file

```
data_file <- list.files(dir_in, pattern = "\\.xlsx$", full.names = TRUE)
md5_in <- md5sum(data_file)
info_in <- data.frame(file = basename(names(md5_in)), checksum = md5_in,
         row.names = NULL)
```

The checksum (MD5 hashes) of the imported file is

```
                  file                         checksum
1 all_sites_analysis.xlsx 6dc873265ae237ede148dfdbfd89cac5
```

Load data into R object

```
imp_data <- loadObject(paste0(dir_in, "all_sites_analysis.Rbin"))
```

The imported file is: "~/analysis/all_sites/derived_data/all_sites_analysis.xlsx"

Define numeric variables

```
# changes the order of columns
imp_data <- imp_data[c(1:22, 27,23:26, 28:34)]
num.var <-19:23
```

The following variables will be used:

```
[19] length
[20] width
[21] thickness
[22] weight
[23] thickness.back
```

Compute summary statistics

Create function to compute the statistics at once

```
nminmaxmeanmedsd <- function(x){
  y <- x[!is.na(x)]
  n_test <- length(y)
  min_test <- min(y)
  max_test <- max(y)
  mean_test <- mean(y)
  med_test <- median(y)
  sd_test <- sd(y)
  out <- c(n_test, min_test, max_test, mean_test, med_test, sd_test)
  names(out) <- c("n", "min", "max", "mean", "median", "sd")
  return(out)
}
```

Compute the summary statistics

Dimensions

```
# Dimensions Keilmesser, Keilmesser-points, Pradnik scraper &
# Later sharpening spall
dimensions <- summaryBy(length + width + thickness ~ technological.class +
             artefact.state, data = imp_data, FUN = nminmaxmeanmedsd)
str(dimensions)
'data.frame':   13 obs. of  20 variables:
 $ technological.class: chr  "flake" "hammerstone" "Keilmesser" "Keilmesser" ...
 $ artefact.state     : chr  "complete" "complete" "complete" "distal_fragment" ...
 $ length.n           : num  2 1 278 1 36 2 13 146 7 3 ...
 $ length.min         : num  54 90 29.7 22 13 ...
 $ length.max         : num  99 90 135.6 22 91.9 ...
 $ length.mean        : num  76.5 90 55.5 22 38.1 ...
 $ length.median      : num  76.5 90 51.9 22 35.6 ...
 $ length.sd          : num  31.8 NA 16.9 NA 16.1 ...
 $ width.n            : num  2 1 278 1 36 2 13 146 7 3 ...
 $ width.min          : num  27 62 14 44 19 ...
 $ width.max          : num  42 62 81.4 44 53.2 ...
 $ width.mean         : num  34.5 62 33.7 44 33.3 ...
 $ width.median       : num  34.5 62 32.4 44 32 ...
```

```
 $ width.sd          : num  10.61 NA 8.84 NA 8.47 ...
 $ thickness.n       : num  2 1 278 1 36 2 13 146 7 3 ...
 $ thickness.min     : num  16 52 7 12 8 10 13.6 2 4 2.32 ...
 $ thickness.max     : num  25 52 31 12 23.6 ...
 $ thickness.mean    : num  20.5 52 16.3 12 14.3 ...
 $ thickness.median  : num  20.5 52 15.8 12 13.6 ...
 $ thickness.sd      : num  6.36 NA 4.33 NA 3.58 ...
```

Save data

Format name of output file

```
file_out <- "all_sites_analysis_stats"
```

The file will be saved as "~/analysis/all_sites/summary_stats/.[ext]".

Write to XLSX

```
write.xlsx(list(dimensions = dimensions),
         file = paste0(dir_out, file_out, ".xlsx"))
```

Save R object

```
saveObject(list(dimensions = dimensions),
         file = paste0(dir_out, file_out, ".Rbin"))
```

Show file information

```
file_out <- c(paste0(dir_out, file_out, ".xlsx"), paste0(dir_out,
          file_out, ".Rbin"))
md5_out <- md5sum(file_out)
info_out <- data.frame(files = basename(names(md5_out)), checksum = md5_out,
                row.names = NULL)
```

The checksum (MD5 hashes) of the exported files are:

```
                         files                         checksum
1 all_sites_analysis_stats.xlsx 7a5de567c202d14ab9c3912f2e287459
2 all_sites_analysis_stats.Rbin 8ff732498420a3d51de58f477d0c8b60
```

---

sessionInfo() and RStudio version

```
sessionInfo()
R version 4.0.2 (2020-06-22)
Platform: x86_64-w64-mingw32/x64 (64-bit)
Running under: Windows 10 x64 (build 19041)

Matrix products: default

locale:
[1] LC_COLLATE=German_Germany.1252  LC_CTYPE=German_Germany.1252
[3] LC_MONETARY=German_Germany.1252 LC_NUMERIC=C
[5] LC_TIME=German_Germany.1252

attached base packages:
[1] tools     stats     graphics  grDevices utils     datasets  methods
[8] base

other attached packages:
[1] doBy_4.6.8        R.utils_2.10.1    R.oo_1.24.0       R.methodsS3_1.8.1
[5] openxlsx_4.2.3
```

```
loaded via a namespace (and not attached):
 [1] zip_2.1.1         Rcpp_1.0.6        compiler_4.0.2    pillar_1.4.7
 [5] digest_0.6.27     lattice_0.20-41   evaluate_0.14     lifecycle_0.2.0
 [9] tibble_3.0.5      gtable_0.3.0      pkgconfig_2.0.3   rlang_0.4.10
[13] Matrix_1.2-18     DBI_1.1.1         yaml_2.2.1        xfun_0.20
[17] dplyr_1.0.3       stringr_1.4.0     knitr_1.31        generics_0.1.0
[21] vctrs_0.3.6       grid_4.0.2        tidyselect_1.1.0  glue_1.4.2
[25] R6_2.5.0          rmarkdown_2.6     tidyr_1.1.2       purrr_0.3.4
[29] ggplot2_3.3.3     magrittr_2.0.1    backports_1.2.0   scales_1.1.1
[33] ellipsis_0.3.1    htmltools_0.5.1.1 MASS_7.3-53       assertthat_0.2.1
[37] colorspace_2.0-0  Deriv_4.1.2       stringi_1.5.3     munsell_0.5.0
[41] broom_0.7.4       crayon_1.4.0
```

RStudio version 1.3.1073.

END OF SCRIPT

Plots - Lithic analysis from three sites: Balver Höhle, Buhlen & Ramioul

Lisa Schunk

2021-02-14

Goal of the script

This script reads the xlsx file (derived data) containing all the information gained through a lithic analysis.
The script will:

60. Read the xlsx file
61. Plot all relevant variables in various combinations
62. Save the plot as PDFs

```
dir_in <-  "analysis/all_Sites/derived_data/"
dir_out <- "analysis/all_sites/plots/"
```

Raw data must be located in “analysis/all_Sites/derived_data/”.
Formatted data will be saved in “analysis/all_sites/plots/”. The knit directory for this script is the project directory.

Load packages

```
library(openxlsx)
Warning: package 'openxlsx' was built under R version 4.0.3
library(readxl)
library(R.utils)
library(tools)
library(chron)
library(ggplot2)
Warning: package 'ggplot2' was built under R version 4.0.3
library(wesanderson)
library(dplyr)
Warning: package 'dplyr' was built under R version 4.0.3
library(ggsci)
```

Get name, path and information of the file

```
data_file <- list.files(dir_in, pattern = "\\.xlsx$", full.names = TRUE)
md5_in <- md5sum(data_file)
info_in <- data.frame(files = basename(names(md5_in)), checksum = md5_in,
          row.names = NULL)
```

The checksum (MD5 hashes) of the imported files are:

```
                  files                         checksum
1 all_sites_analysis.xlsx 6dc873265ae237ede148dfdbfd89cac5
```

Load data into R object

```
imp_data <- read.xlsx(xlsxFile = data_file, sheet = 1, startRow = 1,
                      colNames = TRUE,
                      rowNames = FALSE, skipEmptyRows = FALSE)
```

Data analsysis - plots

Histogram

Histogram dimensions - Keilmesser

```
# Load data sheet Keilmesser
KM_dim <- read.xlsx(xlsxFile = data_file, sheet = 3)
# removes incomplete artefacts
KM_dim <- KM_dim[ , ] %>% arrange(artefact.state)
KM.tip_dim <- KM_dim[-c(279, 316:330), ]

# Keilmesser length
# Calculates the mean value for the plot and ascribes the N value
mean_length <- mean(KM.tip_dim$length, na.rm = TRUE)
n <- doBy::summaryBy(length ~ artefact.state, data = KM.tip_dim, FUN = length)
tag <- gsub(pattern = "_", replacement = " ", paste0(n[[1]],
                                      " (n = ", n[[2]], ")"))

# Histogram Keilmesser length
KM.length <- ggplot(KM.tip_dim, aes(x = length, fill = artefact.state)) +
            geom_histogram(binwidth = 1) +
            labs(x = "length [mm]", y = "n", title = "",
            fill = "artefact state", size = 12) +
            theme_classic() +
            geom_vline(aes(xintercept = mean_length), linetype="dashed",
            size = 1) +
            geom_text(aes(y = mean_length, x = 67, label =
            round(mean_length, 1)), nudge_y = -38) +
            scale_fill_manual(values = wes_palette(n = 2,
            name = "FantasticFox1", type = "continuous"), labels = tag)

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "KM.length", ".pdf")
ggsave(filename = file_out, plot = KM.length, path = dir_out, device = "pdf",
         width = 170, height = 250, units = "mm")


# Keilmesser width
# Calculates the mean value for the plot and ascribes the N value
mean_width <- mean(KM.tip_dim$width, na.rm = TRUE)
n <- doBy::summaryBy(width ~ artefact.state, data = KM.tip_dim, FUN = length)
tag <- gsub(pattern = "_", replacement = " ", paste0(n[[1]],
                                      " (n = ", n[[2]], ")"))

# Histogram Keilmesser width
KM.width <- ggplot(KM.tip_dim, aes(x = width, fill = artefact.state)) +
           geom_histogram(binwidth = 1) +
           labs(x = "width [mm]", y = "n", title = "", fill = "artefact state",
           size = 12) +
           theme_classic() +
           geom_vline(aes(xintercept = mean_width), linetype = "dashed",
           size = 1) +
           geom_text(aes(y = mean_length, x = 42, label = round(mean_width, 1)),
           nudge_y = -34) +
           scale_fill_manual(values = wes_palette(n = 2, name = "FantasticFox1",
           type = "continuous"), labels = tag)

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "KM.width", ".pdf")
ggsave(filename = file_out, plot = KM.width, path = dir_out, device = "pdf",
         width = 170, height = 250, units = "mm")
```

```r
# Keilmesser thickness
# Calculates the mean value for the plot and ascribes the N value
mean_thickness <- mean(KM.tip_dim$thickness, na.rm = TRUE)
n <- doBy::summaryBy(thickness ~ artefact.state, data = KM.tip_dim, FUN = length)
tag <- gsub(pattern = "_", replacement = " ", paste0(n[[1]],
                                    " (n = ", n[[2]], ")"))

# Histogram Keilmesser thickness
KM.thickness  <- ggplot(KM.tip_dim, aes(y = thickness, fill = artefact.state)) +
                geom_histogram(binwidth = 0.8) +
                labs(y = "thickness [mm]", x = "n", title = "",
                fill = "artefact state",
                size = 12) +
                theme_classic() +
                geom_hline(aes(yintercept = mean_thickness),
                linetype = "dashed",size = 1) +
                geom_text(aes(y = mean_thickness, x = 37.5,
                label = round(mean_thickness, 1)), nudge_y = 1) +
                scale_fill_manual(values = wes_palette(n = 2,
                name = "FantasticFox1", type = "continuous"), labels = tag)

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "KM.thickness", ".pdf")
ggsave(filename = file_out, plot = KM.thickness, path = dir_out, device = "pdf",
         width = 250, height = 170, units = "mm")


# Keilmesser Back
# Load data sheet Keilmesser thickness back
KM_back <- read.xlsx(xlsxFile = data_file, sheet = 13)
KM_back <- KM_back[-c(279:330), ]


# Calculates the mean value for the plot and ascribes the N value
mean_KM_back <- mean(KM_back$thickness.back, na.rm = TRUE)
n <- doBy::summaryBy(thickness.back ~ artefact.state, data = KM_back,
                    FUN = length)
tag <- gsub(pattern = "_", replacement = " ", paste0(n[[1]],
                                    " (n = ", n[[2]], ")"))

# Histogram Keilmesser thickness back
KM.back  <- ggplot(KM_back, aes(y = thickness.back, fill = artefact.state)) +
                geom_histogram(binwidth = 0.8) +
                labs(x = "thickness [mm]", y = "n", title = "",
                fill = "artefact state",
                size = 12) +
                theme_classic() +
                geom_hline(aes(yintercept = mean_KM_back), linetype = "dashed",
                size = 1) +
                geom_text(aes(y = mean_KM_back, x = 28.5,
                label = round(mean_KM_back, 1)), nudge_y = -0.7) +
                scale_fill_manual(values = wes_palette(n = 2,
                name = "FantasticFox1", type = "continuous"), labels = tag)

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "KM.back", ".pdf")
ggsave(filename = file_out, plot = KM.back, path = dir_out, device = "pdf",
         width = 250, height = 170, units = "mm")
```

Histogram dimensions - Keilmesser - sites in comparison

```
# Load data sheet Keilmesser
KM_dim <- read.xlsx(xlsxFile = data_file, sheet = 3)
# removes incomplete artefacts
KM_dim <- KM_dim[ , ] %>% arrange(artefact.state)
KM_dim <- KM_dim[-c(279:330), ]

# Keilmesser length
# Calculates the mean value for the plot and ascribes the N value
mean_length <- mean(KM_dim$length, na.rm = TRUE)
n <- doBy::summaryBy(length ~ site, data = KM_dim, FUN = length)
tag <- gsub(pattern = "_", replacement = " ", paste0(n[[1]],
                                   " (n = ", n[[2]], ")"))

# Histogram Keilmesser length
KM.length_sites <- ggplot(KM_dim, aes(x = length, fill = site)) +
           geom_histogram(binwidth = 2) +
           labs(x = "length [mm]", y = "n", title = "", fill = "site",
           size = 12) +
           theme_classic() +
           geom_vline(aes(xintercept = mean_length), linetype="dashed",
           size = 1) +
           geom_text(aes(y = mean_length, x = 67, label =
           round(mean_length, 1)),
           nudge_y = -38) +
           scale_fill_manual(values = wes_palette(n = 3, name = "FantasticFox1",
           type = "continuous"), labels = tag)

file_out <- paste0(file_path_sans_ext(info_in[["file"]]),
                  "KM.length_sites", ".pdf")
ggsave(filename = file_out, plot = KM.length_sites, path = dir_out,
        device = "pdf", width = 170, height = 250, units = "mm")


# Keilmesser width
# Calculates the mean value for the plot and ascribes the N value
mean_width <- mean(KM_dim$width, na.rm = TRUE)
n <- doBy::summaryBy(width ~ site, data = KM_dim, FUN = length)
tag <- gsub(pattern = "_", replacement = " ", paste0(n[[1]],
                                   " (n = ", n[[2]], ")"))

# Histogram Keilmesser width
KM.width_sites <- ggplot(KM_dim, aes(x = width, fill = site)) +
          geom_histogram(binwidth = 1) +
          labs(x = "width [mm]", y = "n", title = "", fill = "site",
          size = 12) +
          theme_classic() +
          geom_vline(aes(xintercept = mean_width), linetype = "dashed",
          size = 1) +
          geom_text(aes(y = mean_length, x = 42, label = round(mean_width, 1)),
          nudge_y = -34) +
          scale_fill_manual(values = wes_palette(n = 3, name = "FantasticFox1",
          type = "continuous"), labels = tag)

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "KM.width_sites",
                 ".pdf")
ggsave(filename = file_out, plot = KM.width_sites, path = dir_out,
        device = "pdf", width = 170, height = 250, units = "mm")
```

```r
# Keilmesser thickness
# Calculates the mean value for the plot and ascribes the N value
mean_thickness <- mean(KM_dim$thickness, na.rm = TRUE)
n <- doBy::summaryBy(thickness ~ site, data = KM_dim, FUN = length)
tag <- gsub(pattern = "_", replacement = " ", paste0(n[[1]],
                                   " (n = ", n[[2]], ")"))

# Histogram Keilmesser thickness
KM.thickness_sites  <- ggplot(KM_dim, aes(y = thickness, fill = site)) +
                     geom_histogram(binwidth = 0.8) +
                     labs(y = "thickness [mm]", x = "n", title = "",
                     fill = "site", size = 12) +
                     theme_classic() +
                     geom_hline(aes(yintercept = mean_thickness),
                     linetype = "dashed", size = 1) +
                     geom_text(aes(y = mean_thickness, x = 37.5,
                     label = round(mean_thickness, 1)), nudge_y = 1) +
                     scale_fill_manual(values = wes_palette(n = 3, name =
                     "FantasticFox1", type = "continuous"), labels = tag)

file_out <- paste0(file_path_sans_ext(info_in[["file"]]),
                 "KM.thickness_sites", ".pdf")
ggsave(filename = file_out, plot = KM.thickness_sites, path = dir_out,
        device = "pdf", width = 250, height = 170, units = "mm")


# Keilmesser Back
# Load data sheet Keilmesser thickness back
KM_back <- read.xlsx(xlsxFile = data_file, sheet = 13)
KM_back <- KM_back[-c(279:330), ]


# Calculates the mean value for the plot and ascribes the N value
mean_KM_back <- mean(KM_back$thickness.back, na.rm = TRUE)
n <- doBy::summaryBy(thickness.back ~ site, data = KM_back, FUN = length)
tag <- gsub(pattern = "_", replacement = " ", paste0(n[[1]],
                                   " (n = ", n[[2]], ")"))

# Histogram Keilmesser thickness back
KM.back_sites  <- ggplot(KM_back, aes(y = thickness.back, fill = site)) +
                geom_histogram(binwidth = 0.8) +
                labs(x = "thickness [mm]", y = "n", title = "", fill = "site",
                size = 12) +
                theme_classic() +
                geom_hline(aes(yintercept = mean_KM_back), linetype = "dashed",
                size = 1) +
                geom_text(aes(y = mean_KM_back, x = 28.5,
                label = round(mean_KM_back, 1)),
                nudge_y = -0.7) +
                scale_fill_manual(values = wes_palette(n = 3,
                name = "FantasticFox1", type = "continuous"), labels = tag)

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "KM.back_sites", ".pdf")
ggsave(filename = file_out, plot = KM.back_sites, path = dir_out, device = "pdf",
         width = 250, height = 170, units = "mm")
```

Histogram dimensions - Pradnik scraper

```r
# Load data sheet Pradnik scraper
PS_dim <- read.xlsx(xlsxFile = data_file, sheet = 4)
```

```
# Pradnik scraper length
# Calculates the mean value for the plot and ascribes the N value
mean_PS_length <- mean(PS_dim$length, na.rm = TRUE)
n <- doBy::summaryBy(length ~ artefact.state, data = PS_dim, FUN = length)
tag <- gsub(pattern = "_", replacement = " ", paste0(n[[1]],
                                 " (n = ", n[[2]], ")"))

# Histogram Pradnik scraper length
PS.length <- ggplot(PS_dim, aes(x = length, fill = artefact.state)) +
          geom_histogram(binwidth = 1) +
          labs(x = "length [mm]", y = "n", title = "", fill = "artefact state",           size = 12) +
          theme_classic() +
          geom_vline(aes(xintercept = mean_PS_length), linetype = "dashed",
          size = 1) +
          geom_text(aes(y = mean_PS_length, x = 52, label =
          round(mean_PS_length, 1)),
          nudge_y = -40.4) +
          scale_fill_manual(values = wes_palette(n = 1, name = "Chevalier1"),
          labels = tag)

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "PS.length", ".pdf")
ggsave(filename = file_out, plot = PS.length, path = dir_out, device = "pdf",
       width = 170, height = 250, units = "mm")


# Pradnik scraper width
# Calculates the mean value for the plot and ascribes the N value
mean_PS_width <- mean(PS_dim$width, na.rm = TRUE)
n <- doBy::summaryBy(width ~ artefact.state, data = PS_dim, FUN = length)
tag <- gsub(pattern = "_", replacement = " ", paste0(n[[1]],
                                 " (n = ", n[[2]], ")"))

# Histogram Pradnik scraper width
PS.width <- ggplot(PS_dim, aes(x = width, fill = artefact.state)) +
         geom_histogram(binwidth = 1) +
         labs(x = "width [mm]", y = "n", title = "", fill = "artefact state",
         size = 12) +
         theme_classic() +
         geom_vline(aes(xintercept = mean_PS_width), linetype="dashed",
         size = 1) +
         geom_text(aes(y = mean_PS_width, x = 35, label =
         round(mean_PS_width, 2)),
         nudge_y = -24.1) +
         scale_fill_manual(values = wes_palette(n = 1, name = "Chevalier1"),
         labels = tag)

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "PS.width", ".pdf")
ggsave(filename = file_out, plot = PS.width, path = dir_out, device = "pdf",
       width = 170, height = 250, units = "mm")


# Pradnik scraper thickness
# Calculates the mean value for the plot and ascribes the n value
mean_PS_thickness <- mean(PS_dim$thickness, na.rm = TRUE)
n <- doBy::summaryBy(thickness ~ artefact.state, data = PS_dim, FUN = length)
tag <- gsub(pattern = "_", replacement = " ", paste0(n[[1]],
                                 " (n = ", n[[2]], ")"))

# Histogram Pradnik scraper thickness
PS.thickness <- ggplot(PS_dim, aes(y = thickness, fill = artefact.state)) +
```

```
            geom_histogram(binwidth = 1) +
            labs(y = "thickness [mm]", x = "n", title = "",
            fill = "artefact state",
            size = 12) +
            theme_classic() +
            geom_hline(aes(yintercept = mean_PS_thickness),
            linetype = "dashed", size = 1) +
            geom_text(aes(y = mean_PS_thickness, x = 6.8,
            label = round(mean_PS_thickness, 1)),
            nudge_y = -0.5) +
            scale_fill_manual(values = wes_palette(n = 1 ,
            name = "Chevalier1"), labels = tag)

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "PS.thickness", ".pdf")
ggsave(filename = file_out, plot = PS.thickness, path = dir_out, device = "pdf",
       width = 250, height = 170, units = "mm")



# Back Pradnik scraper thickness
# Load data sheet Pradnik scraper thickness back
PS_back <- read.xlsx(xlsxFile = data_file, sheet = 14)

# Calculates the mean value for the plot and ascribes the n value
mean_PS_back <- mean(PS_back$thickness.back, na.rm = TRUE)
n <- doBy::summaryBy(thickness.back ~ artefact.state, data = PS_back,
                     FUN = length)
tag <- gsub(pattern = "_", replacement = " ", paste0(n[[1]],
                                  " (n = ", n[[2]], ")"))

# Histogram Pradnik scraper thickness back
PS.back  <- ggplot(PS_back, aes(y = thickness.back, fill = artefact.state)) +
             geom_histogram(binwidth = 0.8) +
             labs(y = "thickness [mm]", x = "n", title = "",
             fill = "artefact state",
             size = 12) +
             theme_classic() +
             geom_hline(aes(yintercept = mean_PS_back), linetype = "dashed",
             size = 1) +
             geom_text(aes(y = mean_PS_back, x = 6.8,
             label = round(mean_PS_back, 1)), nudge_y = -0.5) +
             scale_fill_manual(values = wes_palette(n = 3,
             name = "Chevalier1"), labels = tag)

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "PS.back", ".pdf")
ggsave(filename = file_out, plot = PS.back, path = dir_out, device = "pdf",
       width = 250, height = 170, units = "mm")
Warning: Removed 1 rows containing non-finite values (stat_bin).
```

Histogram dimensions - Pradnik scraper - sites in comparison

```
# Load data sheet Pradnik scraper
PS_dim <- read.xlsx(xlsxFile = data_file, sheet = 4)

# Pradnik scraper length
# Calculates the mean value for the plot and ascribes the N value
mean_PS_length <- mean(PS_dim$length, na.rm = TRUE)
n <- doBy::summaryBy(length ~ site, data = PS_dim, FUN = length)
tag <- gsub(pattern = "_", replacement = " ", paste0(n[[1]],
                                  " (n = ", n[[2]], ")"))

# Histogram Pradnik scraper length
```

```r
PS.length_sites <- ggplot(PS_dim, aes(x = length, fill = site)) +
            geom_histogram(binwidth = 1) +
            labs(x = "length [mm]", y = "n", title = " ", fill = "site",
            size = 12) +
            theme_classic() +
            geom_vline(aes(xintercept = mean_PS_length),
            linetype = "dashed", size = 1) +
            geom_text(aes(y = mean_PS_length, x = 52,
            label = round(mean_PS_length, 1)), nudge_y = -40.4) +
            scale_fill_manual(values = wes_palette(n = 6, name = "Chevalier1",
            type = "continuous"), labels = tag)

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "PS.length_sites",
                  ".pdf")
ggsave(filename = file_out, plot = PS.length_sites, path = dir_out,
        device = "pdf", width = 170, height = 250, units = "mm")


# Pradnik scraper width
# Calculates the mean value for the plot and ascribes the N value
mean_PS_width <- mean(PS_dim$width, na.rm = TRUE)
n <- doBy::summaryBy(width ~ site, data = PS_dim, FUN = length)
tag <- gsub(pattern = "_", replacement = " ", paste0(n[[1]],
                                      " (n = ", n[[2]], ")"))

# Histogram Pradnik scraper width
PS.width_sites <- ggplot(PS_dim, aes(x = width, fill = site)) +
                 geom_histogram(binwidth = 1) +
                 labs(x = "width [mm]", y = "n", title = " ", fill = "site",
                 size = 12) +
                 theme_classic() +
                 geom_vline(aes(xintercept = mean_PS_width),
                 linetype="dashed", size = 1) +
                 geom_text(aes(y = mean_PS_width, x = 35,
                 label = round(mean_PS_width, 2)), nudge_y = -24.1) +
                 scale_fill_manual(values = wes_palette(n = 6,
                 name = "Chevalier1", type = "continuous"),
                 labels = tag)

file_out <- paste0(file_path_sans_ext(info_in[["file"]]),
            "PS.width_sites_sites", ".pdf")
ggsave(filename = file_out, plot = PS.width_sites, path = dir_out,
        device = "pdf", width = 170, height = 250, units = "mm")


# Pradnik scraper thickness
# Calculates the mean value for the plot and ascribes the n value
mean_PS_thickness <- mean(PS_dim$thickness, na.rm = TRUE)
n <- doBy::summaryBy(thickness ~ site, data = PS_dim, FUN = length)
tag <- gsub(pattern = "_", replacement = " ", paste0(n[[1]],
                                      " (n = ", n[[2]], ")"))

# Histogram Pradnik scraper thickness
PS.thickness_sites <- ggplot(PS_dim, aes(y = thickness, fill = site)) +
               geom_histogram(binwidth = 1) +
               labs(y = "thickness [mm]", x = "n", title = " ",
               fill = "site", size = 12) +
               theme_classic() +
               geom_hline(aes(yintercept = mean_PS_thickness),
               linetype = "dashed", size = 1) +
```

```
            geom_text(aes(y = mean_PS_thickness, x = 6.8,
            label = round(mean_PS_thickness, 1)), nudge_y = -0.5) +
            scale_fill_manual(values = wes_palette(n = 6,
            name = "Chevalier1", type = "continuous"),                    labels = tag)

file_out <- paste0(file_path_sans_ext(info_in[["file"]]),
         "PS.thickness_sites", ".pdf")
ggsave(filename = file_out, plot = PS.thickness_sites, path = dir_out,
      device = "pdf", width = 250, height = 170, units = "mm")



# Back Pradnik scraper thickness
# Load data sheet Pradnik scraper thickness back
PS_back <- read.xlsx(xlsxFile = data_file, sheet = 14)

# Calculates the mean value for the plot and ascribes the n value
mean_PS_back <- mean(PS_back$thickness.back, na.rm = TRUE)
n <- doBy::summaryBy(thickness.back ~ site, data = PS_back, FUN = length)
tag <- gsub(pattern = "_", replacement = " ", paste0(n[[1]],
                                   " (n = ", n[[2]], ")"))

# Histogram Pradnik scraper thickness back
PS.back_sites  <- ggplot(PS_back, aes(y = thickness.back, fill = site)) +
             geom_histogram(binwidth = 0.8) +
             labs(y = "thickness [mm]", x = "n", title = "", fill = "site",
             size = 12) + theme_classic() +
             geom_hline(aes(yintercept = mean_PS_back), linetype = "dashed",           size = 1) +
             geom_text(aes(y = mean_PS_back, x = 6.8,
             label = round(mean_PS_back, 1)),
             nudge_y = -0.5) +
             scale_fill_manual(values = wes_palette(n = 6,
             name = "Chevalier1", type = "continuous"), labels = tag)

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "PS.back_sites", ".pdf")
ggsave(filename = file_out, plot = PS.back_sites, path = dir_out,
      device = "pdf", width = 250, height = 170, units = "mm")
Warning: Removed 1 rows containing non-finite values (stat_bin).
```

Histogram dimension - Lateral sharpening spall

```
# Load data sheet lateral sharpening spall
LSS_dim <- read.xlsx(xlsxFile = data_file, sheet = 5)
# removes incomplete artefacts
LSS_dim <-LSS_dim[ , ] %>% arrange(artefact.state)
LSS_dim <- LSS_dim[-c(147:159), ]



# Lateral sharpening spall length
# Calculates the mean value for the plot and ascribes the n value
mean_LSS_length <- mean(LSS_dim$length, na.rm = TRUE)
n <- doBy::summaryBy(length ~ artefact.state, data = LSS_dim, FUN = length)
tag <- gsub(pattern = "_", replacement = " ", paste0(n[[1]],
                                   " (n = ", n[[2]], ")"))

# Histogram lateral sharpening spall length
LSS.length <- ggplot(LSS_dim, aes(x = length, fill = artefact.state)) +
           geom_histogram(binwidth = 1) +
           labs(x = "length [mm]", y = "n", title = "",
           fill = "artefact state", size = 12) +
           theme_classic() +
           geom_vline(aes(xintercept = mean_LSS_length), linetype = "dashed",
```

```
              size = 1) +
              geom_text(aes(y = mean_LSS_length, x = 35,
              label = round(mean_LSS_length, 1)), nudge_y = -17.7) +
              scale_fill_manual(values = wes_palette(n = 1, name = "Royal1"),
                              labels = tag)

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "LSS.length", ".pdf")
ggsave(filename = file_out, plot = LSS.length, path = dir_out, device = "pdf",
          width = 170, height = 250, units = "mm")



# Lateral sharpening spall width
# Calculates the mean value for the plot and ascribes the n value
mean_LSS_width <- mean(LSS_dim$width, na.rm = TRUE)
n <- doBy::summaryBy(width ~ artefact.state, data = LSS_dim, FUN = length)
tag <- gsub(pattern = "_", replacement = " ", paste0(n[[1]],
                                        " (n = ", n[[2]], ")"))

# Histogram lateral sharpening spall width
LSS.width <- ggplot(LSS_dim, aes(x = width, fill = artefact.state)) +
             geom_histogram(binwidth = 1) +
             labs(x = "width [mm]", y = "n", title = "", fill = "artefact state",
             size = 12) +
             theme_classic() +
             geom_vline(aes(xintercept = mean_LSS_width), linetype = "dashed",
             size = 1) +
             geom_text(aes(y = mean_LSS_width, x = 19.8,
             label = round(mean_LSS_width, 1)), nudge_y = -1.55) +
             scale_fill_manual(values = wes_palette(n = 4, name = "Royal1"),
                             labels = tag)

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "LSS.width", ".pdf")
ggsave(filename = file_out, plot = LSS.width, path = dir_out, device = "pdf",
          width = 170, height = 250, units = "mm")



# Lateral sharpening spall thickness
# Calculates the mean value for the plot and ascribes the n value
mean_LSS_thickness <- mean(LSS_dim$thickness, na.rm = TRUE)
n <- doBy::summaryBy(thickness ~ artefact.state, data = LSS_dim, FUN = length)
tag <- gsub(pattern = "_", replacement = " ", paste0(n[[1]],
                                        " (n = ", n[[2]], ")"))

# Histogram lateral sharpening spall thickness
LSS.thickness <- ggplot(LSS_dim, aes(y = thickness, fill = artefact.state)) +
                 geom_histogram(binwidth = 0.5) +
                 labs(y = "thickness[mm]", x = "n", title = "",
                 fill = "artefact state",
                 size = 12) +
                 theme_classic() +
                 geom_hline(aes(yintercept = mean_LSS_thickness),
                 linetype = "dashed", size = 1) +
                 geom_text(aes(y = mean_LSS_thickness, x = 23.9, label =
                 round(mean_LSS_thickness, 2)), nudge_y = -0.3) +
                 scale_fill_manual(values = wes_palette(n = 4, name = "Royal1"),
                                 labels = tag)

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "LSS.thickness", ".pdf")
ggsave(filename = file_out, plot = LSS.thickness, path = dir_out, device = "pdf",
          width = 250, height = 170, units = "mm")
```

Histogram dimension - Lateral sharpening spall - sites in comparison

```
# Load data sheet lateral sharpening spall
LSS_dim <- read.xlsx(xlsxFile = data_file, sheet = 5)
# removes incomplete artefacts
LSS_dim <-LSS_dim[ , ] %>% arrange(artefact.state)
LSS_dim <- LSS_dim[-c(147:159), ]


# Lateral sharpening spall length
# Calculates the mean value for the plot and ascribes the n value
mean_LSS_length <- mean(LSS_dim$length, na.rm = TRUE)
n <- doBy::summaryBy(length ~ site, data = LSS_dim, FUN = length)
tag <- gsub(pattern = "_", replacement = " ", paste0(n[[1]],
                                    " (n = ", n[[2]], ")"))

# Histogram lateral sharpening spall length
LSS.length_sites <- ggplot(LSS_dim, aes(x = length, fill = site)) +
                  geom_histogram(binwidth = 1) +
                  labs(x = "length [mm]", y = "n", title = "", fill = "site",
                  size = 12) +
                  theme_classic() +
                  geom_vline(aes(xintercept = mean_LSS_length),
                  linetype = "dashed", size = 1) +
                  geom_text(aes(y = mean_LSS_length, x = 35,
                  label = round(mean_LSS_length, 1)), nudge_y = -17.7) +
                  scale_fill_manual(values = wes_palette(n = 2, name =
                  "Royal1"), labels = tag)

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "LSS.length_sites",
                  ".pdf")
ggsave(filename = file_out, plot = LSS.length_sites, path = dir_out,
        device = "pdf", width = 170, height = 250, units = "mm")


# Lateral sharpening spall width
# Calculates the mean value for the plot and ascribes the n value
mean_LSS_width <- mean(LSS_dim$width, na.rm = TRUE)
n <- doBy::summaryBy(width ~ site, data = LSS_dim, FUN = length)
tag <- gsub(pattern = "_", replacement = " ", paste0(n[[1]],
                                    " (n = ", n[[2]], ")"))

# Histogram lateral sharpening spall width
LSS.width_sites <- ggplot(LSS_dim, aes(x = width, fill = site)) +
            geom_histogram(binwidth = 1) +
            labs(x = "width [mm]", y = "n", title = "",
            fill = "site", size = 12) +
            theme_classic() +
            geom_vline(aes(xintercept = mean_LSS_width), linetype = "dashed",
            size = 1) +
            geom_text(aes(y = mean_LSS_width, x = 19.8, label =
            round(mean_LSS_width, 1)), nudge_y = -1.55) +
            scale_fill_manual(values = wes_palette(n = 2, name = "Royal1"),
                        labels = tag)

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "LSS.width_sites",
                  ".pdf")
ggsave(filename = file_out, plot = LSS.width_sites, path = dir_out,
        device = "pdf", width = 170, height = 250, units = "mm")
```

```
# Lateral sharpening spall thickness
# Calculates the mean value for the plot and ascribes the n value
mean_LSS_thickness <- mean(LSS_dim$thickness, na.rm = TRUE)
n <- doBy::summaryBy(thickness ~ site, data = LSS_dim, FUN = length)
tag <- gsub(pattern = "_", replacement = " ", paste0(n[[1]],
                                     " (n = ", n[[2]], ")"))

# Histogram lateral sharpening spall thickness
LSS.thickness_sites <- ggplot(LSS_dim, aes(y = thickness, fill = site)) +
                       geom_histogram(binwidth = 0.5) +
                       labs(y = "thickness[mm]", x = "n", title = "",
                       fill = "site",
                       size = 12) +
                       theme_classic() +
                       geom_hline(aes(yintercept = mean_LSS_thickness),
                       linetype = "dashed", size = 1) +
                       geom_text(aes(y = mean_LSS_thickness, x = 23.9, label =
                       round(mean_LSS_thickness, 2)), nudge_y = -0.3) +
                       scale_fill_manual(values = wes_palette(n = 2,
                       name = "Royal1"), labels = tag)

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "LSS.thickness", ".pdf")
ggsave(filename = file_out, plot = LSS.thickness_sites, path = dir_out,
        device = "pdf", width = 250, height = 170, units = "mm")
```

Scatterplot

Length-width ratio

```
# Load data sheet Keilmesser
KM_dim <- read.xlsx(xlsxFile = data_file, sheet = 3)
KM_dim <- KM_dim[ , ] %>% arrange(artefact.state)
KM_comp_dim <- KM_dim[-c(279:330 ), ]

# Keilmesser length VS width
# Ascribes the n value
n <- doBy::summaryBy(width + length ~ site, data = KM_comp_dim, FUN = length)
tag <- gsub(pattern = "_", replacement = " ", paste0(n[[1]],
                                     " (n = ", n[[2]], ")"))

# Scatterplot Keilmesser (complete + tip) length VS width
KM.length_width <- ggplot(KM_comp_dim, aes(y = length, x = width, fill = site)) +
                   geom_point(size = 3, shape = 21) +
                   labs(y = "length [mm]", x = "width [mm]", title = "",
                   fill = "", size = 12) +
                   xlim(0, 100) + ylim(0, 160) +
                   theme_classic() +
                   scale_fill_manual(values = wes_palette(n = 3,
                   name = "FantasticFox1", type = "continuous"), labels = tag)

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "KM.length_width",
                   ".pdf")
ggsave(filename = file_out, plot = KM.length_width, path = dir_out,
         evice = "pdf", width = 170, height = 250, units = "mm")
Error in grDevices::pdf(file = filename, ..., version = version): unused argument (evice = "pdf")
# Keilmesser complete + tips length vs width
# Define the rows with complete Keilmesser and Keilmesser tips
KM_comp.tip_dim <- KM_dim[-c(279, 316:330), ]

# Ascribes the n value
n <- doBy::summaryBy(length + width ~ site, data = KM_comp.tip_dim, FUN = length)
```

```
tag <- gsub(pattern = "_", replacement = " ", paste0(n[[1]],
                                     " (n = ", n[[2]], ")"))

# Scatterplot Keilmesser (complete + tip) length VS width
KM.tip.length_width <- ggplot(KM_comp.tip_dim, aes(y = length, x = width,
                      colour = site, shape = artefact.state)) +
                      geom_point(size = 2) +
                      scale_colour_manual(values = wes_palette(n = 3, name =
                      "FantasticFox1", type = "continuous"), labels = tag) +
                      labs(y = "length [mm]", x = "width [mm]", title = "",
                      fill = "", size = 12) +
                      xlim(0, 100) + ylim(0, 160) +
                      theme_classic()

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "KM.tip.length_width",
                   ".pdf")
ggsave(filename = file_out, plot = KM.tip.length_width, path = dir_out,
       device = "pdf", width = 170, height = 250, units = "mm")


# Load data sheet Pradnik scraper
PS_dim <- read.xlsx(xlsxFile = data_file, sheet = 4)

# Pradnik scraper length VS width
# Ascribes the n value
n <- doBy::summaryBy(length + width ~ site, data = PS_dim, FUN = length)
tag <- gsub(pattern = "_", replacement = " ", paste0(n[[1]],
                                     " (N = ", n[[2]], ")"))

# Scatterplot Pradnik scraper length VS width
PS.length_width <- ggplot(PS_dim, aes(y = length, x = width, fill = site)) +
                   geom_point(size = 3, shape = 21) +
                   labs(y = "length [mm]", x = "width [mm]", title = "",
                   fill = " ", size = 12) +
                   xlim(0, 80) + ylim(0, 80) +
                   theme_classic() +
                   scale_fill_manual(values = wes_palette(n = 6,
                   name = "Chevalier1", type = "continuous"), labels = tag)

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "PS.length_width",
                   ".pdf")
ggsave(filename = file_out, plot = PS.length_width, path = dir_out,
       device = "pdf",
        width = 170, height = 250, units = "mm")




# Lateral sharpening spall length VS width
# Defines only the rows with complete LSS
LSS_dim <- LSS_dim[ , ] %>% arrange(artefact.state)
LSS.comp_dim <- LSS_dim[1:146, ]

# Lateral sharpening spall length VS width
# Ascribes the n value
n <- doBy::summaryBy(length + width ~ site, data = LSS.comp_dim, FUN = length)
tag <- gsub(pattern = "_", replacement = " ", paste0(n[[1]],
                                     " (n = ", n[[2]], ")"))

# Scatterplot lateral sharpening spall length VS width
LSS.length_width <- ggplot(LSS.comp_dim, aes(y = length, x = width,
```

```
                   fill = site)) +
                   geom_point(size = 3, shape = 21) +
                   labs(y = "length [mm]", x = "width [mm]", title = " ",
                   fill = " ", size = 12) +
                   xlim(0, 65) + ylim(0, 65) +
                   theme_classic() +
                   scale_fill_manual(values = wes_palette(n = 2,
                   name = "Royal1"), labels = tag)

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "LSS.length_width",
                  ".pdf")
ggsave(filename = file_out, plot = LSS.length_width, path = dir_out,
        device = "pdf", width = 170, height = 250, units = "mm")


# Keilmesser (complete) + Pradnik scraper length VS width
# Load data sheet dimensions
dim <- read.xlsx(xlsxFile = data_file, sheet = 2)
dim <- dim[ , ] %>% arrange(artefact.state)
# Defines only the relevant rows
KM.PS_dim <- dim[c(4:281, 428:481), ]

# Ascribes the n value
n <- doBy::summaryBy(length + width ~ technological.class, data = KM.PS_dim,
                   FUN = length)
tag <- gsub(pattern = "_", replacement = " ", paste0(n[[1]],
                                     " (n = ", n[[2]], ")"))


KM.PS.length_width <- ggplot(KM.PS_dim, aes(y = length, x = width,
                    fill = technological.class)) +
                    geom_point(size = 3, shape = 21) +
                    labs(y = "length [mm]", x = "width [mm]", title = " ",
                    fill = "artefact category", size = 12) +
                    xlim(0, 100) + ylim(0, 150) +
                    theme_classic() +
                    scale_fill_manual(values = wes_palette(n = 3,
                    name = "GrandBudapest1", type = "continuous"),
                    labels = tag)

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "KM.PS.length_width",
                  ".pdf")
ggsave(filename = file_out, plot = KM.PS.length_width, path = dir_out,
        device = "pdf", width = 170, height = 250, units = "mm")


# Keilmesser (complete): length-width combined with morpho type
# Load data sheet Keilmesser morpho type
KM_morpho.type <- read.xlsx(xlsxFile = data_file, sheet = 17)
# Arranges the data and defines only the relevant rows
KM_morpho.type <- KM_morpho.type[ , ] %>% arrange(artefact.state)
KM_morpho.type <- KM_morpho.type[-c(279:330), ]
KM_morpho.type <- KM_morpho.type[ , ] %>% arrange(morpho.type)
KM_morpho.type <- KM_morpho.type[-c(273:278), ]

# Ascribes the N value
n <- doBy::summaryBy(length + width ~ morpho.type, data = KM_morpho.type,
                   FUN = length)
tag <- gsub(pattern = "_", replacement = " ", paste0(n[[1]],
                                     " (n = ", n[[2]], ")"))
```

```
# Scatterplot Keilmesser (complete): length-width combined with morpho type
KM.width_length_morpho <- ggplot(KM_morpho.type, aes(y = length, x = width,
                        fill = morpho.type)) +
                        geom_point(size = 2, shape = 21) +
                        labs(y = "length [mm]", x = "width [mm]", title = " ",
                        fill = "keilmesser shape", size = 12) +
                        xlim(0, 100) + ylim(0, 160) +
                        theme_classic() +
                        scale_fill_manual(values = wes_palette(n = 7,
                        name = "FantasticFox1",
                        type = "continuous"), labels = tag)

file_out <- paste0(file_path_sans_ext(info_in[["file"]]),
                  "KM.width_length_morpho", ".pdf")
ggsave(filename = file_out, plot = KM.width_length_morpho, path = dir_out,
        device = "pdf", width = 170, height = 250, units = "mm")
```

Length-width ratio with regression line

```
# Load data sheet Keilmesser
KM_dim <- read.xlsx(xlsxFile = data_file, sheet = 3)
KM_dim <- KM_dim[ , ] %>% arrange(artefact.state)
KM_comp_dim <- KM_dim[-c(279:330 ), ]

# Keilmesser length VS width
# Ascribes the n value
n <- doBy::summaryBy(width + length ~ site, data = KM_comp_dim, FUN = length)
tag <- gsub(pattern = "_", replacement = " ", paste0(n[[1]],
                                    " (n = ", n[[2]], ")"))

# Scatterplot Keilmesser (complete + tip) length VS wih
KM.length_width_reg <- ggplot(KM_comp_dim, aes(y = length, x = width,
                    fill = site)) +
                    geom_point(size = 3, shape = 21) +
                    geom_smooth(method = "lm", colour = "black") +
                    scale_fill_manual(values = wes_palette(n = 3, name =
                    "FantasticFox1", type = "continuous"), labels = tag) +
                    labs(y = "length [mm]", x = "width [mm]", title = " ",
                    fill = " ", size = 12) +
                    xlim(0, 100) + ylim(0, 160) +
                    theme_classic()


file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "KM.length_width_reg",
                  ".pdf")
ggsave(filename = file_out, plot = KM.length_width_reg, path = dir_out,
        device = "pdf", width = 170, height = 250, units = "mm")




# Pradnik scraper length VS width
# Ascribes the n value
n <- doBy::summaryBy(length + width ~ site, data = PS_dim, FUN = length)
tag <- gsub(pattern = "_", replacement = " ", paste0(n[[1]],
                                    " (N = ", n[[2]], ")"))

# Scatterplot Pradnik scraper length VS width
PS.length_width_reg <- ggplot(PS_dim, aes(y = length, x = width, fill = site)) +
                    geom_point(size = 3, shape = 21) +
```

```
                 geom_smooth(method = "lm", colour = "black") +
                 labs(y = "length [mm]", x = "width [mm]", title = "",
                 fill = " ", size = 12) +
                 xlim(0, 80) + ylim(0, 80) +
                 theme_classic() +
                 scale_fill_manual(values = wes_palette(n = 6,
                 name = "Chevalier1", type = "continuous"), labels = tag)

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "PS.length_width_reg",
              ".pdf")
ggsave(filename = file_out, plot = PS.length_width_reg, path = dir_out,
       device = "pdf", width = 170, height = 250, units = "mm")
Warning in max(ids, na.rm = TRUE): no non-missing arguments to max; returning -
Inf
# Keilmesser (complete) + Pradnik scraper length VS width
# Load data sheet dimensions
dim <- read.xlsx(xlsxFile = data_file, sheet = 2)
dim <- dim[ , ] %>% arrange(artefact.state)
# Defines only the relevant rows
KM.PS_dim <- dim[c(4:281, 428:481), ]

# Ascribes the n value
n <- doBy::summaryBy(length + width ~ technological.class, data = KM.PS_dim,
              FUN = length)
tag <- gsub(pattern = "_", replacement = " ", paste0(n[[1]],
                              " (n = ", n[[2]], ")"))



KM.PS.length_width_reg <- ggplot(KM.PS_dim, aes(y = length, x = width,
                   fill = technological.class)) +
                   geom_point(size = 3, shape = 21) +
                   geom_smooth(method = "lm", colour = "black") +
                   labs(y = "length [mm]", x = "width [mm]", title = "",
                   fill = "artefact category", size = 12) +
                   xlim(0, 100) + ylim(0, 150) +
                   theme_classic() +
                   scale_fill_manual(values = wes_palette(n = 3,
                   name = "GrandBudapest1",
                   type = "continuous"), labels = tag)

file_out <- paste0(file_path_sans_ext(info_in[["file"]]),
             "KM.PS.length_width_reg", ".pdf")
ggsave(filename = file_out, plot = KM.PS.length_width_reg, path = dir_out,
      device = "pdf", width = 170, height = 250, units = "mm")
```

Barplot

Morpho type Keilmesser

```
# Keilmesser morpho type
# Load data sheet Keilmesser morpho type
KM_morpho.type <- read.xlsx(xlsxFile = data_file, sheet = 17)
# Defines only the rows with complete Keilmesser
KM_morpho.type <- KM_morpho.type[1:279,]

# Barplot Keilmesser morpho type
KM.morpho.type <- ggplot(data = KM_morpho.type) + aes(x = morpho.type,
            fill = morpho.type) +
            geom_bar(stat = "count", width = 0.7) +
            theme_classic() +
            theme(legend.position = "none") +
```

```
                labs(x = " ", y = "n") +
                scale_fill_manual(values = wes_palette(n = 8,
                name = "Royal1", type = "continuous"))

file_out <- paste0(file_path_sans_ext(info_in[["file"]]),
                 "KM.morpho.type", ".pdf")
ggsave(filename = file_out, plot = KM.morpho.type, path = dir_out,
                device = "pdf", width = 190, height = 210, units = "mm")
```

Barplot

Edge retouch

```
# Keilmesser edge retouch
# Load data sheet Keilmesser edge retouch
KM_edge <- read.xlsx(xlsxFile = data_file, sheet = 15)
# Defines only the rows with complete Keilmesser and Keilmesser tips
KM_edge <- KM_edge[-c(279, 316:330),]

# Barplot Keilmesser edge retouch
KM.edge <- ggplot(data = KM_edge) + aes(x = retouch.type.edge,
          fill = retouch.type.edge) + geom_bar(stat = "count", width = 0.5,
          fill = c ("#798E87", "#C27D38", "#972D15", "#29211F")) +
          theme_classic() +
          theme(legend.position = "none") +
          labs(x = " ", y = "n")

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "KM.edge", ".pdf")
ggsave(filename = file_out, plot = KM.edge, path = dir_out, device = "pdf",
         width = 170, height = 200, units = "mm")



# Pradnik scraper edge retouch
# Load data sheet Pradnik scraper edge retouch
PS_edge <- read.xlsx(xlsxFile = data_file, sheet = 16)
# Defines only the rows with complete Keilmesser and Keilmesser tips
PS_edge <- PS_edge[-c(3:5),]

# Barplot Pradnik scraper edge retouch
PS.edge <- ggplot(data = PS_edge) + aes(x = retouch.type.edge,
          fill = retouch.type.edge) +
          geom_bar(stat = "count", width = 0.5, fill = c ("#798E87", "#C27D38",
          "#972D15", "#29211F")) +
          theme_classic() +
          theme(legend.position = "none") +
          labs(x = " ", y = "n")

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "PS.edge", ".pdf")
ggsave(filename = file_out, plot = PS.edge, path = dir_out, device = "pdf",
         width = 170, height = 200, units = "mm")
```

Barplot

Raw material

```
# Keilmesser raw material
# Load data sheet Keilmesser raw material
KM_raw_material <- read.xlsx(xlsxFile = data_file, sheet = 8)

# Barplot Keilmesser raw material
```

```r
KM.raw_material <- ggplot(data = KM_raw_material) + aes(x = raw.material,
                  fill = raw.material) +
                  geom_bar(stat = "count", width = 0.2, fill = c("#D69C4E",
                  "#ECCBAE", "#046C9A")) +
                  theme_classic() +
                  theme(legend.position = "none") +
                  labs(x = "  ", y = "n") +
                  scale_x_discrete(labels=c("Baltic flint", "other",
                  "silicified schist"))



file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "KM.raw_material",
                  ".pdf")
ggsave(filename = file_out, plot = KM.raw_material, path = dir_out,
         device = "pdf")



# Pradnik scraper raw material
# Load data sheet Pradnik scraper raw material
PS_raw_material <- read.xlsx(xlsxFile = data_file, sheet = 9)

# Barplot Pradnik scraper raw material
PS.raw_material <- ggplot(data = PS_raw_material) + aes(x = raw.material,
                  fill = raw.material) +
                  geom_bar(stat = "count", width = 0.2, fill = c("#D69C4E",
                  "#046C9A")) +
                  theme_classic() +
                  theme(legend.position = "none") +
                  labs(x = "  ", y = "n") +
                  scale_x_discrete(labels=c("Baltic flint",
                  "silicified schist"))

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "PS.raw_material",
                   ".pdf")
ggsave(filename = file_out, plot = PS.raw_material, path = dir_out,
         device = "pdf", width = 210, height = 150, units = "mm")



# All tool types raw material
# Load data sheet all tool types raw material
all_raw_material <- read.xlsx(xlsxFile = data_file, sheet = 1)

# Barplot Pradnik scraper raw material
all.raw_material <- ggplot(data = all_raw_material) + aes(x = raw.material,
                   fill = raw.material) + geom_bar(stat = "count", width = 0.2,                    fill = c("#D69C4E", "#ECCBAE",
"#046C9A")) +
                   theme_classic() +
                   theme(legend.position = "none") +
                   labs(x = "  ", y = "n") +
                   scale_x_discrete(labels=c("Baltic flint", "other",
                   "silicified schist"))

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "all.raw_material",
                  ".pdf")
ggsave(filename = file_out, plot = all.raw_material, path = dir_out,
         device = "pdf")
```

Barplot

Morphology back

```
# Keilmesser morphology back
# Load data sheet Keilmesser morphology back
KM_back <- read.xlsx(xlsxFile = data_file, sheet = 13)

# Barplot Keilmesser morphology back
KM.back_morpho <- ggplot(data = KM_back) + aes(x = morphology.back,
                fill = morphology.back) +
                geom_bar(stat = "count", width = 0.5, fill = c("#518BA0",
                "#497C80", "#D69C4E", "#729394","#B9C7AD")) +
                theme_classic() +
                theme(legend.position = "none") +
                labs(x = " ", y = "n") +
                scale_x_discrete(labels=c("cortex + partly retouched",
                "cortex/unworked", "N/A", "partly retouched", "retouched"))

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "KM.back_morpho",
                 ".pdf")
ggsave(filename = file_out, plot = KM.back_morpho, path = dir_out, device = "pdf",
         width = 250, height = 170, units = "mm")

# Load data sheet Pradnik scraper morphology back
PS_back <- read.xlsx(xlsxFile = data_file, sheet = 14)

# Barplot Pradnik scraper morphology back
PS.back_morpho <- ggplot(data = PS_back) + aes(x = morphology.back,
                fill = morphology.back) +
                geom_bar(stat = "count", width = 0.4, fill = c("#518BA0",
                "#497C80", "#729394", "#B9C7AD")) +
                theme_classic() +
                theme(legend.position = "none") +
                labs(x = " ", y = "n") +
                scale_x_discrete(labels=c("cortex + partly retouched",
                "cortex/unworked", "partly retouched", "retouched"))

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "PS.back_morpho",
                 ".pdf")
ggsave(filename = file_out, plot = PS.back_morpho, path = dir_out,
        device = "pdf", width = 250, height = 170, units = "mm")


# Keilmesser blanks
# Load data sheet Keilmesser blanks
KM_cortex_blanks <- read.xlsx(xlsxFile = data_file, sheet = 11)

# Ascribes the N value
n <- doBy::summaryBy(blank ~ cortex, data = KM_cortex_blanks, FUN = length)
tag <- gsub(pattern = "_", replacement = " ", paste0(n[[1]],
                                   " (n = ", n[[2]], ")"))

# Barplot Keilmesser blanks
KM.cortex_blanks <- ggplot(data = KM_cortex_blanks) + aes(x = blank,                  fill = cortex) +
                 geom_bar(stat = "count", width = 0.3) +
                 theme_classic() +
                 labs(x = " ", y = "n") +
                 scale_x_discrete(labels=c("core", "flake", "N/A")) +
                 scale_fill_manual(values = wes_palette(n = 7,
                 name = "Darjeeling2", type = "continuous"), labels = tag)
```

```r
file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "KM.cortex_blanks",
                  ".pdf")
ggsave(filename = file_out, plot = KM.cortex_blanks, path = dir_out,
        device = "pdf", width = 250, height = 170, units = "mm")



# Pradnik scraper blanks
# Load data sheet Pradnik scraper blanks
PS_cortex_blanks <- read.xlsx(xlsxFile = data_file, sheet = 12)

# Ascribes the N value
n <- doBy::summaryBy(blank ~ cortex, data = PS_cortex_blanks, FUN = length)
tag <- gsub(pattern = "_", replacement = " ", paste0(n[[1]],
                                     " (n = ", n[[2]], ")"))

# Barplot Pradnik scraper blanks
PS.cortex_blanks <- ggplot(data = PS_cortex_blanks) + aes(x = blank,
                  fill = cortex) +
                  geom_bar(stat = "count", width = 0.25) +
                  theme_classic() +
                  labs(x = " ", y = "n") +
                  scale_x_discrete(labels=c("core", "flake", "N/A")) +
                  scale_fill_manual(values = wes_palette(n = 7,
                  name = "Darjeeling2", type = "continuous"), labels = tag)

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "PS.cortex_blanks",
                  ".pdf")
ggsave(filename = file_out, plot = PS.cortex_blanks, path = dir_out,
        device = "pdf", width = 250, height = 170, units = "mm")
```

Barplot

Pradnik method

```r
# Keilmesser application Pradnik method
# Load data sheet Keilmesser Pradnik method
KM_Pradnik.method <- read.xlsx(xlsxFile = data_file, sheet = 19)

# Barplot Keilmesser Pradnik method
KM.PM <- ggplot(data = KM_Pradnik.method) + aes(x = application.Pradnik.method,
        fill = application.Pradnik.method) +
        geom_bar(stat = "count", width = 0.3) +
        theme_classic() +
        labs(x = " ", y = "n") +
        theme(legend.position = "none") +
        scale_x_discrete(labels=c("no", "N/A", "yes")) +
        scale_fill_manual(values = wes_palette(n = 5, name = "GrandBudapest1",
        type = "continuous"))

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "KM.PM", ".pdf")
ggsave(filename = file_out, plot = KM.PM, path = dir_out, device = "pdf",
      width = 250, height = 170, units = "mm")
```

Barplot

Lateralisation

```r
# Keilmesser lateralisation
# Load data sheet Keilmesser lateralisation
KM_lateralisation <- read.xlsx(xlsxFile = data_file, sheet = 21)
```

```
# Barplot Keilmesser lateralisation
KM.lat <- ggplot(data = KM_lateralisation) + aes(x = tool.lateralisation,
         fill = site) +
         geom_bar(stat = "count", width = 0.3) +
         theme_classic() +
         labs(x = " ", y = "n") +
         scale_fill_manual(labels=c("Balver Höhle", "Buhlen", "Ramioul"),
         values = wes_palette(n = 9, name = "Royal1", type = "continuous"))

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "KM.lat", ".pdf")
ggsave(filename = file_out, plot = KM.lat, path = dir_out, device = "pdf")


# Pradnik scraper lateralisation
# Load data sheet Pradnik scraper lateralisation
PS_lateralisation <- read.xlsx(xlsxFile = data_file, sheet = 22)

# Barplot Pradnik scraper lateralisation
PS.lat <- ggplot(data = PS_lateralisation) + aes(x = tool.lateralisation,
         fill = site) +
         geom_bar(stat = "count", width = 0.3) +
         theme_classic() +
         labs(x = " ", y = "n") +
         scale_fill_manual(labels=c("Balver Höhle", "Buhlen", "Ramioul"),
         values = wes_palette(n = 9, name = "Royal1", type = "continuous"))

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "PS.lat", ".pdf")
ggsave(filename = file_out, plot = PS.lat, path = dir_out, device = "pdf")
```

Barplot

Barplot lateral resharpening spall type

```
# Lateral resharpening spall type
# Load data sheet lateral resharpening spall type
LSS_type <- read.xlsx(xlsxFile = data_file, sheet = 23)
# Ascribes the N value
n <- doBy::summaryBy(type.lateral.sharpening.spall ~ tool.lateralisation,
                data = LSS_type, FUN = length)
tag <- gsub(pattern = "_", replacement = " ", paste0(n[[1]],
                                   " (n = ", n[[2]], ")"))

# Barplot lateral resharpening spall type
LSS.type <- ggplot(data = LSS_type) + aes(x = type.lateral.sharpening.spall,
          fill = tool.lateralisation) +
          geom_bar(stat = "count", width = 0.2) +
          theme_classic() +
          labs(x = " ", y = "n") +
          labs(fill = "tool lateralisation") +
          scale_x_discrete() +
          scale_fill_manual(values = wes_palette(n = 9, name = "Royal1",
          type = "continuous"), labels = tag)

file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "LSS.type", ".pdf")
ggsave(filename = file_out, plot = LSS.type, path = dir_out, device = "pdf")
```

Ternary plot

Perimeter

```r
library(ggtern)
# Perimeter Keilmesser
# Load data sheet Keilmesser perimeter
KM_perimeter <- read.xlsx(xlsxFile = data_file, sheet = 6)
# Defines only the rows with complete Keilmesser
KM_perimeter <- KM_perimeter[-c (279:330), ]
KM_perimeter <- KM_perimeter [ , ] %>% arrange(morpho.type)
# Removes type 'undefined'
KM_perimeter <- KM_perimeter[-c (273:278), ]

# Ternary diagram Keilmesser perimeter
KM.perimeter  <- ggtern(data = KM_perimeter, aes(x =
              perimeter.distal.posterior.part, y = perimeter.active.edge,
              z = perimeter.basis.back)) +
              geom_point(aes(colour = morpho.type)) +
              theme_bw() +
              scale_colour_startrek() +
              theme_hidetitles() +
              theme_showarrows() +
              xlab("distal.posterior.part")+
              ylab("active edge") +
              zlab("basis + back") +
              labs(colour = "Keilmesser shape") +
              tern_limits(labels=c(0, 20, 40, 60, 80, 100)) +
              theme_rotate(degrees = 330)


file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "KM.perimeter", ".pdf")
ggsave(filename = file_out, plot = KM.perimeter, path = dir_out, device = "pdf")
```

---

sessionInfo() and RStudio version

```
sessionInfo()
R version 4.0.2 (2020-06-22)
Platform: x86_64-w64-mingw32/x64 (64-bit)
Running under: Windows 10 x64 (build 19041)

Matrix products: default

locale:
[1] LC_COLLATE=German_Germany.1252  LC_CTYPE=German_Germany.1252
[3] LC_MONETARY=German_Germany.1252 LC_NUMERIC=C
[5] LC_TIME=German_Germany.1252

attached base packages:
[1] tools     stats     graphics  grDevices utils     datasets  methods
[8] base

other attached packages:
 [1] ggtern_3.3.0      ggsci_2.9         dplyr_1.0.3       wesanderson_0.3.6
 [5] ggplot2_3.3.3     chron_2.3-56      R.utils_2.10.1    R.oo_1.24.0
 [9] R.methodsS3_1.8.1 readxl_1.3.1      openxlsx_4.2.3

loaded via a namespace (and not attached):
 [1] tidyselect_1.1.0   xfun_0.20          purrr_0.3.4        splines_4.0.2
```

```
 [5] lattice_0.20-41    latex2exp_0.4.0    colorspace_2.0-0   vctrs_0.3.6
 [9] generics_0.1.0     doBy_4.6.8         htmltools_0.5.1.1  compositions_2.0-1
[13] mgcv_1.8-33        yaml_2.2.1         rlang_0.4.10       pillar_1.4.7
[17] glue_1.4.2         withr_2.4.1        DBI_1.1.1          plyr_1.8.6
[21] lifecycle_0.2.0    robustbase_0.93-7  stringr_1.4.0      munsell_0.5.0
[25] gtable_0.3.0       cellranger_1.1.0   zip_2.1.1          evaluate_0.14
[29] labeling_0.4.2     knitr_1.31         DEoptimR_1.0-8     proto_1.0.0
[33] broom_0.7.4        Rcpp_1.0.6         scales_1.1.1       backports_1.2.0
[37] farver_2.0.3       gridExtra_2.3      Deriv_4.1.2        tensorA_0.36.2
[41] digest_0.6.27      stringi_1.5.3      grid_4.0.2         magrittr_2.0.1
[45] tibble_3.0.5       crayon_1.4.0       tidyr_1.1.2        pkgconfig_2.0.3
[49] bayesm_3.1-4       ellipsis_0.3.1     MASS_7.3-53        Matrix_1.2-18
[53] assertthat_0.2.1   rmarkdown_2.6      R6_2.5.0           nlme_3.1-151
[57] compiler_4.0.2
```

END OF SCRIPT

Qualitative use-wear analysis

Lisa Schunk

2021-02-04 16:01:17

Goal of the script

This script formats the output of the resulting CSV-file from digitalising the location of use-wear traces in QGIS. The script will:

63. Read in the original CSV-file

64. Format the data

65. Calculate the percentages
66. Plot the data as pie charts

```
dir_in <- "analysis/raw_data"
dir_out <- "analysis/plots/"
```

Raw data must be located in ~/analysis/raw_data.
Formatted data will be saved in ~/analysis/plots/.

The knit directory for this script is the project directory.

Load packages

```
library(openxlsx)
Warning: package 'openxlsx' was built under R version 4.0.3
library(tools)
library(R.utils)
library(chron)
library(ggplot2)
Warning: package 'ggplot2' was built under R version 4.0.3
library(wesanderson)
Warning: package 'wesanderson' was built under R version 4.0.3
library(dplyr)
Warning: package 'dplyr' was built under R version 4.0.3
library(doBy)
Warning: package 'doBy' was built under R version 4.0.3
```

Get names, path and information of the file

```
data_file <- list.files(dir_in, pattern = "\\.csv$", full.names = TRUE)
md5_in <- md5sum(data_file)
info_in <- data.frame(file = basename(names(md5_in)), checksum = md5_in, row.names = NULL)
```

The checksum (MD5 hashes) of the imported file are:

```
     file                         checksum
1 all.csv 963cf31444f489d15dd903c0bc9fe7b6
```

Read in original CSV-file

```
imp_data <- read.csv(data_file, header = TRUE, stringsAsFactors = FALSE, na.strings = "*****")
str(imp_data)
'data.frame':   321 obs. of  6 variables:
 $ tool.type    : chr  "Keilmesser" "Keilmesser" "Keilmesser" "Keilmesser" ...
 $ id           : int  1 1 1 1 1 1 1 1 1 1 ...
 $ site         : chr  "Buhlen" "Buhlen" "Buhlen" "Buhlen" ...
 $ specimen     : chr  "BU-090" "BU-093" "BU-097" "BU-004" ...
 $ area         : chr  "A1" "B1" "B1" "A2" ...
 $ use.wear.type: chr  "A" "A" "A" "A" ...
```

Percentages

Percentages of use-wear types for all tool types together

```
# splits the data into single areas
sp_all <- split(imp_data, imp_data[["area"]])
pct_all <- vector(mode = "list", length = length(sp_all))


for (i in seq_along(sp_all)) {
  pct_all[[i]] <- sp_all[[i]] %>%
            group_by(use.wear.type) %>%
            summarize(perc = round(n() / nrow(.) * 100, digits = 2)) %>%
            mutate(area = names(sp_all)[i])
}

PCT_all <- do.call(rbind, pct_all) %>%
        select(area, use.wear.type, perc)
```

Percentages of use-wear types for all Keilmesser

```
# defines which part of the data belongs to Keilmesser
KM <- imp_data[imp_data[["tool.type"]] == "Keilmesser", ]

# splits the data into single areas
sp_KM <- split(KM, KM[["area"]])
pct_KM <- vector(mode = "list", length = length(sp_KM))


for (i in seq_along(sp_KM)) {
  pct_KM[[i]] <- sp_KM[[i]] %>%
            group_by(use.wear.type) %>%
            summarize(perc = round(n() / nrow(.) * 100, digits = 2)) %>%
            mutate(area = names(sp_KM)[i])
}

PCT_KM <- do.call(rbind, pct_KM) %>%
        select(area, use.wear.type, perc)
```

Percentages of use-wear types for all Keilmesser from Buhlen

```
# defines which part of the data belongs to Keilmesser
KM <- imp_data[imp_data[["tool.type"]] == "Keilmesser", ]
# selects only the data from Buhlen
KM_Buhlen <- KM [ , ] %>% arrange(site)
KM_Buhlen <- KM_Buhlen[105:177, ]

# splits the data into single areas
```

```r
sp_KM_Buhlen <- split(KM_Buhlen, KM_Buhlen[["area"]])
pct_KM_Buhlen <- vector(mode = "list", length = length(sp_KM_Buhlen))


for (i in seq_along(sp_KM_Buhlen)) {
  pct_KM_Buhlen[[i]] <- sp_KM_Buhlen[[i]] %>%
            group_by(use.wear.type) %>%
            summarize(perc = round(n() / nrow(.) * 100, digits = 2)) %>%
            mutate(area = names(sp_KM_Buhlen)[i])
}

PCT_KM_Buhlen <- do.call(rbind, pct_KM_Buhlen) %>%
          select(area, use.wear.type, perc)
```

Percentages of use-wear types for all Keilmesser from Balve

```r
# defines which part of the data belongs to Keilmesser
KM <- imp_data[imp_data[["tool.type"]] == "Keilmesser", ]
# selects only the data from Balve
KM_Balve <- KM [ , ] %>% arrange(site)
KM_Balve <- KM_Balve[1:104, ]

# splits the data into single areas
sp_KM_Balve <- split(KM_Balve, KM_Balve[["area"]])
pct_KM_Balve <- vector(mode = "list", length = length(sp_KM_Balve))


for (i in seq_along(sp_KM_Balve)) {
  pct_KM_Balve[[i]] <- sp_KM_Balve[[i]] %>%
            group_by(use.wear.type) %>%
            summarize(perc = round(n() / nrow(.) * 100, digits = 2)) %>%
            mutate(area = names(sp_KM_Balve)[i])
}

PCT_KM_Balve <- do.call(rbind, pct_KM_Balve) %>%
          select(area, use.wear.type, perc)
```

Percentages of use-wear types for all Keilmesser from Ramioul

```r
# defines which part of the data belongs to Keilmesser
KM <- imp_data[imp_data[["tool.type"]] == "Keilmesser", ]
# selects only the data from Ramioul
KM_Ramioul <- KM [ , ] %>% arrange(site)
KM_Ramioul <- KM_Ramioul[178:195, ]

# splits the data into single areas
sp_KM_Ramioul <- split(KM_Ramioul, KM_Ramioul[["area"]])
pct_KM_Ramioul <- vector(mode = "list", length = length(sp_KM_Ramioul))


for (i in seq_along(sp_KM_Ramioul)) {
  pct_KM_Ramioul[[i]] <- sp_KM_Ramioul[[i]] %>%
            group_by(use.wear.type) %>%
            summarize(perc = round(n() / nrow(.) * 100, digits = 2)) %>%
            mutate(area = names(sp_KM_Ramioul)[i])
}

PCT_KM_Ramioul <- do.call(rbind, pct_KM_Ramioul) %>%
          select(area, use.wear.type, perc)
```

Percentages of use-wear types for all Pradnik scraper

```
# defines which part of the data belongs to Pradnick scraper
PS <- imp_data[imp_data[["tool.type"]] == "Pradnick scraper", ]

# splits the data into single areas
sp_PS <- split(PS, PS[["area"]])
pct_PS <- vector(mode = "list", length = length(sp_PS))


for (i in seq_along(sp_PS)) {
  pct_PS[[i]] <- sp_PS[[i]] %>%
            group_by(use.wear.type) %>%
            summarize(perc = round(n() / nrow(.) * 100, digits = 2)) %>%
            mutate(area = names(sp_PS)[i])
}

PCT_PS <- do.call(rbind, pct_PS) %>%
          select(area, use.wear.type, perc)
```

Percentages of use-wear types for all Pradnik spalls

```
# defines which part of the data belongs to Pradnick spall
LSS <- imp_data[imp_data[["tool.type"]] == "Pradnick spall", ]

# splits the data into single areas
sp_LSS <- split(LSS, LSS[["area"]])
pct_LSS <- vector(mode = "list", length = length(sp_LSS))


for (i in seq_along(sp_LSS)) {
  pct_LSS[[i]] <- sp_LSS[[i]] %>%
            group_by(use.wear.type) %>%
            summarize(perc = round(n() / nrow(.) * 100, digits = 2)) %>%
            mutate(area = names(sp_LSS)[i])
}

PCT_LSS <- do.call(rbind, pct_LSS) %>%
          select(area, use.wear.type, perc)
Error in UseMethod("select"): no applicable method for 'select' applied to an object of class "NULL"
```

Percentages of use-wear types for all scraper

```
# defines which part of the data belongs to Pradnick spall
S <- imp_data[imp_data[["tool.type"]] == "scraper", ]

# splits the data into single areas
sp_S <- split(S, S[["area"]])
pct_S <- vector(mode = "list", length = length(sp_S))


for (i in seq_along(sp_S)) {
  pct_S[[i]] <- sp_S[[i]] %>%
            group_by(use.wear.type) %>%
            summarize(perc = round(n() / nrow(.) * 100, digits = 2)) %>%
            mutate(area = names(sp_S)[i])
}

PCT_S <- do.call(rbind, pct_S) %>%
          select(area, use.wear.type, perc)
```

Pie charts

Colour definitions

```
#05100c black
#999999 gray
#52854c green
#c3d7a4 light green
#487bb6 blue
#a6cee3 light blue
#9a0f0f red
#d16103 orange
#fdbf6f apricot
#ffdb6d yellow
#985633 brown
#134680 dark blue

custom.col <- data.frame(type = unique(imp_data$use.wear.type),
                        col = c("#999999", "#52854c", "#c3d7a4", "#487bb6", "#a6cee3",
                               "#9a0f0f",
                               "#d16103", "#ffdb6d", "#985633", "#134680", "#05100c"))
```

Plots per tool type

Keilmesser

```
# plots first as a bar plot and then converts into a pie chart
for (i in seq_along(sp_KM)){

  col_i <- custom.col[custom.col$type %in% unique(sp_KM[[i]][["use.wear.type"]]), "col"]
  KM_pie <- ggplot(data = sp_KM[[i]], aes(x = area, fill = use.wear.type )) +
          geom_bar(stat = "count", width = 0.5) +
          coord_polar("y", start = 0) +
          theme_void() +
          scale_fill_manual(values = col_i) +
          labs(fill = gsub("\\.", " ", "use-wear type"))



 # saves the plots
  file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "_KM_pie_",
                    names(sp_KM)[i], ".pdf")
   ggsave(filename = file_out, plot = KM_pie, path = dir_out, device = "pdf")

}
```

Keilmesser from Buhlen

```
# plots first as a bar plot and then converts into a pie chart
for (i in seq_along(sp_KM_Buhlen)){

  col_i <- custom.col[custom.col$type %in% unique(sp_KM_Buhlen[[i]][["use.wear.type"]]), "col"]
  KM_Buhlen_pie <- ggplot(data = sp_KM_Buhlen[[i]], aes(x = area, fill = use.wear.type )) +
                geom_bar(stat = "count", width = 0.5) +
                coord_polar("y", start = 0) +
                theme_void() +
                scale_fill_manual(values = col_i) +
                labs(fill = gsub("\\.", " ", "use-wear type"))



 # saves the plots
  file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "_KM_Buhlen_pie_",
                    names(sp_KM_Buhlen)[i], ".pdf")
```

```
  ggsave(filename = file_out, plot = KM_Buhlen_pie, path = dir_out, device = "pdf")

}
```

Keilmesser from Balve

```
# plots first as a bar plot and then converts into a pie chart
for (i in seq_along(sp_KM_Balve)){

 col_i <- custom.col[custom.col$type %in% unique(sp_KM_Balve[[i]][["use.wear.type"]]), "col"]
 KM_Balve_pie <- ggplot(data = sp_KM_Balve[[i]], aes(x = area, fill = use.wear.type )) +
                 geom_bar(stat = "count", width = 0.5) +
                 coord_polar("y", start = 0) +
                 theme_void() +
                 scale_fill_manual(values = col_i) +
                 labs(fill = gsub("\\.", " ", "use-wear type"))



 # saves the plots
 file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "_KM_Balve_pie_",
                    names(sp_KM_Balve)[i], ".pdf")
  ggsave(filename = file_out, plot = KM_Balve_pie, path = dir_out, device = "pdf")

}
```

Keilmesser from Ramioul

```
# plots first as a bar plot and then converts into a pie chart
for (i in seq_along(sp_KM_Ramioul)){

 col_i <- custom.col[custom.col$type %in% unique(sp_KM_Ramioul[[i]][["use.wear.type"]]), "col"]
 KM_Ramioul_pie <- ggplot(data = sp_KM_Ramioul[[i]], aes(x = area,
                                               fill = use.wear.type )) +
                 geom_bar(stat = "count", width = 0.5) +
                 coord_polar("y", start = 0) +
                 theme_void() +
                 scale_fill_manual(values = col_i) +
                 labs(fill = gsub("\\.", " ", "use-wear type"))



 # saves the plots
 file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "_KM_Ramioul_pie_",
                    names(sp_KM_Ramioul)[i], ".pdf")
  ggsave(filename = file_out, plot = KM_Ramioul_pie, path = dir_out, device = "pdf")

}
```

Pradnick scraper

```
# plots first as a bar plot and then converts into a pie chart
for (i in seq_along(sp_PS)){

 col_i <- custom.col[custom.col$type %in% unique(sp_PS[[i]][["use.wear.type"]]), "col"]
 PS_pie <- ggplot(data = sp_PS[[i]], aes(x = area, fill = use.wear.type )) +
           geom_bar(stat = "count", width = 0.5) +
           coord_polar("y", start = 0) +
           theme_void() +
           scale_fill_manual(values = col_i) +
           labs(fill = gsub("\\.", " ", "use-wear type"))



 # saves the plots
```

```r
  file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "_PS_pie_",
                     names(sp_PS)[i], ".pdf")
   ggsave(filename = file_out, plot = PS_pie, path = dir_out, device = "pdf")

}
```

Pradnick spall

```r
# plots first as a bar plot and then converts into a pie chart
for (i in seq_along(sp_LSS)){

  col_i <- custom.col[custom.col$type %in% unique(sp_LSS[[i]][["use.wear.type"]]), "col"]
  LSS_pie <- ggplot(data = sp_LSS[[i]], aes(x = area, fill = use.wear.type )) +
            geom_bar(stat = "count", width = 0.5) +
            coord_polar("y", start = 0) +
            theme_void() +
            scale_fill_manual(values = col_i) +
            labs(fill = gsub("\\.", " ", "use-wear type"))



 # saves the plots
  file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "_LSS_pie_",
                     names(sp_LSS)[i], ".pdf")
   ggsave(filename = file_out, plot = LSS_pie, path = dir_out, device = "pdf")

}
```

Scraper

```r
# plots first as a bar plot and then converts into a pie chart
for (i in seq_along(sp_S)){

  col_i <- custom.col[custom.col$type %in% unique(sp_S[[i]][["use.wear.type"]]), "col"]
  S_pie <- ggplot(data = sp_S[[i]], aes(x = area, fill = use.wear.type )) +
            geom_bar(stat = "count", width = 0.5) +
            coord_polar("y", start = 0) +
            theme_void() +
            scale_fill_manual(values = col_i) +
            labs(fill = gsub("\\.", " ", "use-wear type"))



 # saves the plots
  file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "_S_pie_",
                     names(sp_S)[i], ".pdf")
   ggsave(filename = file_out, plot = S_pie, path = dir_out, device = "pdf")

}
```

Save data

Format name of output file

```r
file_out <- "Use-wear_qualitative_stats"
```

The file will be saved as "~/analysis/summary_stats/.[ext]".

Write to XLSX

```r
write.xlsx(list(all = PCT_all, KM = PCT_KM, PCT_PS = PS, PCT_LSS = LSS, PCT_S = S),
           file = paste0(dir_out, file_out, ".xlsx"))
```

sessionInfo() and RStudio version

```
sessionInfo()
R version 4.0.2 (2020-06-22)
Platform: x86_64-w64-mingw32/x64 (64-bit)
Running under: Windows 10 x64 (build 19041)

Matrix products: default

locale:
[1] LC_COLLATE=German_Germany.1252  LC_CTYPE=German_Germany.1252
[3] LC_MONETARY=German_Germany.1252 LC_NUMERIC=C
[5] LC_TIME=German_Germany.1252

attached base packages:
[1] tools     stats     graphics  grDevices utils     datasets  methods
[8] base

other attached packages:
[1] doBy_4.6.8        dplyr_1.0.3       wesanderson_0.3.6 ggplot2_3.3.3
[5] chron_2.3-56      R.utils_2.10.1    R.oo_1.24.0       R.methodsS3_1.8.1
[9] openxlsx_4.2.3

loaded via a namespace (and not attached):
 [1] zip_2.1.1         Rcpp_1.0.6        compiler_4.0.2    pillar_1.4.7
 [5] digest_0.6.27     lattice_0.20-41   evaluate_0.14     lifecycle_0.2.0
 [9] tibble_3.0.6      gtable_0.3.0      pkgconfig_2.0.3   rlang_0.4.10
[13] Matrix_1.2-18     DBI_1.1.1         yaml_2.2.1        xfun_0.20
[17] withr_2.4.1       stringr_1.4.0     knitr_1.31        generics_0.1.0
[21] vctrs_0.3.6       tidyselect_1.1.0  grid_4.0.2        glue_1.4.2
[25] R6_2.5.0          rmarkdown_2.6     farver_2.0.3      tidyr_1.1.2
[29] purrr_0.3.4       magrittr_2.0.1    backports_1.2.1   MASS_7.3-51.6
[33] scales_1.1.1      htmltools_0.5.1.1 ellipsis_0.3.1    assertthat_0.2.1
[37] colorspace_2.0-0  Deriv_4.1.2       labeling_0.4.2    stringi_1.5.3
[41] munsell_0.5.0     broom_0.7.4       crayon_1.4.0
```

RStudio version 1.3.1073.

END OF SCRIPT

Import CSV from ConfoMap ISO25178 - use-wear archaeology

Ivan Calandra & Lisa Schunk

2021-02-04 17:01:11

Goal of the script

This script formats the output of the resulting CSV-files from applying a template computing ISO25178 parameters in ConfoMap. The script will:

67. Read in the original CSV-files
68. Format the data

69. Write an XLSX-file and save an R object ready for further analysis in R

```
dir_in <- "analysis/raw_data"
dir_out <- "analysis/derived_data/"
```

Raw data must be located in ~/analysis/raw_data.
Formatted data will be saved in ~/analysis/derived_data/.

The knit directory for this script is the project directory.

Load packages

```
library(openxlsx)
Warning: package 'openxlsx' was built under R version 4.0.3
library(tools)
library(R.utils)
library(chron)
library(tidyverse)
Warning: package 'ggplot2' was built under R version 4.0.3
Warning: package 'readr' was built under R version 4.0.3
Warning: package 'dplyr' was built under R version 4.0.3
Warning: package 'forcats' was built under R version 4.0.3
```

Get names, path and information of all files

```
data_files <- list.files(dir_in, pattern = "\\.csv$", full.names = TRUE)
md5_in <- md5sum(data_files)
info_in <- data.frame(files = basename(names(md5_in)), checksum = md5_in,
                      row.names = NULL)
```

The checksum (MD5 hashes) of the imported files are:

```
      files                         checksum
1 BA_pro.csv 448e57518fea7cb79b3d07755ae27504
2 BU_pro.csv 1a24067387cfc3860e4531754721964e
3  R_pro.csv 115819f48ed77a49ee02cbb30cb485a2
```

Read in original CSV-files

```
imp_data <- vector(mode = "list", length = length(data_files))
names(imp_data) <- basename(data_files)
# loop for import data due to the three different CSV files
for (i in seq_along(data_files)) {
  imp_data[[i]] <- read.csv(data_files[i], header = FALSE,
                           stringsAsFactors = FALSE, na.strings = "*****")
}
str(imp_data)
List of 3
 $ BA_pro.csv:'data.frame': 102 obs. of  100 variables:
  ..$ V1  : chr [1:102] "#" "#" "#" "07.09.2020" ...
  ..$ V2  : chr [1:102] "#" "#" "#" "15:08:03" ...
  ..$ V3  : chr [1:102] "#" "#" "#" "E:\\USE-WEAR\\archaeology\\BALVE\\ConfoMap\\BA_pro --- BA_50x_res --- 
BA_20x_ext --- MU-232-B2-01-a_20x07_LSM_Topo.mnt" ...
  ..$ V4  : chr [1:102] "OPERATOR:1" "X-axis rotation angle" "°" "-3.126075388" ...
  ..$ V5  : chr [1:102] "OPERATOR:1" "Y-axis rotation angle" "°" "15.76269757" ...
  ..$ V6  : chr [1:102] "OPERATOR:2" "a0" "nm" "27860.91498" ...
  ..$ V7  : chr [1:102] "OPERATOR:2" "ax" "nm" "-140.1050645" ...
  ..$ V8  : chr [1:102] "OPERATOR:2" "ax2" "nm" "0.152743077" ...
  ..$ V9  : chr [1:102] "OPERATOR:2" "ax3" "nm" "-4.27E-05" ...
  ..$ V10 : chr [1:102] "OPERATOR:2" "ay" "nm" "-14.50031072" ...
  ..$ V11 : chr [1:102] "OPERATOR:2" "axy" "nm" "0.070278252" ...
  ..$ V12 : chr [1:102] "OPERATOR:2" "ax2y" "nm" "-6.42E-05" ...
  ..$ V13 : chr [1:102] "OPERATOR:2" "ay2" "nm" "0.006875652" ...
  ..$ V14 : chr [1:102] "OPERATOR:2" "axy2" "nm" "3.42E-05" ...
  ..$ V15 : chr [1:102] "OPERATOR:2" "ay3" "nm" "-2.29E-05" ...
  ..$ V16 : chr [1:102] "6" "Name" "<no unit>" "BA_50x_res --- BA_20x_ext --- MU-232_B2-01-a_20x07_LSM_Topo" ...
  ..$ V17 : chr [1:102] "6" "Created on" "<no unit>" "07.07.2020 16:58" ...
  ..$ V18 : chr [1:102] "6" "Studiable type" "<no unit>" "Surface" ...
  ..$ V19 : chr [1:102] "6" "Axis name - X" "<no unit>" "X" ...
  ..$ V20 : chr [1:102] "6" "Axis length - X" "µm" "254.9211018" ...
  ..$ V21 : chr [1:102] "6" "Axis size - X" "points" "1198" ...
  ..$ V22 : chr [1:102] "6" "Axis spacing - X" "µm" "0.212966668" ...
  ..$ V23 : chr [1:102] "6" "Axis name - Y" "<no unit>" "Y" ...
  ..$ V24 : chr [1:102] "6" "Axis length - Y" "µm" "254.9211018" ...
  ..$ V25 : chr [1:102] "6" "Axis size - Y" "points" "1198" ...
  ..$ V26 : chr [1:102] "6" "Axis spacing - Y" "µm" "0.212966668" ...
  ..$ V27 : chr [1:102] "6" "Axis name - Z" "<no unit>" "Z" ...
  ..$ V28 : chr [1:102] "6" "Layer type - Z" "<no unit>" "Topography" ...
  ..$ V29 : chr [1:102] "6" "Axis length - Z" "nm" "249563.8891" ...
  ..$ V30 : chr [1:102] "6" "Axis size - Z" "digits" "65505" ...
  ..$ V31 : chr [1:102] "6" "Axis spacing - Z" "nm" "3.809844884" ...
  ..$ V32 : chr [1:102] "6" "NM-points ratio - Z" "%" "0" ...
  ..$ V33 : chr [1:102] "8" "Name" "<no unit>" "BA_50x_res --- BA_20x_ext --- MU-232-B2-01-a_20x07_LSM_Topo > 
Leveled (LS-plane)" ...
  ..$ V34 : chr [1:102] "8" "Created on" "<no unit>" "07.07.2020 16:58" ...
  ..$ V35 : chr [1:102] "8" "Studiable type" "<no unit>" "Surface" ...
  ..$ V36 : chr [1:102] "8" "Axis name - X" "<no unit>" "X" ...
  ..$ V37 : chr [1:102] "8" "Axis length - X" "µm" "254.9211018" ...
  ..$ V38 : chr [1:102] "8" "Axis size - X" "points" "1198" ...
  ..$ V39 : chr [1:102] "8" "Axis spacing - X" "µm" "0.212966668" ...
  ..$ V40 : chr [1:102] "8" "Axis name - Y" "<no unit>" "Y" ...
  ..$ V41 : chr [1:102] "8" "Axis length - Y" "µm" "254.9211018" ...
  ..$ V42 : chr [1:102] "8" "Axis size - Y" "points" "1198" ...
  ..$ V43 : chr [1:102] "8" "Axis spacing - Y" "µm" "0.212966668" ...
  ..$ V44 : chr [1:102] "8" "Axis name - Z" "<no unit>" "Z" ...
  ..$ V45 : chr [1:102] "8" "Layer type - Z" "<no unit>" "Topography" ...
  ..$ V46 : chr [1:102] "8" "Axis length - Z" "nm" "270491.3671" ...
  ..$ V47 : chr [1:102] "8" "Axis size - Z" "digits" "70998" ...
  ..$ V48 : chr [1:102] "8" "Axis spacing - Z" "nm" "3.809844884" ...
```

```
  ..$ V49 : chr [1:102] "8" "NM-points ratio - Z" "%" "0" ...
  ..$ V50 : chr [1:102] "15" "Name" "<no unit>" "BA_50x_res --- BA_20x_ext --- MU-232-B2-01-a_20x07_LSM_Topo > Leveled (LS-plane) > Form removed (LS-poly 3) > O"| __truncated__ ...
  ..$ V51 : chr [1:102] "15" "Created on" "<no unit>" "07.07.2020 16:58" ...
  ..$ V52 : chr [1:102] "15" "Studiable type" "<no unit>" "Surface" ...
  ..$ V53 : chr [1:102] "15" "Axis name - X" "<no unit>" "X" ...
  ..$ V54 : chr [1:102] "15" "Axis length - X" "µm" "254.9211018" ...
  ..$ V55 : chr [1:102] "15" "Axis size - X" "points" "1198" ...
  ..$ V56 : chr [1:102] "15" "Axis spacing - X" "µm" "0.212966668" ...
  ..$ V57 : chr [1:102] "15" "Axis name - Y" "<no unit>" "Y" ...
  ..$ V58 : chr [1:102] "15" "Axis length - Y" "µm" "254.9211018" ...
  ..$ V59 : chr [1:102] "15" "Axis size - Y" "points" "1198" ...
  ..$ V60 : chr [1:102] "15" "Axis spacing - Y" "µm" "0.212966668" ...
  ..$ V61 : chr [1:102] "15" "Axis name - Z" "<no unit>" "Z" ...
  ..$ V62 : chr [1:102] "15" "Layer type - Z" "<no unit>" "Topography" ...
  ..$ V63 : chr [1:102] "15" "Axis length - Z" "nm" "20482.48807" ...
  ..$ V64 : chr [1:102] "15" "Axis size - Z" "digits" "53762" ...
  ..$ V65 : chr [1:102] "15" "Axis spacing - Z" "nm" "0.380984488" ...
  ..$ V66 : chr [1:102] "15" "NM-points ratio - Z" "%" "0" ...
  ..$ V67 : chr [1:102] "17" "Sq" "nm" "3243.46492" ...
  ..$ V68 : chr [1:102] "17" "Ssk" "<no unit>" "0.063364928" ...
  ..$ V69 : chr [1:102] "17" "Sku" "<no unit>" "3.456648954" ...
  ..$ V70 : chr [1:102] "17" "Sp" "nm" "10477.07343" ...
  ..$ V71 : chr [1:102] "17" "Sv" "nm" "10005.41463" ...
  ..$ V72 : chr [1:102] "17" "Sz" "nm" "20482.48807" ...
  ..$ V73 : chr [1:102] "17" "Sa" "nm" "2505.545764" ...
  ..$ V74 : chr [1:102] "17" "Smr (c = 1000 nm below highest peak)" "%" "0.551009273" ...
  ..$ V75 : chr [1:102] "17" "Smc (p = 10.00%)" "nm" "3753.565649" ...
  ..$ V76 : chr [1:102] "17" "Sxp (p = 50.00%  q = 97.50%)" "nm" "6582.264251" ...
  ..$ V77 : chr [1:102] "17" "Sal (s = 0.2000)" "µm" "25.94647646" ...
  ..$ V78 : chr [1:102] "17" "Str (s = 0.2000)" "<no unit>" "0.321132254" ...
  ..$ V79 : chr [1:102] "17" "Std (Reference angle = 0.000°)" "°" "42.49526812" ...
  ..$ V80 : chr [1:102] "17" "Sdq" "<no unit>" "0.602524437" ...
  ..$ V81 : chr [1:102] "17" "Sdr" "%" "9.99401306" ...
  ..$ V82 : chr [1:102] "17" "Vm (p = 10.00%)" "µm³/µm²" "0.209379149" ...
  ..$ V83 : chr [1:102] "17" "Vv (p = 10.00%)" "µm³/µm²" "3.962846805" ...
  ..$ V84 : chr [1:102] "17" "Vmp (p = 10.00%)" "µm³/µm²" "0.209379149" ...
  ..$ V85 : chr [1:102] "17" "Vmc (p = 10.00%  q = 80.00%)" "µm³/µm²" "2.775219749" ...
  ..$ V86 : chr [1:102] "17" "Vvc (p = 10.00%  q = 80.00%)" "µm³/µm²" "3.55940934" ...
  ..$ V87 : chr [1:102] "17" "Vvv (p = 80.00%)" "µm³/µm²" "0.403437465" ...
  ..$ V88 : chr [1:102] "18" "Maximum depth of furrows" "nm" "12698.49874" ...
  ..$ V89 : chr [1:102] "18" "Mean depth of furrows" "nm" "2585.970205" ...
  ..$ V90 : chr [1:102] "18" "Mean density of furrows" "cm/cm2" "2987.422098" ...
  ..$ V91 : chr [1:102] "19" "First direction" "°" "44.9809005" ...
  ..$ V92 : chr [1:102] "19" "Second direction" "°" "26.45485129" ...
  ..$ V93 : chr [1:102] "19" "Third direction" "°" "63.52628654" ...
  ..$ V94 : chr [1:102] "20" "Isotropy" "%" "13.49804216" ...
  ..$ V95 : chr [1:102] "21" "Length-scale anisotropy (Sfrax) (epLsar)" "<no unit>" "0.003682853" ...
  ..$ V96 : chr [1:102] "21" "Length-scale anisotropy (NewEplsar)" "<no unit>" "0.018102172" ...
  ..$ V97 : chr [1:102] "22" "Fractal complexity (Asfc)" "<no unit>" "12.79944237" ...
  ..$ V98 : chr [1:102] "22" "Scale of max complexity (Smfc)" "µm²" "2.508392949" ...
  ..$ V99 : chr [1:102] "22" "HAsfc9 (HAsfc9)" "<no unit>" "0.629247569" ...
  .. [list output truncated]
 $ BU_pro.csv:'data.frame': 21 obs. of  100 variables:
  ..$ V1  : chr [1:21] "#" "#" "#" "07.09.2020" ...
  ..$ V2  : chr [1:21] "#" "#" "#" "14:54:55" ...
  ..$ V3  : chr [1:21] "#" "#" "#" "E:\\USE-WEAR\\archaeology\\BUHLEN\\ConfoMap\\BU_pro --- BU_50x_res ---  -  -  - Users - schunk - Documents - US"| __truncated__ ...
  ..$ V4  : chr [1:21] "OPERATOR:1" "X-axis rotation angle" "°" "-2.694053682" ...
  ..$ V5  : chr [1:21] "OPERATOR:1" "Y-axis rotation angle" "°" "-4.169364046" ...
  ..$ V6  : chr [1:21] "OPERATOR:2" "a0" "nm" "-5316.302467" ...
```

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  ..$ V7  : chr [1:21] "OPERATOR:2" "ax" "nm" "20.87003088" ...
  ..$ V8  : chr [1:21] "OPERATOR:2" "ax2" "nm" "-0.023343306" ...
  ..$ V9  : chr [1:21] "OPERATOR:2" "ax3" "nm" "7.67E-06" ...
  ..$ V10 : chr [1:21] "OPERATOR:2" "ay" "nm" "6.260864436" ...
  ..$ V11 : chr [1:21] "OPERATOR:2" "axy" "nm" "0.003825339" ...
  ..$ V12 : chr [1:21] "OPERATOR:2" "ax2y" "nm" "-9.87E-06" ...
  ..$ V13 : chr [1:21] "OPERATOR:2" "ay2" "nm" "-0.006613336" ...
  ..$ V14 : chr [1:21] "OPERATOR:2" "axy2" "nm" "4.10E-06" ...
  ..$ V15 : chr [1:21] "OPERATOR:2" "ay3" "nm" "8.83E-07" ...
  ..$ V16 : chr [1:21] "6" "Name" "<no unit>" "BU_50x_res ---  -  -  - Users - schunk - Documents - USE-WEAR - BUHLEN
- LSM - BU-003 - BU-003_C1-01-a_50x09_LSM_Topo" ...
  ..$ V17 : chr [1:21] "6" "Created on" "<no unit>" "07.02.2020 10:45" ...
  ..$ V18 : chr [1:21] "6" "Studiable type" "<no unit>" "Surface" ...
  ..$ V19 : chr [1:21] "6" "Axis name - X" "<no unit>" "X" ...
  ..$ V20 : chr [1:21] "6" "Axis length - X" "µm" "255.4748056" ...
  ..$ V21 : chr [1:21] "6" "Axis size - X" "points" "1198" ...
  ..$ V22 : chr [1:21] "6" "Axis spacing - X" "µm" "0.213429245" ...
  ..$ V23 : chr [1:21] "6" "Axis name - Y" "<no unit>" "Y" ...
  ..$ V24 : chr [1:21] "6" "Axis length - Y" "µm" "255.4748056" ...
  ..$ V25 : chr [1:21] "6" "Axis size - Y" "points" "1198" ...
  ..$ V26 : chr [1:21] "6" "Axis spacing - Y" "µm" "0.213429245" ...
  ..$ V27 : chr [1:21] "6" "Axis name - Z" "<no unit>" "Z" ...
  ..$ V28 : chr [1:21] "6" "Layer type - Z" "<no unit>" "Topography" ...
  ..$ V29 : chr [1:21] "6" "Axis length - Z" "nm" "38041.42788" ...
  ..$ V30 : chr [1:21] "6" "Axis size - Z" "digits" "64277" ...
  ..$ V31 : chr [1:21] "6" "Axis spacing - Z" "nm" "0.591835772" ...
  ..$ V32 : chr [1:21] "6" "NM-points ratio - Z" "%" "0" ...
  ..$ V33 : chr [1:21] "8" "Name" "<no unit>" "BU_50x_res ---  -  -  - Users - schunk - Documents - USE-WEAR - BUHLEN
- LSM - BU-003 - BU-003-C1-01-a_50x09_LS"| __truncated__ ...
  ..$ V34 : chr [1:21] "8" "Created on" "<no unit>" "07.02.2020 10:45" ...
  ..$ V35 : chr [1:21] "8" "Studiable type" "<no unit>" "Surface" ...
  ..$ V36 : chr [1:21] "8" "Axis name - X" "<no unit>" "X" ...
  ..$ V37 : chr [1:21] "8" "Axis length - X" "µm" "255.4748056" ...
  ..$ V38 : chr [1:21] "8" "Axis size - X" "points" "1198" ...
  ..$ V39 : chr [1:21] "8" "Axis spacing - X" "µm" "0.213429245" ...
  ..$ V40 : chr [1:21] "8" "Axis name - Y" "<no unit>" "Y" ...
  ..$ V41 : chr [1:21] "8" "Axis length - Y" "µm" "255.4748056" ...
  ..$ V42 : chr [1:21] "8" "Axis size - Y" "points" "1198" ...
  ..$ V43 : chr [1:21] "8" "Axis spacing - Y" "µm" "0.213429245" ...
  ..$ V44 : chr [1:21] "8" "Axis name - Z" "<no unit>" "Z" ...
  ..$ V45 : chr [1:21] "8" "Layer type - Z" "<no unit>" "Topography" ...
  ..$ V46 : chr [1:21] "8" "Axis length - Z" "nm" "18938.74469" ...
  ..$ V47 : chr [1:21] "8" "Axis size - Z" "digits" "32000" ...
  ..$ V48 : chr [1:21] "8" "Axis spacing - Z" "nm" "0.591835772" ...
  ..$ V49 : chr [1:21] "8" "NM-points ratio - Z" "%" "0" ...
  ..$ V50 : chr [1:21] "15" "Name" "<no unit>" "BU_50x_res ---  -  -  - Users - schunk - Documents - USE-WEAR -
BUHLEN - LSM - BU-003 - BU-003-C1-01-a_50x09_LS"| __truncated__ ...
  ..$ V51 : chr [1:21] "15" "Created on" "<no unit>" "07.02.2020 10:45" ...
  ..$ V52 : chr [1:21] "15" "Studiable type" "<no unit>" "Surface" ...
  ..$ V53 : chr [1:21] "15" "Axis name - X" "<no unit>" "X" ...
  ..$ V54 : chr [1:21] "15" "Axis length - X" "µm" "255.4748056" ...
  ..$ V55 : chr [1:21] "15" "Axis size - X" "points" "1198" ...
  ..$ V56 : chr [1:21] "15" "Axis spacing - X" "µm" "0.213429245" ...
  ..$ V57 : chr [1:21] "15" "Axis name - Y" "<no unit>" "Y" ...
  ..$ V58 : chr [1:21] "15" "Axis length - Y" "µm" "255.4748056" ...
  ..$ V59 : chr [1:21] "15" "Axis size - Y" "points" "1198" ...
  ..$ V60 : chr [1:21] "15" "Axis spacing - Y" "µm" "0.213429245" ...
  ..$ V61 : chr [1:21] "15" "Axis name - Z" "<no unit>" "Z" ...
  ..$ V62 : chr [1:21] "15" "Layer type - Z" "<no unit>" "Topography" ...
  ..$ V63 : chr [1:21] "15" "Axis length - Z" "nm" "8682.585869" ...
  ..$ V64 : chr [1:21] "15" "Axis size - Z" "digits" "146706" ...
```

```
  ..$ V65 : chr [1:21] "15" "Axis spacing - Z" "nm" "0.059183577" ...
  ..$ V66 : chr [1:21] "15" "NM-points ratio - Z" "%" "0" ...
  ..$ V67 : chr [1:21] "17" "Sq" "nm" "1048.895159" ...
  ..$ V68 : chr [1:21] "17" "Ssk" "<no unit>" "0.132560228" ...
  ..$ V69 : chr [1:21] "17" "Sku" "<no unit>" "3.516410324" ...
  ..$ V70 : chr [1:21] "17" "Sp" "nm" "5140.389593" ...
  ..$ V71 : chr [1:21] "17" "Sv" "nm" "3542.196276" ...
  ..$ V72 : chr [1:21] "17" "Sz" "nm" "8682.585869" ...
  ..$ V73 : chr [1:21] "17" "Sa" "nm" "814.220228" ...
  ..$ V74 : chr [1:21] "17" "Smr (c = 1000 nm below highest peak)" "%" "0.085139289" ...
  ..$ V75 : chr [1:21] "17" "Smc (p = 10.00%)" "nm" "1348.441983" ...
  ..$ V76 : chr [1:21] "17" "Sxp (p = 50.00%  q = 97.50%)" "nm" "1988.48162" ...
  ..$ V77 : chr [1:21] "17" "Sal (s = 0.2000)" "µm" "28.35891284" ...
  ..$ V78 : chr [1:21] "17" "Str (s = 0.2000)" "<no unit>" "0.360722274" ...
  ..$ V79 : chr [1:21] "17" "Std (Reference angle = 0.000°)" "°" "140.7494502" ...
  ..$ V80 : chr [1:21] "17" "Sdq" "<no unit>" "0.222325802" ...
  ..$ V81 : chr [1:21] "17" "Sdr" "%" "2.287042675" ...
  ..$ V82 : chr [1:21] "17" "Vm (p = 10.00%)" "µm³/µm²" "0.057522401" ...
  ..$ V83 : chr [1:21] "17" "Vv (p = 10.00%)" "µm³/µm²" "1.405952937" ...
  ..$ V84 : chr [1:21] "17" "Vmp (p = 10.00%)" "µm³/µm²" "0.057522401" ...
  ..$ V85 : chr [1:21] "17" "Vmc (p = 10.00%  q = 80.00%)" "µm³/µm²" "0.893352314" ...
  ..$ V86 : chr [1:21] "17" "Vvc (p = 10.00%  q = 80.00%)" "µm³/µm²" "1.286082915" ...
  ..$ V87 : chr [1:21] "17" "Vvv (p = 80.00%)" "µm³/µm²" "0.119870022" ...
  ..$ V88 : chr [1:21] "18" "Maximum depth of furrows" "nm" "3486.622897" ...
  ..$ V89 : chr [1:21] "18" "Mean depth of furrows" "nm" "899.2230935" ...
  ..$ V90 : chr [1:21] "18" "Mean density of furrows" "cm/cm2" "2578.372416" ...
  ..$ V91 : chr [1:21] "19" "First direction" "°" "135.0094627" ...
  ..$ V92 : chr [1:21] "19" "Second direction" "°" "90.00677511" ...
  ..$ V93 : chr [1:21] "19" "Third direction" "°" "153.5489476" ...
  ..$ V94 : chr [1:21] "20" "Isotropy" "%" "75.30256987" ...
  ..$ V95 : chr [1:21] "21" "Length-scale anisotropy (Sfrax) (epLsar)" "<no unit>" "0.00164011" ...
  ..$ V96 : chr [1:21] "21" "Length-scale anisotropy (NewEplsar)" "<no unit>" "0.018376251" ...
  ..$ V97 : chr [1:21] "22" "Fractal complexity (Asfc)" "<no unit>" "3.698324762" ...
  ..$ V98 : chr [1:21] "22" "Scale of max complexity (Smfc)" "µm²" "4.610763815" ...
  ..$ V99 : chr [1:21] "22" "HAsfc9 (HAsfc9)" "<no unit>" "0.148106526" ...
  .. [list output truncated]
 $ R_pro.csv :'data.frame': 36 obs. of  100 variables:
  ..$ V1  : chr [1:36] "#" "#" "#" "07.09.2020" ...
  ..$ V2  : chr [1:36] "#" "#" "#" "14:31:36" ...
  ..$ V3  : chr [1:36] "#" "#" "#" "E:\\USE-WEAR\\archaeology\\RAMIOUL\\ConfoMap\\R_pro --- R_50x_res ---  -  - Users - schunk - Documents - USE-WE"| __truncated__ ...
  ..$ V4  : chr [1:36] "OPERATOR:1" "X-axis rotation angle" "°" "0.694920518" ...
  ..$ V5  : chr [1:36] "OPERATOR:1" "Y-axis rotation angle" "°" "2.627071571" ...
  ..$ V6  : chr [1:36] "OPERATOR:2" "a0" "nm" "1672.074411" ...
  ..$ V7  : chr [1:36] "OPERATOR:2" "ax" "nm" "-3.802595656" ...
  ..$ V8  : chr [1:36] "OPERATOR:2" "ax2" "nm" "0.010569345" ...
  ..$ V9  : chr [1:36] "OPERATOR:2" "ax3" "nm" "-9.36E-06" ...
  ..$ V10 : chr [1:36] "OPERATOR:2" "ay" "nm" "-7.303528796" ...
  ..$ V11 : chr [1:36] "OPERATOR:2" "axy" "nm" "0.004108866" ...
  ..$ V12 : chr [1:36] "OPERATOR:2" "ax2y" "nm" "3.14E-06" ...
  ..$ V13 : chr [1:36] "OPERATOR:2" "ay2" "nm" "0.00761333" ...
  ..$ V14 : chr [1:36] "OPERATOR:2" "axy2" "nm" "-3.12E-06" ...
  ..$ V15 : chr [1:36] "OPERATOR:2" "ay3" "nm" "-2.74E-06" ...
  ..$ V16 : chr [1:36] "6" "Name" "<no unit>" "R_50x_res ---  -  - Users - schunk - Documents - USE-WEAR - RAMIOUL - LSM - R-002 - R-002_A1-01-a_50x09_LSM_Topo" ...
  ..$ V17 : chr [1:36] "6" "Created on" "<no unit>" "07.01.2020 09:56" ...
  ..$ V18 : chr [1:36] "6" "Studiable type" "<no unit>" "Surface" ...
  ..$ V19 : chr [1:36] "6" "Axis name - X" "<no unit>" "X" ...
  ..$ V20 : chr [1:36] "6" "Axis length - X" "µm" "255.4748056" ...
  ..$ V21 : chr [1:36] "6" "Axis size - X" "points" "1198" ...
  ..$ V22 : chr [1:36] "6" "Axis spacing - X" "µm" "0.213429245" ...
```

```
..$ V23 : chr [1:36] "6" "Axis name - Y" "<no unit>" "Y" ...
..$ V24 : chr [1:36] "6" "Axis length - Y" "µm" "255.4748056" ...
..$ V25 : chr [1:36] "6" "Axis size - Y" "points" "1198" ...
..$ V26 : chr [1:36] "6" "Axis spacing - Y" "µm" "0.213429245" ...
..$ V27 : chr [1:36] "6" "Axis name - Z" "<no unit>" "Z" ...
..$ V28 : chr [1:36] "6" "Layer type - Z" "<no unit>" "Topography" ...
..$ V29 : chr [1:36] "6" "Axis length - Z" "nm" "20213.11055" ...
..$ V30 : chr [1:36] "6" "Axis size - Z" "digits" "66293" ...
..$ V31 : chr [1:36] "6" "Axis spacing - Z" "nm" "0.304905655" ...
..$ V32 : chr [1:36] "6" "NM-points ratio - Z" "%" "0" ...
..$ V33 : chr [1:36] "8" "Name" "<no unit>" "R_50x_res ---  -  - Users - schunk - Documents - USE-WEAR - RAMIOUL -
LSM - R-002 - R-002_A1-01-a_50x09_LSM_Top"| __truncated__ ...
..$ V34 : chr [1:36] "8" "Created on" "<no unit>" "07.01.2020 09:56" ...
..$ V35 : chr [1:36] "8" "Studiable type" "<no unit>" "Surface" ...
..$ V36 : chr [1:36] "8" "Axis name - X" "<no unit>" "X" ...
..$ V37 : chr [1:36] "8" "Axis length - X" "µm" "255.4748056" ...
..$ V38 : chr [1:36] "8" "Axis size - X" "points" "1198" ...
..$ V39 : chr [1:36] "8" "Axis spacing - X" "µm" "0.213429245" ...
..$ V40 : chr [1:36] "8" "Axis name - Y" "<no unit>" "Y" ...
..$ V41 : chr [1:36] "8" "Axis length - Y" "µm" "255.4748056" ...
..$ V42 : chr [1:36] "8" "Axis size - Y" "points" "1198" ...
..$ V43 : chr [1:36] "8" "Axis spacing - Y" "µm" "0.213429245" ...
..$ V44 : chr [1:36] "8" "Axis name - Z" "<no unit>" "Z" ...
..$ V45 : chr [1:36] "8" "Layer type - Z" "<no unit>" "Topography" ...
..$ V46 : chr [1:36] "8" "Axis length - Z" "nm" "10441.79904" ...
..$ V47 : chr [1:36] "8" "Axis size - Z" "digits" "34246" ...
..$ V48 : chr [1:36] "8" "Axis spacing - Z" "nm" "0.304905655" ...
..$ V49 : chr [1:36] "8" "NM-points ratio - Z" "%" "0" ...
..$ V50 : chr [1:36] "15" "Name" "<no unit>" "R_50x_res ---  -  - Users - schunk - Documents - USE-WEAR - RAMIOUL
- LSM - R-002 - R-002_A1-01-a_50x09_LSM_Top"| __truncated__ ...
..$ V51 : chr [1:36] "15" "Created on" "<no unit>" "07.01.2020 09:56" ...
..$ V52 : chr [1:36] "15" "Studiable type" "<no unit>" "Surface" ...
..$ V53 : chr [1:36] "15" "Axis name - X" "<no unit>" "X" ...
..$ V54 : chr [1:36] "15" "Axis length - X" "µm" "255.4748056" ...
..$ V55 : chr [1:36] "15" "Axis size - X" "points" "1198" ...
..$ V56 : chr [1:36] "15" "Axis spacing - X" "µm" "0.213429245" ...
..$ V57 : chr [1:36] "15" "Axis name - Y" "<no unit>" "Y" ...
..$ V58 : chr [1:36] "15" "Axis length - Y" "µm" "255.4748056" ...
..$ V59 : chr [1:36] "15" "Axis size - Y" "points" "1198" ...
..$ V60 : chr [1:36] "15" "Axis spacing - Y" "µm" "0.213429245" ...
..$ V61 : chr [1:36] "15" "Axis name - Z" "<no unit>" "Z" ...
..$ V62 : chr [1:36] "15" "Layer type - Z" "<no unit>" "Topography" ...
..$ V63 : chr [1:36] "15" "Axis length - Z" "nm" "6777.412398" ...
..$ V64 : chr [1:36] "15" "Axis size - Z" "digits" "222279" ...
..$ V65 : chr [1:36] "15" "Axis spacing - Z" "nm" "0.030490565" ...
..$ V66 : chr [1:36] "15" "NM-points ratio - Z" "%" "0" ...
..$ V67 : chr [1:36] "17" "Sq" "nm" "965.6698832" ...
..$ V68 : chr [1:36] "17" "Ssk" "<no unit>" "0.223698651" ...
..$ V69 : chr [1:36] "17" "Sku" "<no unit>" "3.305367398" ...
..$ V70 : chr [1:36] "17" "Sp" "nm" "2982.770056" ...
..$ V71 : chr [1:36] "17" "Sv" "nm" "3794.642342" ...
..$ V72 : chr [1:36] "17" "Sz" "nm" "6777.412398" ...
..$ V73 : chr [1:36] "17" "Sa" "nm" "753.1662694" ...
..$ V74 : chr [1:36] "17" "Smr (c = 1000 nm below highest peak)" "%" "3.36939136" ...
..$ V75 : chr [1:36] "17" "Smc (p = 10.00%)" "nm" "1286.370713" ...
..$ V76 : chr [1:36] "17" "Sxp (p = 50.00%  q = 97.50%)" "nm" "1714.056906" ...
..$ V77 : chr [1:36] "17" "Sal (s = 0.2000)" "µm" "20.8354156" ...
..$ V78 : chr [1:36] "17" "Str (s = 0.2000)" "<no unit>" "0.286866253" ...
..$ V79 : chr [1:36] "17" "Std (Reference angle = 0.000°)" "°" "98.49823473" ...
..$ V80 : chr [1:36] "17" "Sdq" "<no unit>" "0.18024731" ...
..$ V81 : chr [1:36] "17" "Sdr" "%" "1.545220979" ...
```

```
..$ V82 : chr [1:36] "17" "Vm (p = 10.00%)" "µm³/µm²" "0.056528148" ...
..$ V83 : chr [1:36] "17" "Vv (p = 10.00%)" "µm³/µm²" "1.342889309" ...
..$ V84 : chr [1:36] "17" "Vmp (p = 10.00%)" "µm³/µm²" "0.056528148" ...
..$ V85 : chr [1:36] "17" "Vmc (p = 10.00%  q = 80.00%)" "µm³/µm²" "0.838905952" ...
..$ V86 : chr [1:36] "17" "Vvc (p = 10.00%  q = 80.00%)" "µm³/µm²" "1.242258083" ...
..$ V87 : chr [1:36] "17" "Vvv (p = 80.00%)" "µm³/µm²" "0.100631226" ...
..$ V88 : chr [1:36] "18" "Maximum depth of furrows" "nm" "4680.149344" ...
..$ V89 : chr [1:36] "18" "Mean depth of furrows" "nm" "1003.094218" ...
..$ V90 : chr [1:36] "18" "Mean density of furrows" "cm/cm2" "2236.279395" ...
..$ V91 : chr [1:36] "19" "First direction" "°" "135.014308" ...
..$ V92 : chr [1:36] "19" "Second direction" "°" "90.00996958" ...
..$ V93 : chr [1:36] "19" "Third direction" "°" "153.4974777" ...
..$ V94 : chr [1:36] "20" "Isotropy" "%" "53.47867338" ...
..$ V95 : chr [1:36] "21" "Length-scale anisotropy (Sfrax) (epLsar)" "<no unit>" "0.003935162" ...
..$ V96 : chr [1:36] "21" "Length-scale anisotropy (NewEplsar)" "<no unit>" "0.018107507" ...
..$ V97 : chr [1:36] "22" "Fractal complexity (Asfc)" "<no unit>" "2.288328872" ...
..$ V98 : chr [1:36] "22" "Scale of max complexity (Smfc)" "µm²" "9.024672658" ...
..$ V99 : chr [1:36] "22" "HAsfc9 (HAsfc9)" "<no unit>" "0.215684673" ...
.. [list output truncated]
```

Format data

Merge three datasets

```
# check pairwise if the three lines of headers are identical among the datasets
# merges the data based on the three lines of headers while they get only
# used in the first CSV file
comp <- all(sapply(list(imp_data[[1]][1:3, ], imp_data[[2]][1:3, ]),
                   FUN = identical, imp_data[[3]][1:3, ]))
if (comp == TRUE) {
  merged_data <- rbind(imp_data[[1]], imp_data[[2]][-(1:3), ],
                       imp_data[[3]][-(1:3), ])
} else {
  stop("The headers are not identical among the datasets")
}

str(merged_data)
'data.frame':   153 obs. of  100 variables:
 $ V1  : chr  "#" "#" "#" "07.09.2020" ...
 $ V2  : chr  "#" "#" "#" "15:08:03" ...
 $ V3  : chr  "#" "#" "#" "E:\\USE-WEAR\\archaeology\\BALVE\\ConfoMap\\BA_pro --- BA_50x_res --- BA_20x_ext --- MU-232-B2-01-a_20x07_LSM_Topo.mnt" ...
 $ V4  : chr  "OPERATOR:1" "X-axis rotation angle" "°" "-3.126075388" ...
 $ V5  : chr  "OPERATOR:1" "Y-axis rotation angle" "°" "15.76269757" ...
 $ V6  : chr  "OPERATOR:2" "a0" "nm" "27860.91498" ...
 $ V7  : chr  "OPERATOR:2" "ax" "nm" "-140.1050645" ...
 $ V8  : chr  "OPERATOR:2" "ax2" "nm" "0.152743077" ...
 $ V9  : chr  "OPERATOR:2" "ax3" "nm" "-4.27E-05" ...
 $ V10 : chr  "OPERATOR:2" "ay" "nm" "-14.50031072" ...
 $ V11 : chr  "OPERATOR:2" "axy" "nm" "0.070278252" ...
 $ V12 : chr  "OPERATOR:2" "ax2y" "nm" "-6.42E-05" ...
 $ V13 : chr  "OPERATOR:2" "ay2" "nm" "0.006875652" ...
 $ V14 : chr  "OPERATOR:2" "axy2" "nm" "3.42E-05" ...
 $ V15 : chr  "OPERATOR:2" "ay3" "nm" "-2.29E-05" ...
 $ V16 : chr  "6" "Name" "<no unit>" "BA_50x_res --- BA_20x_ext --- MU-232_B2-01-a_20x07_LSM_Topo" ...
 $ V17 : chr  "6" "Created on" "<no unit>" "07.07.2020 16:58" ...
 $ V18 : chr  "6" "Studiable type" "<no unit>" "Surface" ...
 $ V19 : chr  "6" "Axis name - X" "<no unit>" "X" ...
 $ V20 : chr  "6" "Axis length - X" "µm" "254.9211018" ...
```

```
 $ V21 : chr  "6" "Axis size - X" "points" "1198" ...
 $ V22 : chr  "6" "Axis spacing - X" "µm" "0.212966668" ...
 $ V23 : chr  "6" "Axis name - Y" "<no unit>" "Y" ...
 $ V24 : chr  "6" "Axis length - Y" "µm" "254.9211018" ...
 $ V25 : chr  "6" "Axis size - Y" "points" "1198" ...
 $ V26 : chr  "6" "Axis spacing - Y" "µm" "0.212966668" ...
 $ V27 : chr  "6" "Axis name - Z" "<no unit>" "Z" ...
 $ V28 : chr  "6" "Layer type - Z" "<no unit>" "Topography" ...
 $ V29 : chr  "6" "Axis length - Z" "nm" "249563.8891" ...
 $ V30 : chr  "6" "Axis size - Z" "digits" "65505" ...
 $ V31 : chr  "6" "Axis spacing - Z" "nm" "3.809844884" ...
 $ V32 : chr  "6" "NM-points ratio - Z" "%" "0" ...
 $ V33 : chr  "8" "Name" "<no unit>" "BA_50x_res --- BA_20x_ext --- MU-232-B2-01-a_20x07_LSM_Topo > Leveled (LS-plane)" ...
 $ V34 : chr  "8" "Created on" "<no unit>" "07.07.2020 16:58" ...
 $ V35 : chr  "8" "Studiable type" "<no unit>" "Surface" ...
 $ V36 : chr  "8" "Axis name - X" "<no unit>" "X" ...
 $ V37 : chr  "8" "Axis length - X" "µm" "254.9211018" ...
 $ V38 : chr  "8" "Axis size - X" "points" "1198" ...
 $ V39 : chr  "8" "Axis spacing - X" "µm" "0.212966668" ...
 $ V40 : chr  "8" "Axis name - Y" "<no unit>" "Y" ...
 $ V41 : chr  "8" "Axis length - Y" "µm" "254.9211018" ...
 $ V42 : chr  "8" "Axis size - Y" "points" "1198" ...
 $ V43 : chr  "8" "Axis spacing - Y" "µm" "0.212966668" ...
 $ V44 : chr  "8" "Axis name - Z" "<no unit>" "Z" ...
 $ V45 : chr  "8" "Layer type - Z" "<no unit>" "Topography" ...
 $ V46 : chr  "8" "Axis length - Z" "nm" "270491.3671" ...
 $ V47 : chr  "8" "Axis size - Z" "digits" "70998" ...
 $ V48 : chr  "8" "Axis spacing - Z" "nm" "3.809844884" ...
 $ V49 : chr  "8" "NM-points ratio - Z" "%" "0" ...
 $ V50 : chr  "15" "Name" "<no unit>" "BA_50x_res --- BA_20x_ext --- MU-232-B2-01-a_20x07_LSM_Topo > Leveled (LS-plane) > Form removed (LS-poly 3) > O"| __truncated__ ...
 $ V51 : chr  "15" "Created on" "<no unit>" "07.07.2020 16:58" ...
 $ V52 : chr  "15" "Studiable type" "<no unit>" "Surface" ...
 $ V53 : chr  "15" "Axis name - X" "<no unit>" "X" ...
 $ V54 : chr  "15" "Axis length - X" "µm" "254.9211018" ...
 $ V55 : chr  "15" "Axis size - X" "points" "1198" ...
 $ V56 : chr  "15" "Axis spacing - X" "µm" "0.212966668" ...
 $ V57 : chr  "15" "Axis name - Y" "<no unit>" "Y" ...
 $ V58 : chr  "15" "Axis length - Y" "µm" "254.9211018" ...
 $ V59 : chr  "15" "Axis size - Y" "points" "1198" ...
 $ V60 : chr  "15" "Axis spacing - Y" "µm" "0.212966668" ...
 $ V61 : chr  "15" "Axis name - Z" "<no unit>" "Z" ...
 $ V62 : chr  "15" "Layer type - Z" "<no unit>" "Topography" ...
 $ V63 : chr  "15" "Axis length - Z" "nm" "20482.48807" ...
 $ V64 : chr  "15" "Axis size - Z" "digits" "53762" ...
 $ V65 : chr  "15" "Axis spacing - Z" "nm" "0.380984488" ...
 $ V66 : chr  "15" "NM-points ratio - Z" "%" "0" ...
 $ V67 : chr  "17" "Sq" "nm" "3243.46492" ...
 $ V68 : chr  "17" "Ssk" "<no unit>" "0.063364928" ...
 $ V69 : chr  "17" "Sku" "<no unit>" "3.456648954" ...
 $ V70 : chr  "17" "Sp" "nm" "10477.07343" ...
 $ V71 : chr  "17" "Sv" "nm" "10005.41463" ...
 $ V72 : chr  "17" "Sz" "nm" "20482.48807" ...
 $ V73 : chr  "17" "Sa" "nm" "2505.545764" ...
 $ V74 : chr  "17" "Smr (c = 1000 nm below highest peak)" "%" "0.551009273" ...
 $ V75 : chr  "17" "Smc (p = 10.00%)" "nm" "3753.565649" ...
 $ V76 : chr  "17" "Sxp (p = 50.00%  q = 97.50%)" "nm" "6582.264251" ...
 $ V77 : chr  "17" "Sal (s = 0.2000)" "µm" "25.94647646" ...
 $ V78 : chr  "17" "Str (s = 0.2000)" "<no unit>" "0.321132254" ...
 $ V79 : chr  "17" "Std (Reference angle = 0.000°)" "°" "42.49526812" ...
```

```
 $ V80 : chr  "17"  "Sdq"  "<no unit>"  "0.602524437" ...
 $ V81 : chr  "17"  "Sdr"  "%"  "9.99401306" ...
 $ V82 : chr  "17"  "Vm (p = 10.00%)"  "µm³/µm²"  "0.209379149" ...
 $ V83 : chr  "17"  "Vv (p = 10.00%)"  "µm³/µm²"  "3.962846805" ...
 $ V84 : chr  "17"  "Vmp (p = 10.00%)"  "µm³/µm²"  "0.209379149" ...
 $ V85 : chr  "17"  "Vmc (p = 10.00%  q = 80.00%)"  "µm³/µm²"  "2.775219749" ...
 $ V86 : chr  "17"  "Vvc (p = 10.00%  q = 80.00%)"  "µm³/µm²"  "3.55940934" ...
 $ V87 : chr  "17"  "Vvv (p = 80.00%)"  "µm³/µm²"  "0.403437465" ...
 $ V88 : chr  "18"  "Maximum depth of furrows"  "nm"  "12698.49874" ...
 $ V89 : chr  "18"  "Mean depth of furrows"  "nm"  "2585.970205" ...
 $ V90 : chr  "18"  "Mean density of furrows"  "cm/cm2"  "2987.422098" ...
 $ V91 : chr  "19"  "First direction"  "°"  "44.9809005" ...
 $ V92 : chr  "19"  "Second direction"  "°"  "26.45485129" ...
 $ V93 : chr  "19"  "Third direction"  "°"  "63.52628654" ...
 $ V94 : chr  "20"  "Isotropy"  "%"  "13.49804216" ...
 $ V95 : chr  "21"  "Length-scale anisotropy (Sfrax) (epLsar)"  "<no unit>"  "0.003682853" ...
 $ V96 : chr  "21"  "Length-scale anisotropy (NewEplsar)"  "<no unit>"  "0.018102172" ...
 $ V97 : chr  "22"  "Fractal complexity (Asfc)"  "<no unit>"  "12.79944237" ...
 $ V98 : chr  "22"  "Scale of max complexity (Smfc)"  "µm²"  "2.508392949" ...
 $ V99 : chr  "22"  "HAsfc9 (HAsfc9)"  "<no unit>"  "0.629247569" ...
  [list output truncated]
```

Keep only interesting columns and rows

```
# keeps only the columns and rows of interest for the analysis
data_keep_col <- c(1:2, 16:17, 20:22, 24:26, 29:32, 67:100)
data_keep_rows <- which(merged_data[[1]] != "#")
data_keep <- merged_data[data_keep_rows, data_keep_col]
```

Add headers

```
head_data_keep <- unlist(merged_data[2, data_keep_col])
colnames(data_keep) <- gsub("\\.+", "\\.", make.names(head_data_keep))
colnames(data_keep) <- gsub("\\.$", "", colnames(data_keep))
```

Identify results using frame numbers

```
# combines the results from the different analysis based on the column
# numbers (ID from MountainsMAp)
frames <- as.numeric(unlist(merged_data[1, data_keep_col]))
Warning: NAs introduced by coercion
ID <- which(frames == 6)[-(1:2)]
ISO <- which(frames == 17)
furrow <- which(frames == 18)
diriso <- which(frames %in% 19:20)
SSFA <- which(frames %in% 21:22)
```

Shorten the names for parameters

```
# keeps only the important information of the headers
colnames(data_keep)[ISO] <- sapply(strsplit(names(data_keep)[ISO], ".", fixed = TRUE),
                                   `[[`, 1)
colnames(data_keep)[SSFA] <- gsub("^([A-Za-z0-9]+\\.)+", "", colnames(data_keep)[SSFA])
```

Save units

```
# takes the units which were part of the headers and separates them;
# creates a data frame
var_num <- c(ID, ISO, furrow, diriso, SSFA)
#extract 'unit' line for considered columns
units_var <- unlist(merged_data[3, data_keep_col])[var_num]
# gets names associated to the units
names(units_var) <- head_data_keep[var_num]
# puts all of it into a data.frame
units_var_table <- data.frame(variable = names(units_var), unit = units_var)
```

Convert to numeric

```
for (i in var_num) {
  data_keep[[i]] <- gsub(",", "\\.", data_keep[[i]])
  data_keep[[i]] <- as.numeric(data_keep[[i]])
}
```

Split the column ‘Name’ into several columns

```
# these lines extract the artefact ID out of the path name
stud_name <- gsub("^([A-Za-z0-9_]+( --- ))+", "", data_keep[["Name"]])
stud_name <- gsub("([A-Za-z0-9_-]*( - ))+", "", stud_name)
split_name <- do.call(rbind, strsplit(stud_name, "_"))[, 1:3]
split_loc <- do.call(rbind, strsplit(split_name[, 2], "-"))

# splits location (A1-3,B1-3,C1-3,D1-3) in location (A,B,C,D) and sublocation (1,2,3,4)
split_subloc1 <- substr(split_loc[,1], 1, 1)
split_subloc2 <- substr(split_loc[,1], 2, 2)

# splits the ID in the separat information
data_final <- data.frame(split_name[, -2], split_subloc1, split_subloc2,
                         split_loc[, 2-3], data_keep[-3], stringsAsFactors = FALSE)
colnames(data_final)[1:9] <- c("Sample", "Objective", "Location", "Sublocation",
                               "Area", "Spot", "Analysis.date", "Analysis.time",
                               "Acquisition.date.time")
```

Format date and time columns

```
data_final[["Analysis.date"]] <- as.Date(data_final[["Analysis.date"]],
                                         format = "%d.%m.%Y")
data_final[["Analysis.time"]] <- times(data_final[["Analysis.time"]])
```

The column `data_final[["Acquisition.date.time"]]` includes several formats and is therefore left as `character` without convertion to `POSIXct`.

Add columns with further information and corrects 50x objectives’ NAs

```
# extracte the site name based on the ID
data_final[grep("R-0", data_final[["Sample"]]), "Site"] <- "Ramioul"
data_final[grep("MU-", data_final[["Sample"]]), "Site"] <- "Balve"
data_final[grep("BU-", data_final[["Sample"]]), "Site"] <- "Buhlen"
data_final[["Site"]] <- factor(data_final[["Site"]])

# adds the raw material by defining the flint samples, everything else is lydite
data_final[["Raw.material"]] <- factor(ifelse(data_final[["Sample"]] %in%
                                       c("MU-224", "MU-197", "R-002", "R-006",
                                         "R-007", "R-008" ,"R-010" ,"R-013"),
                                         "flint", "lydite"))

# add the tool type - Keilmesser
data_final[grep("MU-003", data_final[["Sample"]]), "Tool.type"] <- "Keilmesser"
data_final[grep("MU-008", data_final[["Sample"]]), "Tool.type"] <- "Keilmesser"
data_final[grep("MU-020", data_final[["Sample"]]), "Tool.type"] <- "Keilmesser"
data_final[grep("MU-021", data_final[["Sample"]]), "Tool.type"] <- "Keilmesser"
data_final[grep("MU-041", data_final[["Sample"]]), "Tool.type"] <- "Keilmesser"
data_final[grep("MU-107", data_final[["Sample"]]), "Tool.type"] <- "Keilmesser"
data_final[grep("MU-111", data_final[["Sample"]]), "Tool.type"] <- "Keilmesser"
data_final[grep("MU-112", data_final[["Sample"]]), "Tool.type"] <- "Keilmesser"
data_final[grep("MU-199", data_final[["Sample"]]), "Tool.type"] <- "Keilmesser"
data_final[grep("MU-202", data_final[["Sample"]]), "Tool.type"] <- "Keilmesser"
data_final[grep("MU-224", data_final[["Sample"]]), "Tool.type"] <- "Keilmesser"
data_final[grep("MU-232", data_final[["Sample"]]), "Tool.type"] <- "Keilmesser"
data_final[grep("MU-197", data_final[["Sample"]]), "Tool.type"] <- "Keilmesser"
```

```r
data_final[grep("MU-240", data_final[["Sample"]]), "Tool.type"] <- "Keilmesser"
data_final[grep("MU-246", data_final[["Sample"]]), "Tool.type"] <- "Keilmesser"
data_final[grep("MU-273", data_final[["Sample"]]), "Tool.type"] <- "Keilmesser"

data_final[grep("R-002", data_final[["Sample"]]), "Tool.type"] <- "Keilmesser"
data_final[grep("R-006", data_final[["Sample"]]), "Tool.type"] <- "Keilmesser"
data_final[grep("R-007", data_final[["Sample"]]), "Tool.type"] <- "Keilmesser"
data_final[grep("R-008", data_final[["Sample"]]), "Tool.type"] <- "Keilmesser"
data_final[grep("R-020", data_final[["Sample"]]), "Tool.type"] <- "Keilmesser"

data_final[grep("BU-003", data_final[["Sample"]]), "Tool.type"] <- "Keilmesser"
data_final[grep("BU-032", data_final[["Sample"]]), "Tool.type"] <- "Keilmesser"
data_final[grep("BU-077", data_final[["Sample"]]), "Tool.type"] <- "Keilmesser"
data_final[grep("BU-173", data_final[["Sample"]]), "Tool.type"] <- "Keilmesser"

# add the tool type - Prądnik spall
data_final[grep("MU-104", data_final[["Sample"]]), "Tool.type"] <- "Prądnik spall"
data_final[grep("MU-119", data_final[["Sample"]]), "Tool.type"] <- "Prądnik spall"
data_final[grep("MU-217", data_final[["Sample"]]), "Tool.type"] <- "Prądnik spall"

data_final[grep("BU-128", data_final[["Sample"]]), "Tool.type"] <- "Prądnik spall"

# add the tool type - Scraper
data_final[grep("MU-019", data_final[["Sample"]]), "Tool.type"] <- "Scraper"
data_final[grep("MU-025", data_final[["Sample"]]), "Tool.type"] <- "Scraper"
data_final[grep("MU-279", data_final[["Sample"]]), "Tool.type"] <- "Scraper"

data_final[grep("R-013", data_final[["Sample"]]), "Tool.type"] <- "Scraper"


# add the tool type - Prądnik scraper
data_final[grep("R-010", data_final[["Sample"]]), "Tool.type"] <- "Prądnik scraper"
data_final[grep("BU-115", data_final[["Sample"]]), "Tool.type"] <- "Prądnik scraper"
data_final[["Tool.type"]] <- factor(data_final[["Tool.type"]])

# add the use-wear type - Balve
data_final[data_final[["Sample"]] == "MU-003" & data_final[["Location"]] == "D" &
           data_final[["Sublocation"]] == "1", "Usewear.type"] <- "B"
data_final[data_final[["Sample"]] == "MU-008" & data_final[["Location"]] == "B" &
           data_final[["Sublocation"]] == "2", "Usewear.type"] <- "C"
data_final[data_final[["Sample"]] == "MU-020" & data_final[["Location"]] == "A" &
           data_final[["Sublocation"]] == "1", "Usewear.type"] <- "D"
data_final[data_final[["Sample"]] == "MU-020" & data_final[["Location"]] == "A" &
           data_final[["Sublocation"]] == "2", "Usewear.type"] <- "D2"
data_final[data_final[["Sample"]] == "MU-021" & data_final[["Location"]] == "C" &
           data_final[["Sublocation"]] == "3", "Usewear.type"] <- "B"
data_final[data_final[["Sample"]] == "MU-021" & data_final[["Location"]] == "D" &
           data_final[["Sublocation"]] == "1", "Usewear.type"] <- "D2"
data_final[data_final[["Sample"]] == "MU-041" & data_final[["Location"]] == "D" &
           data_final[["Sublocation"]] == "1", "Usewear.type"] <- "E"
data_final[data_final[["Sample"]] == "MU-041" & data_final[["Location"]] == "D" &
           data_final[["Sublocation"]] == "2", "Usewear.type"] <- "E"
data_final[data_final[["Sample"]] == "MU-107" & data_final[["Location"]] == "B" &
           data_final[["Sublocation"]] == "1", "Usewear.type"] <- "C"
data_final[data_final[["Sample"]] == "MU-107" & data_final[["Location"]] == "D" &
           data_final[["Sublocation"]] == "2", "Usewear.type"] <- "C"
data_final[data_final[["Sample"]] == "MU-111" & data_final[["Location"]] == "B" &
           data_final[["Sublocation"]] == "1", "Usewear.type"] <- "E"
data_final[data_final[["Sample"]] == "MU-112" & data_final[["Location"]] == "C" &
           data_final[["Sublocation"]] == "1", "Usewear.type"] <- "E"
```

```
data_final[data_final[["Sample"]] == "MU-199" & data_final[["Location"]] == "A" &
           data_final[["Sublocation"]] == "2", "Usewear.type"] <- "E"
data_final[data_final[["Sample"]] == "MU-199" & data_final[["Location"]] == "C" &
           data_final[["Sublocation"]] == "3", "Usewear.type"] <- "C"
data_final[data_final[["Sample"]] == "MU-202" & data_final[["Location"]] == "C" &
           data_final[["Sublocation"]] == "2", "Usewear.type"] <- "A"
data_final[data_final[["Sample"]] == "MU-202" & data_final[["Location"]] == "D" &
           data_final[["Sublocation"]] == "2", "Usewear.type"] <- "C"
data_final[data_final[["Sample"]] == "MU-224" & data_final[["Location"]] == "D" &
           data_final[["Sublocation"]] == "1", "Usewear.type"] <- "B2"
data_final[data_final[["Sample"]] == "MU-224" & data_final[["Location"]] == "B" &
           data_final[["Sublocation"]] == "1", "Usewear.type"] <- "C"
data_final[data_final[["Sample"]] == "MU-232" & data_final[["Location"]] == "B" &
           data_final[["Sublocation"]] == "2" & data_final[["Area"]]
         == "01", "Usewear.type"] <- "E"
data_final[data_final[["Sample"]] == "MU-232" & data_final[["Location"]] == "B" &
           data_final[["Sublocation"]] == "2" & data_final[["Area"]]
         == "02", "Usewear.type"] <- "A"
data_final[data_final[["Sample"]] == "MU-197" & data_final[["Location"]] == "B" &
           data_final[["Sublocation"]] == "2", "Usewear.type"] <- "F"
data_final[data_final[["Sample"]] == "MU-197" & data_final[["Location"]] == "D" &
           data_final[["Sublocation"]] == "3", "Usewear.type"] <- "F"
data_final[data_final[["Sample"]] == "MU-240" & data_final[["Location"]] == "C" &
           data_final[["Sublocation"]] == "2", "Usewear.type"] <- "C+A"
data_final[data_final[["Sample"]] == "MU-240" & data_final[["Location"]] == "D" &
           data_final[["Sublocation"]] == "1", "Usewear.type"] <- "F"
data_final[data_final[["Sample"]] == "MU-246" & data_final[["Location"]] == "D" &
           data_final[["Sublocation"]] == "1", "Usewear.type"] <- "C/E"
data_final[data_final[["Sample"]] == "MU-273" & data_final[["Location"]] == "B" &
           data_final[["Sublocation"]] == "3", "Usewear.type"] <- "C/E"
data_final[data_final[["Sample"]] == "MU-019" & data_final[["Location"]] == "A" &
           data_final[["Sublocation"]] == "3", "Usewear.type"] <- "B2"
data_final[data_final[["Sample"]] == "MU-025" & data_final[["Location"]] == "B" &
           data_final[["Sublocation"]] == "2", "Usewear.type"] <- "B"
data_final[data_final[["Sample"]] == "MU-279" & data_final[["Location"]] == "C" &
           data_final[["Sublocation"]] == "2", "Usewear.type"] <- "C"
data_final[data_final[["Sample"]] == "MU-104" & data_final[["Location"]] == "D" &
           data_final[["Sublocation"]] == "1", "Usewear.type"] <- "C/E"
data_final[data_final[["Sample"]] == "MU-119" & data_final[["Location"]] == "C" &
           data_final[["Sublocation"]] == "1", "Usewear.type"] <- "C"
data_final[data_final[["Sample"]] == "MU-217" & data_final[["Location"]] == "A" &
           data_final[["Sublocation"]] == "2", "Usewear.type"] <- "A"

# add the use-wear type - Ramioul
data_final[data_final[["Sample"]] == "R-002" & data_final[["Location"]] == "A" &
           data_final[["Sublocation"]] == "1", "Usewear.type"] <- "D"
data_final[data_final[["Sample"]] == "R-006" & data_final[["Location"]] == "C" &
           data_final[["Sublocation"]] == "3", "Usewear.type"] <- "E"
data_final[data_final[["Sample"]] == "R-007" & data_final[["Location"]] == "C" &
           data_final[["Sublocation"]] == "2", "Usewear.type"] <- "G"
data_final[data_final[["Sample"]] == "R-008" & data_final[["Location"]] == "C" &
           data_final[["Sublocation"]] == "1", "Usewear.type"] <- "D"
data_final[data_final[["Sample"]] == "R-020" & data_final[["Location"]] == "C" &
           data_final[["Sublocation"]] == "2", "Usewear.type"] <- "A"
data_final[data_final[["Sample"]] == "R-020" & data_final[["Location"]] == "C" &
           data_final[["Sublocation"]] == "3", "Usewear.type"] <- "G"
data_final[data_final[["Sample"]] == "R-010" & data_final[["Location"]] == "B" &
           data_final[["Sublocation"]] == "2", "Usewear.type"] <- "C"
data_final[data_final[["Sample"]] == "R-010" & data_final[["Location"]] == "C" &
           data_final[["Sublocation"]] == "1", "Usewear.type"] <- "C/E"
data_final[data_final[["Sample"]] == "R-013" & data_final[["Location"]] == "C" &
```

```
          data_final[["Sublocation"]] == "1", "Usewear.type"] <- "G"
data_final[data_final[["Sample"]] == "R-013" & data_final[["Location"]] == "C" &
          data_final[["Sublocation"]] == "3", "Usewear.type"] <- "D2"

# add the use-wear type - Buhlen
data_final[data_final[["Sample"]] == "BU-003" & data_final[["Location"]] == "C" &
          data_final[["Sublocation"]] == "1", "Usewear.type"] <- "C"
data_final[data_final[["Sample"]] == "BU-032" & data_final[["Location"]] == "B" &
          data_final[["Sublocation"]] == "3", "Usewear.type"] <- "D2"
data_final[data_final[["Sample"]] == "BU-077" & data_final[["Location"]] == "B" &
          data_final[["Sublocation"]] == "3", "Usewear.type"] <- "C/E"
data_final[data_final[["Sample"]] == "BU-173" & data_final[["Location"]] == "C" &
          data_final[["Sublocation"]] == "2", "Usewear.type"] <- "C"
data_final[data_final[["Sample"]] == "BU-128" & data_final[["Location"]] == "D" &
          data_final[["Sublocation"]] == "2", "Usewear.type"] <- "C"
data_final[data_final[["Sample"]] == "BU-115" & data_final[["Location"]] == "A" &
          data_final[["Sublocation"]] == "2", "Usewear.type"] <- "C"
data_final[["Usewear.type"]] <- factor(data_final[["Usewear.type"]])

# correct information about the used objectives
data_final[data_final[["Objective"]] == "50x09", "Objective"] <- "50x095"
data_final[data_final[["Objective"]] == "50x07", "Objective"] <- "50x075"
data_final[["Objective"]] <- factor(data_final[["Objective"]])
```

Ignore some columns and reorder columns

```
data_final <- data_final[c(1,54, 56, 55, 3:6, 57, 2, 7:53 )]
```

Add units as comment()

```
comment(data_final) <- units_var
```

Type comment(data_final) to check the units of the columns.

Check the result

```
str(data_final)
'data.frame':   150 obs. of  57 variables:
 $ Sample                 : chr  "MU-232" "MU-232" "MU-232" "MU-003" ...
 $ Site                   : Factor w/ 3 levels "Balve","Buhlen",..: 1 1 1 1 1 1 1 1 1 1 ...
 $ Tool.type              : Factor w/ 4 levels "Keilmesser","Pradnik scraper",..: 1 1 1 1 1 1 1 1 1 4 ...
 $ Raw.material           : Factor w/ 2 levels "flint","lydite": 2 2 2 2 2 2 2 2 2 2 ...
 $ Location               : chr  "B" "B" "B" "D" ...
 $ Sublocation            : chr  "2" "2" "2" "1" ...
 $ Area                   : chr  "01" "01" "01" "01" ...
 $ Spot                   : chr  "a" "b" "c" "a" ...
 $ Usewear.type           : Factor w/ 11 levels "A","B","B2","C",..: 9 9 9 2 2 2 4 4 4 3 ...
 $ Objective              : Factor w/ 3 levels "20x07","50x075",..: 1 1 1 3 3 3 2 2 2 3 ...
 $ Analysis.date          : Date, format: "2020-09-07" "2020-09-07" ...
 $ Analysis.time          : 'times' num  15:08:03 15:08:27 15:08:51 15:09:16 15:09:41 ...
  ..- attr(*, "format")= chr "h:m:s"
 $ Acquisition.date.time  : chr  "07.07.2020 16:58" "07.08.2020 10:35" "07.08.2020 12:10" "07.03.2020 10:44" ...
 $ Axis.length.X          : num  255 255 255 255 255 ...
 $ Axis.size.X            : num  1198 1198 1198 1198 1198 ...
 $ Axis.spacing.X         : num  0.213 0.213 0.213 0.213 0.213 ...
 $ Axis.length.Y          : num  255 255 255 255 255 ...
 $ Axis.size.Y            : num  1198 1198 1198 1198 1198 ...
 $ Axis.spacing.Y         : num  0.213 0.213 0.213 0.213 0.213 ...
 $ Axis.length.Z          : num  249564 99661 162726 38576 39610 ...
 $ Axis.size.Z            : num  65505 35461 32419 65340 66654 ...
 $ Axis.spacing.Z         : num  3.81 2.81 5.019 0.59 0.594 ...
 $ NM.points.ratio.Z      : num  0 0 0 0 0 0 0 0 0 0 ...
 $ Sq                     : num  3243 2493 4332 1912 1936 ...
```

```
 $ Ssk                     : num  0.0634 -0.9445 0.1816 -0.058 -0.2928 ...
 $ Sku                     : num  3.46 7.36 3.08 3.75 3.47 ...
 $ Sp                      : num  10477 7460 12748 6231 5796 ...
 $ Sv                      : num  10005 12962 16115 6843 6575 ...
 $ Sz                      : num  20482 20422 28864 13075 12371 ...
 $ Sa                      : num  2506 1813 3409 1464 1495 ...
 $ Smr                     : num  0.551 0.697 0.388 0.784 0.586 ...
 $ Smc                     : num  3754 2956 5778 2454 2429 ...
 $ Sxp                     : num  6582 4878 7854 3949 4400 ...
 $ Sal                     : num  25.9 20.5 23.4 24.4 24.9 ...
 $ Str                     : num  0.321 0.215 0.241 0.784 0.767 ...
 $ Std                     : num  42.5 93 51 103.7 106.7 ...
 $ Sdq                     : num  0.603 0.376 0.557 0.301 0.298 ...
 $ Sdr                     : num  9.99 5.11 10.54 4.13 4.09 ...
 $ Vm                      : num  0.2094 0.1157 0.2311 0.0944 0.0828 ...
 $ Vv                      : num  3.96 3.07 6.01 2.55 2.51 ...
 $ Vmp                     : num  0.2094 0.1157 0.2311 0.0944 0.0828 ...
 $ Vmc                     : num  2.78 1.82 3.63 1.59 1.6 ...
 $ Vvc                     : num  3.56 2.73 5.53 2.31 2.24 ...
 $ Vvv                     : num  0.403 0.342 0.48 0.238 0.275 ...
 $ Maximum.depth.of.furrows: num  12698 14381 16377 7155 7130 ...
 $ Mean.depth.of.furrows   : num  2586 2471 3670 2350 2229 ...
 $ Mean.density.of.furrows : num  2987 1790 1901 2032 2098 ...
 $ First.direction         : num  44.9809 90.00638 89.98321 0.01527 0.00574 ...
 $ Second.direction        : num  26.5 135 63.5 116.5 135 ...
 $ Third.direction         : num  63.5 116.4 45 135 90 ...
 $ Isotropy                : num  13.5 64.5 14.9 87 86.3 ...
 $ epLsar                  : num  0.00368 0.0024 0.00301 0.00161 0.00236 ...
 $ NewEplsar               : num  0.0181 0.0177 0.0179 0.0171 0.0171 ...
 $ Asfc                    : num  12.8 6.85 12.12 5.51 5.36 ...
 $ Smfc                    : num  2.51 67.38 48.16 94.68 55.32 ...
 $ HAsfc9                  : num  0.629 0.444 0.496 0.666 0.75 ...
 $ HAsfc81                 : num  0.81 2.106 1.515 0.845 0.704 ...
 - attr(*, "comment")= Named chr [1:44] "µm" "points" "µm" "µm" ...
  ..- attr(*, "names")= chr [1:44] "Axis length - X" "Axis size - X" "Axis spacing - X" "Axis length - Y" ...
head(data_final)
  Sample  Site  Tool.type Raw.material Location Sublocation Area Spot
4 MU-232 Balve Keilmesser       lydite        B           2   01    a
5 MU-232 Balve Keilmesser       lydite        B           2   01    b
6 MU-232 Balve Keilmesser       lydite        B           2   01    c
7 MU-003 Balve Keilmesser       lydite        D           1   01    a
8 MU-003 Balve Keilmesser       lydite        D           1   01    b
9 MU-003 Balve Keilmesser       lydite        D           1   01    c
  Usewear.type Objective Analysis.date Analysis.time Acquisition.date.time
4            E     20x07    2020-09-07      15:08:03      07.07.2020 16:58
5            E     20x07    2020-09-07      15:08:27      07.08.2020 10:35
6            E     20x07    2020-09-07      15:08:51      07.08.2020 12:10
7            B    50x095    2020-09-07      15:09:16      07.03.2020 10:44
8            B    50x095    2020-09-07      15:09:41      07.03.2020 11:12
9            B    50x095    2020-09-07      15:10:06      07.03.2020 11:41
  Axis.length.X Axis.size.X Axis.spacing.X Axis.length.Y Axis.size.Y
4      254.9211        1198      0.2129667      254.9211        1198
5      254.9211        1198      0.2129667      254.9211        1198
6      254.9211        1198      0.2129667      254.9211        1198
7      255.4748        1198      0.2134292      255.4748        1198
8      255.4748        1198      0.2134292      255.4748        1198
9      255.4748        1198      0.2134292      255.4748        1198
  Axis.spacing.Y Axis.length.Z Axis.size.Z Axis.spacing.Z NM.points.ratio.Z
4      0.2129667     249563.89       65505      3.8098449                 0
5      0.2129667      99661.32       35461      2.8104487                 0
6      0.2129667     162726.02       32419      5.0194644                 0
```

```
7     0.2134292     38576.34      65340      0.5903939               0
8     0.2134292     39610.00      66654      0.5942629               0
9     0.2134292     54863.85      65476      0.8379230               0
        Sq        Ssk       Sku        Sp        Sv        Sz       Sa       Smr
4 3243.465  0.06336493 3.456649 10477.073 10005.415 20482.49 2505.546 0.5510093
5 2492.686 -0.94453683 7.359355  7460.055 12962.351 20422.41 1813.230 0.6974769
6 4332.029  0.18155179 3.082953 12748.436 16115.492 28863.93 3408.910 0.3877226
7 1911.594 -0.05804613 3.752128  6231.490  6843.079 13074.57 1464.401 0.7842546
8 1935.862 -0.29284833 3.470592  5795.609  6575.044 12370.65 1495.026 0.5859935
9 1413.907 -0.06958621 3.838747  4844.954  5857.249 10702.20 1072.493 0.5892249
       Smc      Sxp      Sal       Str       Std       Sdq       Sdr        Vm
4 3753.566 6582.264 25.94648 0.3211323  42.49527 0.6025244  9.994013 0.20937915
5 2956.412 4877.546 20.48344 0.2150411  93.00821 0.3764870  5.107810 0.11573925
6 5778.475 7853.570 23.40141 0.2410375  50.99436 0.5568364 10.537913 0.23108609
7 2453.748 3948.846 24.43419 0.7836240 103.74504 0.3008461  4.134572 0.09440997
8 2429.328 4399.880 24.92475 0.7667171 106.74682 0.2981428  4.087375 0.08277282
9 1730.839 2853.606 24.16152 0.6924723  93.49320 0.2037989  1.984276 0.08328707
        Vv        Vmp       Vmc       Vvc       Vvv Maximum.depth.of.furrows
4 3.962847 0.20937915 2.775220 3.559409 0.4034375                12698.499
5 3.072057 0.11573925 1.817445 2.730142 0.3419151                14380.925
6 6.009789 0.23108609 3.631368 5.530158 0.4796309                16377.341
7 2.548137 0.09440997 1.586519 2.310376 0.2377615                 7155.043
8 2.512080 0.08277282 1.595735 2.237261 0.2748192                 7129.788
9 1.814126 0.08328707 1.177174 1.626516 0.1876105                 5360.417
  Mean.depth.of.furrows Mean.density.of.furrows First.direction
4              2585.970                2987.422    44.980900500
5              2471.097                1790.038    90.006383440
6              3669.761                1900.754    89.983209400
7              2349.892                2031.595     0.015269467
8              2228.674                2097.686     0.005735854
9              1402.133                2425.201    89.998777760
  Second.direction Third.direction Isotropy      epLsar  NewEplsar       Asfc
4      26.45485129        63.52629 13.49804 0.003682853 0.01810217 12.799442
5     135.00460320       116.44208 64.54651 0.002403307 0.01765029  6.845867
6      63.53048970        44.99152 14.91093 0.003013051 0.01791572 12.117159
7     116.47085940       134.97172 86.95322 0.001612903 0.01709833  5.512847
8     135.02555380        89.99612 86.25183 0.002359666 0.01713881  5.359400
9       0.01726191        45.00826 86.90223 0.000603190 0.01747737  2.502234
       Smfc    HAsfc9   HAsfc81
4  2.508393 0.6292476 0.8101995
5 67.378699 0.4439865 2.1056364
6 48.160760 0.4956623 1.5145332
7 94.675258 0.6660730 0.8450922
8 55.323498 0.7499158 0.7038073
9  7.377919 1.1014543 1.1663644
```

Save data

Format name of output file

```
file_out <- "Use-wear"
```

The files will be saved as "~/Use-wear.[ext]".

Write to XLSX

```
write.xlsx(list(data = data_final, units = units_var_table),
           file = paste0(dir_out, file_out, ".xlsx"))
```

Save R object

```
saveObject(data_final, file = paste0(dir_out, file_out, ".Rbin"))
```

---

sessionInfo() and RStudio version

```
sessionInfo()
R version 4.0.2 (2020-06-22)
Platform: x86_64-w64-mingw32/x64 (64-bit)
Running under: Windows 10 x64 (build 19041)

Matrix products: default

locale:
[1] LC_COLLATE=German_Germany.1252  LC_CTYPE=German_Germany.1252
[3] LC_MONETARY=German_Germany.1252 LC_NUMERIC=C
[5] LC_TIME=German_Germany.1252

attached base packages:
[1] tools     stats     graphics  grDevices utils     datasets  methods
[8] base

other attached packages:
 [1] forcats_0.5.1     stringr_1.4.0     dplyr_1.0.3       purrr_0.3.4
 [5] readr_1.4.0       tidyr_1.1.2       tibble_3.0.6      ggplot2_3.3.3
 [9] tidyverse_1.3.0   chron_2.3-56      R.utils_2.10.1    R.oo_1.24.0
[13] R.methodsS3_1.8.1 openxlsx_4.2.3

loaded via a namespace (and not attached):
 [1] tidyselect_1.1.0  xfun_0.20         haven_2.3.1       colorspace_2.0-0
 [5] vctrs_0.3.6       generics_0.1.0    htmltools_0.5.1.1 yaml_2.2.1
 [9] rlang_0.4.10      pillar_1.4.7      withr_2.4.1       glue_1.4.2
[13] DBI_1.1.1         dbplyr_2.0.0      modelr_0.1.8      readxl_1.3.1
[17] lifecycle_0.2.0   munsell_0.5.0     gtable_0.3.0      cellranger_1.1.0
[21] rvest_0.3.6       zip_2.1.1         evaluate_0.14     knitr_1.31
[25] broom_0.7.4       Rcpp_1.0.6        backports_1.2.1   scales_1.1.1
[29] jsonlite_1.7.2    fs_1.5.0          hms_1.0.0         digest_0.6.27
[33] stringi_1.5.3     grid_4.0.2        cli_2.3.0         magrittr_2.0.1
[37] crayon_1.4.0      pkgconfig_2.0.3   ellipsis_0.3.1    xml2_1.3.2
[41] reprex_1.0.0      lubridate_1.7.9.2 rstudioapi_0.13   assertthat_0.2.1
[45] rmarkdown_2.6     httr_1.4.2        R6_2.5.0          compiler_4.0.2
```

RStudio version 1.3.1073.

END OF SCRIPT

Summary statistics - use-wear archaeology

Lisa Schunk

2021-02-04 17:08:17

Goal of the script

This script computes standard descriptive statistics for each group.
The groups are based on:

70. Tool type
71. Raw material
72. Spots (replicas)
73. Use-wear type

It computes the following statistics:

74. n (sample size = length): number of measurements
75. smallest value (min)
76. largest value (max)
77. mean
78. median
79. standard deviation (sd)

```
dir_in <- "analysis/derived_data/"
dir_out <- "analysis/summary_stats/"
```

Raw data must be located in ~/analysis/derived_data/.
Formatted data will be saved in ~/analysis/summary_stats/. The knit directory for this script is the project directory. —

Load packages

```
library(openxlsx)
Warning: package 'openxlsx' was built under R version 4.0.3
library(R.utils)
library(tools)
library(doBy)
Warning: package 'doBy' was built under R version 4.0.3
```

Get names, path and information of all files

```
data_file <- list.files(dir_in, pattern = "\\.Rbin$", full.names = TRUE)
md5_in <- md5sum(data_file)
info_in <- data.frame(file = basename(names(md5_in)), checksum = md5_in,
                      row.names = NULL)
```

The checksum (MD5 hashes) of the imported files are:

```
          file                         checksum
1 Use-wear.Rbin 558d5b8d978e0d27f0cf6d308b0734de
```

Load data into R object

```
imp_data <- loadObject(data_file)
str(imp_data)
'data.frame':   150 obs. of  57 variables:
 $ Sample                  : chr  "MU-232" "MU-232" "MU-232" "MU-003" ...
 $ Site                    : Factor w/ 3 levels "Balve","Buhlen",..: 1 1 1 1 1 1 1 1 1 1 ...
 $ Tool.type               : Factor w/ 4 levels "Keilmesser","Pradnik scraper",..: 1 1 1 1 1 1 1 1 1 4 ...
 $ Raw.material            : Factor w/ 2 levels "flint","lydite": 2 2 2 2 2 2 2 2 2 2 ...
 $ Location                : chr  "B" "B" "B" "D" ...
 $ Sublocation             : chr  "2" "2" "2" "1" ...
 $ Area                    : chr  "01" "01" "01" "01" ...
 $ Spot                    : chr  "a" "b" "c" "a" ...
 $ Usewear.type            : Factor w/ 11 levels "A","B","B2","C",..: 9 9 9 2 2 2 4 4 4 3 ...
 $ Objective               : Factor w/ 3 levels "20x07","50x075",..: 1 1 1 3 3 3 2 2 2 3 ...
 $ Analysis.date           : Date, format: "2020-09-07" "2020-09-07" ...
 $ Analysis.time           : 'times' num  0.631 0.631 0.631 0.631 0.632 ...
  ..- attr(*, "format")= chr "h:m:s"
 $ Acquisition.date.time   : chr  "07.07.2020 16:58" "07.08.2020 10:35" "07.08.2020 12:10" "07.03.2020 10:44" ...
 $ Axis.length.X           : num  255 255 255 255 255 ...
 $ Axis.size.X             : num  1198 1198 1198 1198 1198 ...
 $ Axis.spacing.X          : num  0.213 0.213 0.213 0.213 0.213 ...
 $ Axis.length.Y           : num  255 255 255 255 255 ...
 $ Axis.size.Y             : num  1198 1198 1198 1198 1198 ...
 $ Axis.spacing.Y          : num  0.213 0.213 0.213 0.213 0.213 ...
 $ Axis.length.Z           : num  249564 99661 162726 38576 39610 ...
 $ Axis.size.Z             : num  65505 35461 32419 65340 66654 ...
 $ Axis.spacing.Z          : num  3.81 2.81 5.019 0.59 0.594 ...
 $ NM.points.ratio.Z       : num  0 0 0 0 0 0 0 0 0 0 ...
 $ Sq                      : num  3243 2493 4332 1912 1936 ...
 $ Ssk                     : num  0.0634 -0.9445 0.1816 -0.058 -0.2928 ...
 $ Sku                     : num  3.46 7.36 3.08 3.75 3.47 ...
 $ Sp                      : num  10477 7460 12748 6231 5796 ...
 $ Sv                      : num  10005 12962 16115 6843 6575 ...
 $ Sz                      : num  20482 20422 28864 13075 12371 ...
 $ Sa                      : num  2506 1813 3409 1464 1495 ...
 $ Smr                     : num  0.551 0.697 0.388 0.784 0.586 ...
 $ Smc                     : num  3754 2956 5778 2454 2429 ...
 $ Sxp                     : num  6582 4878 7854 3949 4400 ...
 $ Sal                     : num  25.9 20.5 23.4 24.4 24.9 ...
 $ Str                     : num  0.321 0.215 0.241 0.784 0.767 ...
 $ Std                     : num  42.5 93 51 103.7 106.7 ...
 $ Sdq                     : num  0.603 0.376 0.557 0.301 0.298 ...
 $ Sdr                     : num  9.99 5.11 10.54 4.13 4.09 ...
 $ Vm                      : num  0.2094 0.1157 0.2311 0.0944 0.0828 ...
 $ Vv                      : num  3.96 3.07 6.01 2.55 2.51 ...
 $ Vmp                     : num  0.2094 0.1157 0.2311 0.0944 0.0828 ...
 $ Vmc                     : num  2.78 1.82 3.63 1.59 1.6 ...
 $ Vvc                     : num  3.56 2.73 5.53 2.31 2.24 ...
 $ Vvv                     : num  0.403 0.342 0.48 0.238 0.275 ...
 $ Maximum.depth.of.furrows: num  12698 14381 16377 7155 7130 ...
 $ Mean.depth.of.furrows   : num  2586 2471 3670 2350 2229 ...
 $ Mean.density.of.furrows : num  2987 1790 1901 2032 2098 ...
 $ First.direction         : num  44.9809 90.00638 89.98321 0.01527 0.00574 ...
 $ Second.direction        : num  26.5 135 63.5 116.5 135 ...
 $ Third.direction         : num  63.5 116.4 45 135 90 ...
 $ Isotropy                : num  13.5 64.5 14.9 87 86.3 ...
 $ epLsar                  : num  0.00368 0.0024 0.00301 0.00161 0.00236 ...
 $ NewEplsar               : num  0.0181 0.0177 0.0179 0.0171 0.0171 ...
 $ Asfc                    : num  12.8 6.85 12.12 5.51 5.36 ...
 $ Smfc                    : num  2.51 67.38 48.16 94.68 55.32 ...
 $ HAsfc9                  : num  0.629 0.444 0.496 0.666 0.75 ...
```

```
 $ HAsfc81                : num  0.81 2.106 1.515 0.845 0.704 ...
 - attr(*, "comment")= Named chr [1:44] "µm" "points" "µm" "µm" ...
  ..- attr(*, "names")= chr [1:44] "Axis length - X" "Axis size - X" "Axis spacing - X" "Axis length - Y" ...
```

The imported file is: "~/analysis/derived_data/Use-wear.Rbin"

Define numeric variables

```
num.var <- 24:length(imp_data)
```

The following variables will be used:

```
[24] Sq
[25] Ssk
[26] Sku
[27] Sp
[28] Sv
[29] Sz
[30] Sa
[31] Smr
[32] Smc
[33] Sxp
[34] Sal
[35] Str
[36] Std
[37] Sdq
[38] Sdr
[39] Vm
[40] Vv
[41] Vmp
[42] Vmc
[43] Vvc
[44] Vvv
[45] Maximum.depth.of.furrows
[46] Mean.depth.of.furrows
[47] Mean.density.of.furrows
[48] First.direction
[49] Second.direction
[50] Third.direction
[51] Isotropy
[52] epLsar
[53] NewEplsar
[54] Asfc
[55] Smfc
[56] HAsfc9
[57] HAsfc81
```

Compute summary statistics

Create function to compute the statistics at once

```
nminmaxmeanmedsd <- function(x){
    y <- x[!is.na(x)]
    n_test <- length(y)
    min_test <- min(y)
    max_test <- max(y)
    mean_test <- mean(y)
    med_test <- median(y)
    sd_test <- sd(y)
```

```
  out <- c(n_test, min_test, max_test, mean_test, med_test, sd_test)
  names(out) <- c("n", "min", "max", "mean", "median", "sd")
  return(out)
}
```

Compute the summary statistics in groups

Spots

```
spot <- summaryBy(.~Sample+Location+Sublocation+Area,
              data = imp_data[c("Sample","Location", "Sublocation", "Area" ,
                        names(imp_data)[num.var])],
              FUN = nminmaxmeanmedsd)
str(spot)
'data.frame':   50 obs. of  208 variables:
 $ Sample              : chr  "BU-003" "BU-032" "BU-077" "BU-115" ...
 $ Location            : chr  "C" "B" "B" "A" ...
 $ Sublocation         : chr  "1" "3" "3" "2" ...
 $ Area                : chr  "01" "01" "01" "01" ...
 $ Sq.n                : num  3 3 3 3 3 3 3 3 3 3 ...
 $ Sq.min              : num  948 534 797 973 1231 ...
 $ Sq.max              : num  1049 832 999 1008 2171 ...
 $ Sq.mean             : num  999 704 901 988 1663 ...
 $ Sq.median           : num  1001 746 908 983 1586 ...
 $ Sq.sd               : num  50.3 153.3 101.1 18 474.6 ...
 $ Ssk.n               : num  3 3 3 3 3 3 3 3 3 3 ...
 $ Ssk.min             : num  -0.574 -0.392 -0.855 0.121 -0.281 ...
 $ Ssk.max             : num  0.13256 -0.12753 -0.2485 0.40616 0.00382 ...
 $ Ssk.mean            : num  -0.291 -0.298 -0.55 0.258 -0.108 ...
 $ Ssk.median          : num  -0.4305 -0.376 -0.5461 0.2465 -0.0476 ...
 $ Ssk.sd              : num  0.373 0.148 0.303 0.143 0.152 ...
 $ Sku.n               : num  3 3 3 3 3 3 3 3 3 3 ...
 $ Sku.min             : num  3.1 3.3 3.8 2.93 2.98 ...
 $ Sku.max             : num  3.72 5.18 5.18 3.42 3.31 ...
 $ Sku.mean            : num  3.44 4.26 4.7 3.09 3.12 ...
 $ Sku.median          : num  3.52 4.3 5.13 2.93 3.07 ...
 $ Sku.sd              : num  0.316 0.94 0.782 0.287 0.17 ...
 $ Sp.n                : num  3 3 3 3 3 3 3 3 3 3 ...
 $ Sp.min              : num  2312 2085 1814 2917 3791 ...
 $ Sp.max              : num  5140 2859 3330 3517 5795 ...
 $ Sp.mean             : num  3366 2344 2531 3130 4634 ...
 $ Sp.median           : num  2645 2087 2450 2955 4315 ...
 $ Sp.sd               : num  1546 446 761 336 1040 ...
 $ Sv.n                : num  3 3 3 3 3 3 3 3 3 3 ...
 $ Sv.min              : num  3199 2780 3406 2558 3846 ...
 $ Sv.max              : num  3908 3390 4275 2775 7204 ...
 $ Sv.mean             : num  3549 2989 3911 2671 5365 ...
 $ Sv.median           : num  3542 2797 4051 2680 5043 ...
 $ Sv.sd               : num  354 347 451 109 1702 ...
 $ Sz.n                : num  3 3 3 3 3 3 3 3 3 3 ...
 $ Sz.min              : num  5511 4865 5856 5597 7637 ...
 $ Sz.max              : num  8683 6249 7605 6074 13000 ...
 $ Sz.mean             : num  6915 5332 6442 5800 9998 ...
 $ Sz.median           : num  6553 4884 5865 5730 9358 ...
 $ Sz.sd               : num  1617 794 1007 246 2738 ...
 $ Sa.n                : num  3 3 3 3 3 3 3 3 3 3 ...
 $ Sa.min              : num  749 392 620 774 953 ...
 $ Sa.max              : num  814 623 717 790 1757 ...
 $ Sa.mean             : num  780 537 672 783 1319 ...
 $ Sa.median           : num  777 596 678 783 1246 ...
 $ Sa.sd               : num  32.69 126.46 48.95 8.02 406.83 ...
 $ Smr.n               : num  3 3 3 3 3 3 3 3 3 3 ...
```

```
 $ Smr.min                          : num  0.0851 1.2278 1.337 1.6065 0.8016 ...
 $ Smr.max                          : num  6.82 4.48 13.77 3.49 2.12 ...
 $ Smr.mean                         : num  3.31 2.81 7.22 2.74 1.64 ...
 $ Smr.median                       : num  3.01 2.72 6.54 3.13 1.99 ...
 $ Smr.sd                           : num  3.38 1.626 6.243 0.999 0.725 ...
 $ Smc.n                            : num  3 3 3 3 3 3 3 3 3 3 ...
 $ Smc.min                          : num  1148 665 929 1249 1483 ...
 $ Smc.max                          : num  1348 961 1182 1297 2692 ...
 $ Smc.mean                         : num  1215 839 1092 1272 2068 ...
 $ Smc.median                       : num  1149 892 1165 1272 2029 ...
 $ Smc.sd                           : num  115 155 142 24 605 ...
 $ Sxp.n                            : num  3 3 3 3 3 3 3 3 3 3 ...
 $ Sxp.min                          : num  1988 1081 1751 1757 2554 ...
 $ Sxp.max                          : num  2409 1925 2450 1845 4662 ...
 $ Sxp.mean                         : num  2184 1554 2089 1806 3492 ...
 $ Sxp.median                       : num  2155 1656 2066 1815 3261 ...
 $ Sxp.sd                           : num  211.8 431.3 350 44.7 1072.8 ...
 $ Sal.n                            : num  3 3 3 3 3 3 3 3 3 3 ...
 $ Sal.min                          : num  23.3 19.9 24.5 21.5 18.8 ...
 $ Sal.max                          : num  28.4 25.1 31.5 24.6 29.1 ...
 $ Sal.mean                         : num  25.1 22 27.9 22.7 23.8 ...
 $ Sal.median                       : num  23.7 20.9 27.7 22.1 23.6 ...
 $ Sal.sd                           : num  2.83 2.74 3.51 1.66 5.17 ...
 $ Str.n                            : num  3 3 3 3 3 3 3 3 3 3 ...
 $ Str.min                          : num  0.361 0.682 0.504 0.851 0.446 ...
 $ Str.max                          : num  0.797 0.853 0.869 0.88 0.539 ...
 $ Str.mean                         : num  0.631 0.785 0.694 0.863 0.507 ...
 $ Str.median                       : num  0.735 0.819 0.711 0.856 0.536 ...
 $ Str.sd                           : num  0.2359 0.0909 0.1833 0.0156 0.0529 ...
 $ Std.n                            : num  3 3 3 3 3 3 3 3 3 3 ...
 $ Std.min                          : num  132.5 2.27 93.5 120.25 16.49 ...
 $ Std.max                          : num  141 177 141 138 39 ...
 $ Std.mean                         : num  136.9 102.7 118.5 128.9 26.8 ...
 $ Std.median                       : num  137 129 122 129 25 ...
 $ Std.sd                           : num  4.15 90.11 23.64 8.63 11.37 ...
 $ Sdq.n                            : num  3 3 3 3 3 3 3 3 3 3 ...
 $ Sdq.min                          : num  0.22 0.123 0.15 0.177 0.217 ...
 $ Sdq.max                          : num  0.227 0.179 0.171 0.178 0.244 ...
 $ Sdq.mean                         : num  0.223 0.147 0.164 0.178 0.232 ...
 $ Sdq.median                       : num  0.222 0.138 0.17 0.178 0.236 ...
 $ Sdq.sd                           : num  0.003198 0.028963 0.012165 0.000543 0.013865 ...
 $ Sdr.n                            : num  3 3 3 3 3 3 3 3 3 3 ...
 $ Sdr.min                          : num  2.287 0.733 1.094 1.538 2.283 ...
 $ Sdr.max                          : num  2.49 1.52 1.43 1.56 2.8 ...
 $ Sdr.mean                         : num  2.37 1.06 1.31 1.55 2.58 ...
 $ Sdr.median                       : num  2.35 0.934 1.402 1.555 2.661 ...
 $ Sdr.sd                           : num  0.1012 0.4097 0.1856 0.0109 0.2661 ...
 $ Vm.n                             : num  3 3 3 3 3 3 3 3 3 3 ...
 $ Vm.min                           : num  0.0359 0.0283 0.0273 0.0525 0.0718 ...
 $ Vm.max                           : num  0.0575 0.0442 0.0543 0.0666 0.0865 ...
 $ Vm.mean                          : num  0.0448 0.035 0.0423 0.0585 0.079 ...
 $ Vm.median                        : num  0.0409 0.0326 0.0452 0.0564 0.0787 ...
  [list output truncated]
```

Tool type

```
tool <- summaryBy(.~Tool.type+Location+Sublocation,
                  data = imp_data[c("Tool.type", "Location", "Sublocation",
                                    names(imp_data)[num.var])],
                  FUN = nminmaxmeanmedsd)
str(tool)
```

```
'data.frame':	23 obs. of  207 variables:
 $ Tool.type                  : Factor w/ 4 levels "Keilmesser","Pradnik scraper",..: 1 1 1 1 1 1 1 1 1 1 ...
 $ Location                   : chr  "A" "A" "B" "B" ...
 $ Sublocation                : chr  "1" "2" "1" "2" ...
 $ Sq.n                       : num  9 6 9 12 9 9 15 12 18 9 ...
 $ Sq.min                     : num  966 1243 956 906 534 ...
 $ Sq.max                     : num  1641 1947 1703 5272 1994 ...
 $ Sq.mean                    : num  1271 1423 1336 2261 1071 ...
 $ Sq.median                  : num  1340 1309 1375 1831 908 ...
 $ Sq.sd                      : num  266 272 214 1371 455 ...
 $ Ssk.n                      : num  9 6 9 12 9 9 15 12 18 9 ...
 $ Ssk.min                    : num  -0.798 -0.882 -0.734 -0.945 -1.37 ...
 $ Ssk.max                    : num  0.518 0.899 0.27 0.762 -0.128 ...
 $ Ssk.mean                   : num  -0.0551 -0.1608 -0.3334 0.1352 -0.5698 ...
 $ Ssk.median                 : num  0.0596 -0.1428 -0.2483 0.2147 -0.5461 ...
 $ Ssk.sd                     : num  0.452 0.69 0.318 0.491 0.371 ...
 $ Sku.n                      : num  9 6 9 12 9 9 15 12 18 9 ...
 $ Sku.min                    : num  2.99 2.92 2.82 2.76 3.18 ...
 $ Sku.max                    : num  4.76 7.61 5.74 7.36 6.71 ...
 $ Sku.mean                   : num  3.64 4.66 4.04 4.43 4.54 ...
 $ Sku.median                 : num  3.31 3.64 4.16 3.93 4.3 ...
 $ Sku.sd                     : num  0.621 2.03 0.926 1.613 1.121 ...
 $ Sp.n                       : num  9 6 9 12 9 9 15 12 18 9 ...
 $ Sp.min                     : num  2620 3361 2912 3210 1814 ...
 $ Sp.max                     : num  5611 5622 5319 18307 4624 ...
 $ Sp.mean                    : num  4119 4442 4079 7950 3060 ...
 $ Sp.median                  : num  4565 4548 4053 5974 2859 ...
 $ Sp.sd                      : num  1013 816 783 4262 1061 ...
 $ Sv.n                       : num  9 6 9 12 9 9 15 12 18 9 ...
 $ Sv.min                     : num  3548 4048 2908 2762 2780 ...
 $ Sv.max                     : num  5328 10177 8150 17699 7908 ...
 $ Sv.mean                    : num  4449 6714 5387 8022 4551 ...
 $ Sv.median                  : num  4408 6213 5474 5841 4051 ...
 $ Sv.sd                      : num  671 2597 1397 5162 1815 ...
 $ Sz.n                       : num  9 6 9 12 9 9 15 12 18 9 ...
 $ Sz.min                     : num  6772 8576 5820 7042 4865 ...
 $ Sz.max                     : num  10199 13538 12220 36006 11688 ...
 $ Sz.mean                    : num  8568 11156 9466 15972 7611 ...
 $ Sz.median                  : num  8969 10939 9490 12836 6249 ...
 $ Sz.sd                      : num  1423 1930 1821 8982 2737 ...
 $ Sa.n                       : num  9 6 9 12 9 9 15 12 18 9 ...
 $ Sa.min                     : num  717 919 766 677 392 ...
 $ Sa.max                     : num  1285 1580 1375 3806 1563 ...
 $ Sa.mean                    : num  989 1103 1034 1728 811 ...
 $ Sa.median                  : num  1006 1011 1040 1424 678 ...
 $ Sa.sd                      : num  217 248 178 1015 354 ...
 $ Smr.n                      : num  9 6 9 12 9 9 15 12 18 9 ...
 $ Smr.min                    : num  0.26 0.583 0.5 0.196 0.408 ...
 $ Smr.max                    : num  4.05 2.98 2.71 2.95 13.77 ...
 $ Smr.mean                   : num  1.552 1.312 1.217 0.714 3.616 ...
 $ Smr.median                 : num  0.872 0.837 0.928 0.357 1.337 ...
 $ Smr.sd                     : num  1.413 0.973 0.769 0.849 4.297 ...
 $ Smc.n                      : num  9 6 9 12 9 9 15 12 18 9 ...
 $ Smc.min                    : num  1227 1505 1169 1039 665 ...
 $ Smc.max                    : num  2236 2368 2329 6299 2442 ...
 $ Smc.mean                   : num  1593 1777 1635 2838 1253 ...
 $ Smc.median                 : num  1488 1597 1597 2434 1165 ...
 $ Smc.sd                     : num  363 352 330 1685 529 ...
 $ Sxp.n                      : num  9 6 9 12 9 9 15 12 18 9 ...
 $ Sxp.min                    : num  1714 1920 2057 1639 1081 ...
 $ Sxp.max                    : num  3413 4425 3189 11231 4878 ...
```

```
 $ Sxp.mean                : num  2566 2740 2883 4352 2550 ...
 $ Sxp.median              : num  2638 2500 3001 3304 2066 ...
 $ Sxp.sd                  : num  643 870 350 2890 1226 ...
 $ Sal.n                   : num  9 6 9 12 9 9 15 12 18 9 ...
 $ Sal.min                 : num  20.8 21.4 18.5 15.7 19.9 ...
 $ Sal.max                 : num  27.7 36.6 27.7 29.5 33 ...
 $ Sal.mean                : num  24.9 26.2 23.8 23.2 25.7 ...
 $ Sal.median              : num  24.9 24.6 23.9 23.8 25.1 ...
 $ Sal.sd                  : num  2.36 5.52 2.89 3.94 4.47 ...
 $ Str.n                   : num  8 6 8 12 9 8 14 12 17 8 ...
 $ Str.min                 : num  0.192 0.498 0.467 0.215 0.504 ...
 $ Str.max                 : num  0.858 0.88 0.91 0.858 0.869 ...
 $ Str.mean                : num  0.533 0.744 0.675 0.548 0.756 ...
 $ Str.median              : num  0.519 0.773 0.674 0.588 0.778 ...
 $ Str.sd                  : num  0.268 0.131 0.155 0.233 0.115 ...
 $ Std.n                   : num  9 6 9 12 9 9 15 12 18 9 ...
 $ Std.min                 : num  47.76 50.99 79.26 3.51 2.27 ...
 $ Std.max                 : num  98.5 151.7 137.5 166.5 176.5 ...
 $ Std.mean                : num  88.3 91.2 96.7 66 94.1 ...
 $ Std.median              : num  93.5 86.1 86.2 64.3 115 ...
 $ Std.sd                  : num  15.5 40.5 22.1 43.8 60 ...
 $ Sdq.n                   : num  9 6 9 12 9 9 15 12 18 9 ...
 $ Sdq.min                 : num  0.166 0.254 0.158 0.256 0.123 ...
 $ Sdq.max                 : num  0.271 0.419 0.271 0.649 0.37 ...
 $ Sdq.mean                : num  0.227 0.327 0.207 0.363 0.212 ...
 $ Sdq.median              : num  0.244 0.322 0.181 0.281 0.171 ...
 $ Sdq.sd                  : num  0.0424 0.0613 0.0502 0.1494 0.0891 ...
 $ Sdr.n                   : num  9 6 9 12 9 9 15 12 18 9 ...
 $ Sdr.min                 : num  1.345 2.811 1.195 3.061 0.733 ...
 $ Sdr.max                 : num  3.43 6.67 3.42 12.99 6.02 ...
 $ Sdr.mean                : num  2.49 4.4 2.14 5.47 2.38 ...
 $ Sdr.median              : num  2.77 4.28 1.6 3.54 1.43 ...
 $ Sdr.sd                  : num  0.833 1.426 0.999 3.548 1.887 ...
 $ Vm.n                    : num  9 6 9 12 9 9 15 12 18 9 ...
 $ Vm.min                  : num  0.0401 0.0513 0.041 0.0622 0.0273 ...
 $ Vm.max                  : num  0.0988 0.113 0.0878 0.4079 0.06 ...
 $ Vm.mean                 : num  0.065 0.0735 0.063 0.1326 0.0439 ...
 $ Vm.median               : num  0.0606 0.0706 0.0597 0.0898 0.0452 ...
 $ Vm.sd                   : num  0.019 0.0212 0.0158 0.103 0.0119 ...
  [list output truncated]
```

Raw material

```
raw_material <- summaryBy(.~Raw.material+Location+Sublocation,
                          data = imp_data[c("Raw.material", "Location", "Sublocation",
                                            names(imp_data)[num.var])],
                          FUN = nminmaxmeanmedsd)
str(raw_material)
'data.frame':	19 obs. of  207 variables:
 $ Raw.material            : Factor w/ 2 levels "flint","lydite": 1 1 1 1 1 1 1 1 2 2 ...
 $ Location                : chr  "A" "B" "B" "C" ...
 $ Sublocation             : chr  "1" "1" "2" "1" ...
 $ Sq.n                    : num  3 3 6 12 3 6 3 3 6 12 ...
 $ Sq.min                  : num  966 1375 663 426 382 ...
 $ Sq.max                  : num  1120 1703 1057 2273 912 ...
 $ Sq.mean                 : num  1028 1490 865 1200 678 ...
 $ Sq.median               : num  999 1392 864 949 741 ...
 $ Sq.sd                   : num  81.2 184.7 136 603.8 270.7 ...
 $ Ssk.n                   : num  3 3 6 12 3 6 3 3 6 12 ...
 $ Ssk.min                 : num  -0.552 -0.734 -0.386 -4.568 -1.719 ...
 $ Ssk.max                 : num  0.224 0.27 1.087 0.303 -0.348 ...
 $ Ssk.mean                : num  -0.0794 -0.2012 0.3329 -1.0663 -1.2266 ...
```

```
 $ Ssk.median                  : num  0.0897 -0.1396 0.4308 -0.3499 -1.6128 ...
 $ Ssk.sd                      : num  0.414 0.505 0.618 1.45 0.763 ...
 $ Sku.n                       : num  3 3 6 12 3 6 3 3 6 12 ...
 $ Sku.min                     : num  2.99 2.82 3.2 3.11 3.43 ...
 $ Sku.max                     : num  4.2 5.74 8.34 34.69 9.72 ...
 $ Sku.mean                    : num  3.5 4.41 5.55 9.32 7.13 ...
 $ Sku.median                  : num  3.31 4.66 5.9 5.56 8.24 ...
 $ Sku.sd                      : num  0.628 1.477 1.968 9.183 3.289 ...
 $ Sp.n                        : num  3 3 6 12 3 6 3 3 6 12 ...
 $ Sp.min                      : num  2620 4070 1982 1894 795 ...
 $ Sp.max                      : num  3224 5319 5768 12492 1957 ...
 $ Sp.mean                     : num  2942 4827 4095 3862 1524 ...
 $ Sp.median                   : num  2983 5093 4130 2721 1819 ...
 $ Sp.sd                       : num  304 666 1452 3011 635 ...
 $ Sv.n                        : num  3 3 6 12 3 6 3 3 6 12 ...
 $ Sv.min                      : num  3548 4762 2362 1627 2158 ...
 $ Sv.max                      : num  4339 8150 4335 15753 6129 ...
 $ Sv.mean                     : num  3894 6169 3147 6907 3739 ...
 $ Sv.median                   : num  3795 5597 2923 4311 2929 ...
 $ Sv.sd                       : num  404 1765 782 4996 2106 ...
 $ Sz.n                        : num  3 3 6 12 3 6 3 3 6 12 ...
 $ Sz.min                      : num  6772 9855 4345 3613 2953 ...
 $ Sz.max                      : num  6959 12220 8852 23963 8086 ...
 $ Sz.mean                     : num  6836 10997 7243 10769 5262 ...
 $ Sz.median                   : num  6777 10916 7551 6977 4748 ...
 $ Sz.sd                       : num  106 1185 1555 6966 2605 ...
 $ Sa.n                        : num  3 3 6 12 3 6 3 3 6 12 ...
 $ Sa.min                      : num  753 1035 518 326 270 ...
 $ Sa.max                      : num  897 1375 831 1601 643 ...
 $ Sa.mean                     : num  808 1150 653 840 502 ...
 $ Sa.median                   : num  773 1040 643 704 591 ...
 $ Sa.sd                       : num  77.6 194.9 110.4 386 202.2 ...
 $ Smr.n                       : num  3 3 6 12 3 6 3 3 6 12 ...
 $ Smr.min                     : num  2.624 0.525 0.281 0.168 10.264 ...
 $ Smr.max                     : num  4.05 1.27 5.33 10.13 79.01 ...
 $ Smr.mean                    : num  3.347 0.874 1.637 3.056 34.529 ...
 $ Smr.median                  : num  3.369 0.823 0.485 1.935 14.309 ...
 $ Smr.sd                      : num  0.712 0.377 2.08 3.238 38.579 ...
 $ Smc.n                       : num  3 3 6 12 3 6 3 3 6 12 ...
 $ Smc.min                     : num  1227 1592 765 511 393 ...
 $ Smc.max                     : num  1488 2329 1364 2479 968 ...
 $ Smc.mean                    : num  1334 1840 1017 1262 767 ...
 $ Smc.median                  : num  1286 1597 975 1099 941 ...
 $ Smc.sd                      : num  137 424 212 570 324 ...
 $ Sxp.n                       : num  3 3 6 12 3 6 3 3 6 12 ...
 $ Sxp.min                     : num  1714 2991 1415 916 1062 ...
 $ Sxp.max                     : num  2334 3025 1960 5191 2101 ...
 $ Sxp.mean                    : num  2040 3006 1661 2674 1563 ...
 $ Sxp.median                  : num  2072 3001 1652 2191 1525 ...
 $ Sxp.sd                      : num  311.3 17.4 181.9 1458.3 520.4 ...
 $ Sal.n                       : num  3 3 6 12 3 6 3 3 6 12 ...
 $ Sal.min                     : num  20.8 23.4 15.7 19.2 17.4 ...
 $ Sal.max                     : num  23.1 24.6 22 29.1 29.7 ...
 $ Sal.mean                    : num  22.3 24 18.8 24 25 ...
 $ Sal.median                  : num  22.9 23.9 18.1 24.1 27.9 ...
 $ Sal.sd                      : num  1.274 0.573 2.681 3.022 6.607 ...
 $ Str.n                       : num  2 2 6 12 3 4 2 3 6 12 ...
 $ Str.min                     : num  0.287 0.59 0.639 0.295 0.361 ...
 $ Str.max                     : num  0.603 0.786 0.858 0.896 0.938 ...
 $ Str.mean                    : num  0.445 0.688 0.732 0.757 0.677 ...
 $ Str.median                  : num  0.445 0.688 0.724 0.787 0.732 ...
```

```
 $ Str.sd          : num  0.2233 0.1389 0.0924 0.1586 0.2923 ...
 $ Std.n           : num  3 3 6 12 3 6 3 3 6 12 ...
 $ Std.min         : num  47.76 82.49 16.74 8.76 36 ...
 $ Std.max         : num  98.5 132.5 81.2 101.5 93.5 ...
 $ Std.mean        : num  79.9 102.8 57 66.6 59.9 ...
 $ Std.median      : num  93.5 93.5 63.9 69.1 50.3 ...
 $ Std.sd          : num  28 26.3 26.1 28.9 29.9 ...
 $ Sdq.n           : num  3 3 6 12 3 6 3 3 6 12 ...
 $ Sdq.min         : num  0.166 0.267 0.15 0.104 0.112 ...
 $ Sdq.max         : num  0.18 0.271 0.277 0.292 0.149 ...
 $ Sdq.mean        : num  0.173 0.269 0.223 0.196 0.127 ...
 $ Sdq.median      : num  0.174 0.269 0.239 0.185 0.121 ...
 $ Sdq.sd          : num  0.00731 0.00192 0.05326 0.05879 0.01962 ...
 $ Sdr.n           : num  3 3 6 12 3 6 3 3 6 12 ...
 $ Sdr.min         : num  1.345 3.361 1.097 0.53 0.617 ...
 $ Sdr.max         : num  1.55 3.42 3.58 3.75 1.08 ...
 $ Sdr.mean        : num  1.457 3.396 2.458 1.741 0.805 ...
 $ Sdr.median      : num  1.482 3.411 2.722 1.622 0.721 ...
 $ Sdr.sd          : num  0.1025 0.0302 1.0302 0.8737 0.2404 ...
 $ Vm.n            : num  3 3 6 12 3 6 3 3 6 12 ...
 $ Vm.min          : num  0.0401 0.063 0.0314 0.0221 0.0102 ...
 $ Vm.max          : num  0.0565 0.0878 0.0682 0.1566 0.0371 ...
 $ Vm.mean         : num  0.0497 0.0793 0.0563 0.0571 0.0245 ...
 $ Vm.median       : num  0.0525 0.0869 0.0602 0.0458 0.0263 ...
 $ Vm.sd           : num  0.00855 0.01407 0.01376 0.03675 0.01356 ...
  [list output truncated]
```

Use-wear type with sample

```
wear <- summaryBy(.~Sample+Location+Sublocation+Area+Usewear.type,
                  data = imp_data[c("Sample", "Location", "Sublocation",
                                    "Area","Usewear.type",
                                    names(imp_data)[num.var])],
                  FUN = nminmaxmeanmedsd)
str(wear)
'data.frame':   50 obs. of  209 variables:
 $ Sample          : chr  "BU-003" "BU-032" "BU-077" "BU-115" ...
 $ Location        : chr  "C" "B" "B" "A" ...
 $ Sublocation     : chr  "1" "3" "3" "2" ...
 $ Area            : chr  "01" "01" "01" "01" ...
 $ Usewear.type    : Factor w/ 11 levels "A","B","B2","C",..: 4 8 5 4 4 4 2 4 3 7 ...
 $ Sq.n            : num  3 3 3 3 3 3 3 3 3 3 ...
 $ Sq.min          : num  948 534 797 973 1231 ...
 $ Sq.max          : num  1049 832 999 1008 2171 ...
 $ Sq.mean         : num  999 704 901 988 1663 ...
 $ Sq.median       : num  1001 746 908 983 1586 ...
 $ Sq.sd           : num  50.3 153.3 101.1 18 474.6 ...
 $ Ssk.n           : num  3 3 3 3 3 3 3 3 3 3 ...
 $ Ssk.min         : num  -0.574 -0.392 -0.855 0.121 -0.281 ...
 $ Ssk.max         : num  0.13256 -0.12753 -0.2485 0.40616 0.00382 ...
 $ Ssk.mean        : num  -0.291 -0.298 -0.55 0.258 -0.108 ...
 $ Ssk.median      : num  -0.4305 -0.376 -0.5461 0.2465 -0.0476 ...
 $ Ssk.sd          : num  0.373 0.148 0.303 0.143 0.152 ...
 $ Sku.n           : num  3 3 3 3 3 3 3 3 3 3 ...
 $ Sku.min         : num  3.1 3.3 3.8 2.93 2.98 ...
 $ Sku.max         : num  3.72 5.18 5.18 3.42 3.31 ...
 $ Sku.mean        : num  3.44 4.26 4.7 3.09 3.12 ...
 $ Sku.median      : num  3.52 4.3 5.13 2.93 3.07 ...
 $ Sku.sd          : num  0.316 0.94 0.782 0.287 0.17 ...
 $ Sp.n            : num  3 3 3 3 3 3 3 3 3 3 ...
 $ Sp.min          : num  2312 2085 1814 2917 3791 ...
 $ Sp.max          : num  5140 2859 3330 3517 5795 ...
```

```
$ Sp.mean        : num  3366 2344 2531 3130 4634 ...
$ Sp.median      : num  2645 2087 2450 2955 4315 ...
$ Sp.sd          : num  1546 446 761 336 1040 ...
$ Sv.n           : num  3 3 3 3 3 3 3 3 3 3 ...
$ Sv.min         : num  3199 2780 3406 2558 3846 ...
$ Sv.max         : num  3908 3390 4275 2775 7204 ...
$ Sv.mean        : num  3549 2989 3911 2671 5365 ...
$ Sv.median      : num  3542 2797 4051 2680 5043 ...
$ Sv.sd          : num  354 347 451 109 1702 ...
$ Sz.n           : num  3 3 3 3 3 3 3 3 3 3 ...
$ Sz.min         : num  5511 4865 5856 5597 7637 ...
$ Sz.max         : num  8683 6249 7605 6074 13000 ...
$ Sz.mean        : num  6915 5332 6442 5800 9998 ...
$ Sz.median      : num  6553 4884 5865 5730 9358 ...
$ Sz.sd          : num  1617 794 1007 246 2738 ...
$ Sa.n           : num  3 3 3 3 3 3 3 3 3 3 ...
$ Sa.min         : num  749 392 620 774 953 ...
$ Sa.max         : num  814 623 717 790 1757 ...
$ Sa.mean        : num  780 537 672 783 1319 ...
$ Sa.median      : num  777 596 678 783 1246 ...
$ Sa.sd          : num  32.69 126.46 48.95 8.02 406.83 ...
$ Smr.n          : num  3 3 3 3 3 3 3 3 3 3 ...
$ Smr.min        : num  0.0851 1.2278 1.337 1.6065 0.8016 ...
$ Smr.max        : num  6.82 4.48 13.77 3.49 2.12 ...
$ Smr.mean       : num  3.31 2.81 7.22 2.74 1.64 ...
$ Smr.median     : num  3.01 2.72 6.54 3.13 1.99 ...
$ Smr.sd         : num  3.38 1.626 6.243 0.999 0.725 ...
$ Smc.n          : num  3 3 3 3 3 3 3 3 3 3 ...
$ Smc.min        : num  1148 665 929 1249 1483 ...
$ Smc.max        : num  1348 961 1182 1297 2692 ...
$ Smc.mean       : num  1215 839 1092 1272 2068 ...
$ Smc.median     : num  1149 892 1165 1272 2029 ...
$ Smc.sd         : num  115 155 142 24 605 ...
$ Sxp.n          : num  3 3 3 3 3 3 3 3 3 3 ...
$ Sxp.min        : num  1988 1081 1751 1757 2554 ...
$ Sxp.max        : num  2409 1925 2450 1845 4662 ...
$ Sxp.mean       : num  2184 1554 2089 1806 3492 ...
$ Sxp.median     : num  2155 1656 2066 1815 3261 ...
$ Sxp.sd         : num  211.8 431.3 350 44.7 1072.8 ...
$ Sal.n          : num  3 3 3 3 3 3 3 3 3 3 ...
$ Sal.min        : num  23.3 19.9 24.5 21.5 18.8 ...
$ Sal.max        : num  28.4 25.1 31.5 24.6 29.1 ...
$ Sal.mean       : num  25.1 22 27.9 22.7 23.8 ...
$ Sal.median     : num  23.7 20.9 27.7 22.1 23.6 ...
$ Sal.sd         : num  2.83 2.74 3.51 1.66 5.17 ...
$ Str.n          : num  3 3 3 3 3 3 3 3 3 3 ...
$ Str.min        : num  0.361 0.682 0.504 0.851 0.446 ...
$ Str.max        : num  0.797 0.853 0.869 0.88 0.539 ...
$ Str.mean       : num  0.631 0.785 0.694 0.863 0.507 ...
$ Str.median     : num  0.735 0.819 0.711 0.856 0.536 ...
$ Str.sd         : num  0.2359 0.0909 0.1833 0.0156 0.0529 ...
$ Std.n          : num  3 3 3 3 3 3 3 3 3 3 ...
$ Std.min        : num  132.5 2.27 93.5 120.25 16.49 ...
$ Std.max        : num  141 177 141 138 39 ...
$ Std.mean       : num  136.9 102.7 118.5 128.9 26.8 ...
$ Std.median     : num  137 129 122 129 25 ...
$ Std.sd         : num  4.15 90.11 23.64 8.63 11.37 ...
$ Sdq.n          : num  3 3 3 3 3 3 3 3 3 3 ...
$ Sdq.min        : num  0.22 0.123 0.15 0.177 0.217 ...
$ Sdq.max        : num  0.227 0.179 0.171 0.178 0.244 ...
$ Sdq.mean       : num  0.223 0.147 0.164 0.178 0.232 ...
```

```
 $ Sdq.median          : num  0.222 0.138 0.17 0.178 0.236 ...
 $ Sdq.sd              : num  0.003198 0.028963 0.012165 0.000543 0.013865 ...
 $ Sdr.n               : num  3 3 3 3 3 3 3 3 3 3 ...
 $ Sdr.min             : num  2.287 0.733 1.094 1.538 2.283 ...
 $ Sdr.max             : num  2.49 1.52 1.43 1.56 2.8 ...
 $ Sdr.mean            : num  2.37 1.06 1.31 1.55 2.58 ...
 $ Sdr.median          : num  2.35 0.934 1.402 1.555 2.661 ...
 $ Sdr.sd              : num  0.1012 0.4097 0.1856 0.0109 0.2661 ...
 $ Vm.n                : num  3 3 3 3 3 3 3 3 3 3 ...
 $ Vm.min              : num  0.0359 0.0283 0.0273 0.0525 0.0718 ...
 $ Vm.max              : num  0.0575 0.0442 0.0543 0.0666 0.0865 ...
 $ Vm.mean             : num  0.0448 0.035 0.0423 0.0585 0.079 ...
  [list output truncated]
```

Use-wear type

```
use_type <- summaryBy(.~Tool.type+Usewear.type,
                      data = imp_data[c("Tool.type","Usewear.type",
                                        names(imp_data)[num.var])],
                    FUN = nminmaxmeanmedsd)
str(use_type)
'data.frame':   21 obs. of  206 variables:
 $ Tool.type           : Factor w/ 4 levels "Keilmesser","Pradnik scraper",..: 1 1 1 1 1 1 1 1 1 1 ...
 $ Usewear.type        : Factor w/ 11 levels "A","B","B2","C",..: 1 2 3 4 5 6 7 8 9 10 ...
 $ Sq.n                : num  9 6 3 24 9 3 12 9 21 9 ...
 $ Sq.min              : num  1419 1100 902 948 797 ...
 $ Sq.max              : num  5272 2062 1889 8384 1994 ...
 $ Sq.mean             : num  2891 1709 1331 2592 1336 ...
 $ Sq.median           : num  2299 1872 1200 1677 1347 ...
 $ Sq.sd               : num  1413 372 506 2193 399 ...
 $ Ssk.n               : num  9 6 3 24 9 3 12 9 21 9 ...
 $ Ssk.min             : num  -0.734 -0.925 -0.454 -2.751 -1.37 ...
 $ Ssk.max             : num  0.457 -0.058 0.548 0.398 -0.249 ...
 $ Ssk.mean            : num  -0.1289 -0.2818 -0.0562 -0.4405 -0.579 ...
 $ Ssk.median          : num  -0.21 -0.173 -0.263 -0.248 -0.546 ...
 $ Ssk.sd              : num  0.393 0.328 0.532 0.695 0.356 ...
 $ Sku.n               : num  9 6 3 24 9 3 12 9 21 9 ...
 $ Sku.min             : num  2.76 3.04 3.24 2.82 2.93 ...
 $ Sku.max             : num  5.85 5.76 4.52 14.57 6.71 ...
 $ Sku.mean            : num  3.68 4.02 3.81 4.87 4.12 ...
 $ Sku.median          : num  3.12 3.8 3.67 3.71 3.8 ...
 $ Sku.sd              : num  1.081 0.945 0.653 3.046 1.301 ...
 $ Sp.n                : num  9 6 3 24 9 3 12 9 21 9 ...
 $ Sp.min              : num  3491 3817 3112 2312 1814 ...
 $ Sp.max              : num  18307 6231 4896 28502 4636 ...
 $ Sp.mean             : num  9144 5172 4209 7800 3594 ...
 $ Sp.median           : num  8267 5212 4620 5194 3780 ...
 $ Sp.sd               : num  4522 870 960 6775 1072 ...
 $ Sv.n                : num  9 6 3 24 9 3 12 9 21 9 ...
 $ Sv.min              : num  4793 4940 2997 3199 3406 ...
 $ Sv.max              : num  19926 9752 6471 36672 7908 ...
 $ Sv.mean             : num  10126 6780 4534 10928 5204 ...
 $ Sv.median           : num  8110 6643 4135 6294 4971 ...
 $ Sv.sd               : num  5697 1620 1771 9953 1441 ...
 $ Sz.n                : num  9 6 3 24 9 3 12 9 21 9 ...
 $ Sz.min              : num  8825 8756 6108 5511 5856 ...
 $ Sz.max              : num  36006 14514 11367 58945 11688 ...
 $ Sz.mean             : num  19270 11951 8744 18729 8797 ...
 $ Sz.median           : num  15403 12330 8755 11168 9472 ...
 $ Sz.sd               : num  9629 1994 2629 16052 2290 ...
 $ Sa.n                : num  9 6 3 24 9 3 12 9 21 9 ...
 $ Sa.min              : num  1127 839 685 749 620 ...
```

```
$ Sa.max            : num  3806 1640 1482 6501 1563 ...
$ Sa.mean           : num  2222 1308 1018 1926 1028 ...
$ Sa.median         : num  1848 1402 888 1317 1035 ...
$ Sa.sd             : num  1017 299 414 1595 326 ...
$ Smr.n             : num  9 6 3 24 9 3 12 9 21 9 ...
$ Smr.min           : num  0.1834 0.586 0.6543 0.0851 0.4082 ...
$ Smr.max           : num  2.16 1.18 1.29 6.82 13.77 ...
$ Smr.mean          : num  0.562 0.767 1.017 1.252 3.805 ...
$ Smr.median        : num  0.357 0.732 1.11 0.717 1.038 ...
$ Smr.sd            : num  0.621 0.22 0.326 1.505 4.775 ...
$ Smc.n             : num  9 6 3 24 9 3 12 9 21 9 ...
$ Smc.min           : num  1660 1421 1021 1148 929 ...
$ Smc.max           : num  6299 2666 2333 10517 2442 ...
$ Smc.mean          : num  3581 2135 1582 3055 1593 ...
$ Smc.median        : num  2839 2270 1392 2170 1527 ...
$ Smc.sd            : num  1651 478 677 2537 490 ...
$ Sxp.n             : num  9 6 3 24 9 3 12 9 21 9 ...
$ Sxp.min           : num  2738 2103 2105 1988 1751 ...
$ Sxp.max           : num  11231 4476 4459 20698 4878 ...
$ Sxp.mean          : num  6120 3707 2905 5766 3129 ...
$ Sxp.median        : num  4860 4174 2150 3153 3191 ...
$ Sxp.sd            : num  3234 1000 1346 5382 1017 ...
$ Sal.n             : num  9 6 3 24 9 3 12 9 21 9 ...
$ Sal.min           : num  19.3 21.6 18.3 18.9 22.5 ...
$ Sal.max           : num  31.5 29.8 30.7 31.3 33 ...
$ Sal.mean          : num  25.4 24.5 25.4 25 27.3 ...
$ Sal.median        : num  25.9 24.3 27.4 24.8 26.2 ...
$ Sal.sd            : num  4.04 2.93 6.41 3.08 4.05 ...
$ Str.n             : num  8 6 2 22 9 3 11 9 20 9 ...
$ Str.min           : num  0.284 0.404 0.733 0.23 0.418 ...
$ Str.max           : num  0.794 0.784 0.781 0.919 0.869 ...
$ Str.mean          : num  0.676 0.681 0.757 0.616 0.655 ...
$ Str.median        : num  0.74 0.73 0.757 0.619 0.711 ...
$ Str.sd            : num  0.173 0.143 0.0345 0.1807 0.1694 ...
$ Std.n             : num  9 6 3 24 9 3 12 9 21 9 ...
$ Std.min           : num  3.51 13.5 39.01 16.75 3.74 ...
$ Std.max           : num  177 176 176 166 141 ...
$ Std.mean          : num  100.9 84.6 88.8 101.5 61.7 ...
$ Std.median        : num  129 98.6 51 93.9 65 ...
$ Std.sd            : num  65.7 62.4 76.2 36.7 57.6 ...
$ Sdq.n             : num  9 6 3 24 9 3 12 9 21 9 ...
$ Sdq.min           : num  0.256 0.195 0.22 0.161 0.142 ...
$ Sdq.max           : num  0.649 0.301 0.269 1.032 0.37 ...
$ Sdq.mean          : num  0.414 0.25 0.238 0.379 0.22 ...
$ Sdq.median        : num  0.434 0.251 0.226 0.29 0.171 ...
$ Sdq.sd            : num  0.1208 0.0452 0.0266 0.2311 0.0832 ...
$ Sdr.n             : num  9 6 3 24 9 3 12 9 21 9 ...
$ Sdr.min           : num  3.061 1.811 2.282 1.265 0.993 ...
$ Sdr.max           : num  12.99 4.13 3.37 27.81 6.02 ...
$ Sdr.mean          : num  7.12 2.97 2.69 6.37 2.5 ...
$ Sdr.median        : num  7.4 2.9 2.41 3.73 1.43 ...
$ Sdr.sd            : num  3.146 0.998 0.598 6.481 1.802 ...
$ Vm.n              : num  9 6 3 24 9 3 12 9 21 9 ...
$ Vm.min            : num  0.0499 0.0563 0.0523 0.0359 0.0273 ...
$ Vm.max            : num  0.4079 0.0944 0.1039 0.543 0.0722 ...
$ Vm.mean           : num  0.1477 0.0793 0.0746 0.1372 0.0523 ...
$ Vm.median         : num  0.0989 0.0819 0.0678 0.0861 0.0534 ...
$ Vm.sd             : num  0.1102 0.0126 0.0265 0.1404 0.0129 ...
$ Vv.n              : num  9 6 3 24 9 3 12 9 21 9 ...
 [list output truncated]
```

Tool type and use-wear type

```
tool_use <- summaryBy(.~Tool.type+Location+Sublocation+Usewear.type,
                      data = imp_data[c("Tool.type", "Location",
                                        "Sublocation","Usewear.type",
                                        names(imp_data)[num.var])],
                      FUN = nminmaxmeanmedsd)
str(tool_use)
'data.frame':   43 obs. of  208 variables:
 $ Tool.type                    : Factor w/ 4 levels "Keilmesser","Pradnik scraper",..: 1 1 1 1 1 1 1 1 1 1 ...
 $ Location                     : chr  "A" "A" "A" "B" ...
 $ Sublocation                  : chr  "1" "2" "2" "1" ...
 $ Usewear.type                 : Factor w/ 11 levels "A","B","B2","C",..: 7 8 9 4 9 1 4 9 10 5 ...
 $ Sq.n                         : num  9 3 3 6 3 3 3 3 3 6 ...
 $ Sq.min                       : num  966 1243 1247 1273 956 ...
 $ Sq.max                       : num  1641 1482 1947 1703 1331 ...
 $ Sq.mean                      : num  1271 1354 1492 1438 1132 ...
 $ Sq.median                    : num  1340 1337 1282 1397 1108 ...
 $ Sq.sd                        : num  266 121 395 146 188 ...
 $ Ssk.n                        : num  9 3 3 6 3 3 3 3 3 6 ...
 $ Ssk.min                      : num  -0.798 0.0907 -0.8824 -0.7343 -0.5862 ...
 $ Ssk.max                      : num  0.518 0.899 -0.376 0.27 -0.185 ...
 $ Ssk.mean                     : num  -0.0551 0.3903 -0.7119 -0.3372 -0.3257 ...
 $ Ssk.median                   : num  0.0596 0.1809 -0.8769 -0.3864 -0.2055 ...
 $ Ssk.sd                       : num  0.452 0.443 0.291 0.375 0.226 ...
 $ Sku.n                        : num  9 3 3 6 3 3 3 3 3 6 ...
 $ Sku.min                      : num  2.99 3.3 2.92 2.82 2.92 ...
 $ Sku.max                      : num  4.76 3.86 7.61 5.74 4.43 ...
 $ Sku.mean                     : num  3.64 3.53 5.8 4.24 3.63 ...
 $ Sku.median                   : num  3.31 3.42 6.87 4.33 3.54 ...
 $ Sku.sd                       : num  0.621 0.298 2.519 0.995 0.758 ...
 $ Sp.n                         : num  9 3 3 6 3 3 3 3 3 6 ...
 $ Sp.min                       : num  2620 4528 3361 3261 2912 ...
 $ Sp.max                       : num  5611 5622 4567 5319 4053 ...
 $ Sp.mean                      : num  4119 5009 3875 4355 3528 ...
 $ Sp.median                    : num  4565 4877 3696 4221 3621 ...
 $ Sp.sd                        : num  1013 559 623 757 576 ...
 $ Sv.n                         : num  9 3 3 6 3 3 3 3 3 6 ...
 $ Sv.min                       : num  3548 4048 7296 4762 2908 ...
 $ Sv.max                       : num  5328 5130 10177 8150 5148 ...
 $ Sv.mean                      : num  4449 4523 8905 5958 4243 ...
 $ Sv.median                    : num  4408 4392 9241 5538 4674 ...
 $ Sv.sd                        : num  671 553 1470 1178 1180 ...
 $ Sz.n                         : num  9 3 3 6 3 3 3 3 3 6 ...
 $ Sz.min                       : num  6772 8576 11864 8739 5820 ...
 $ Sz.max                       : num  10199 10014 13538 12220 9201 ...
 $ Sz.mean                      : num  8568 9532 12779 10313 7772 ...
 $ Sz.median                    : num  8969 10007 12937 10257 8295 ...
 $ Sz.sd                        : num  1423 828 848 1223 1750 ...
 $ Sa.n                         : num  9 3 3 6 3 3 3 3 3 6 ...
 $ Sa.min                       : num  717 963 919 953 766 ...
 $ Sa.max                       : num  1285 1141 1580 1375 1049 ...
 $ Sa.mean                      : num  989 1055 1151 1109 884 ...
 $ Sa.median                    : num  1006 1059 954 1068 837 ...
 $ Sa.sd                        : num  217 89 372 147 147 ...
 $ Smr.n                        : num  9 3 3 6 3 3 3 3 3 6 ...
 $ Smr.min                      : num  0.26 0.583 1.001 0.525 0.5 ...
 $ Smr.max                      : num  4.048 0.673 2.982 2.71 1.443 ...
 $ Smr.mean                     : num  1.552 0.632 1.991 1.347 0.957 ...
 $ Smr.median                   : num  0.872 0.642 1.991 1.048 0.928 ...
 $ Smr.sd                       : num  1.4132 0.0458 0.9902 0.8926 0.4719 ...
 $ Smc.n                        : num  9 3 3 6 3 3 3 3 3 6 ...
```

```
$ Smc.min                    : num  1227 1572 1505 1554 1169 ...
$ Smc.max                    : num  2236 2053 2368 2329 1685 ...
$ Smc.mean                   : num  1593 1749 1805 1761 1383 ...
$ Smc.median                 : num  1488 1622 1544 1620 1295 ...
$ Smc.sd                     : num  363 264 488 298 269 ...
$ Sxp.n                      : num  9 3 3 6 3 3 3 3 3 6 ...
$ Sxp.min                    : num  1714 1920 2530 2991 2057 ...
$ Sxp.max                    : num  3413 2469 4425 3189 2749 ...
$ Sxp.mean                   : num  2566 2244 3236 3072 2503 ...
$ Sxp.median                 : num  2638 2343 2755 3068 2703 ...
$ Sxp.sd                     : num  642.9 287.6 1035.1 78.8 386.8 ...
$ Sal.n                      : num  9 3 3 6 3 3 3 3 3 6 ...
$ Sal.min                    : num  20.8 21.4 22.6 20.4 18.5 ...
$ Sal.max                    : num  27.7 36.6 25.4 27.7 26.8 ...
$ Sal.mean                   : num  24.9 28.5 23.9 24 23.5 ...
$ Sal.median                 : num  24.9 27.5 23.8 23.9 25.2 ...
$ Sal.sd                     : num  2.36 7.63 1.43 2.33 4.43 ...
$ Str.n                      : num  8 3 3 5 3 3 3 3 3 6 ...
$ Str.min                    : num  0.192 0.498 0.73 0.59 0.467 ...
$ Str.max                    : num  0.858 0.808 0.88 0.91 0.574 ...
$ Str.mean                   : num  0.533 0.685 0.802 0.766 0.523 ...
$ Str.median                 : num  0.519 0.749 0.797 0.786 0.529 ...
$ Str.sd                     : num  0.2683 0.1644 0.075 0.1146 0.0537 ...
$ Std.n                      : num  9 3 3 6 3 3 3 3 3 6 ...
$ Std.min                    : num  47.8 73.5 51 82.5 79.3 ...
$ Std.max                    : num  98.5 151.7 98.7 137.5 86.8 ...
$ Std.mean                   : num  88.3 115.6 66.9 103 84 ...
$ Std.median                 : num  93.5 121.5 51 89.9 86 ...
$ Std.sd                     : num  15.48 39.46 27.57 25.06 4.13 ...
$ Sdq.n                      : num  9 3 3 6 3 3 3 3 3 6 ...
$ Sdq.min                    : num  0.166 0.354 0.254 0.161 0.158 ...
$ Sdq.max                    : num  0.271 0.419 0.29 0.271 0.178 ...
$ Sdq.mean                   : num  0.227 0.378 0.276 0.229 0.165 ...
$ Sdq.median                 : num  0.244 0.36 0.284 0.245 0.158 ...
$ Sdq.sd                     : num  0.0424 0.036 0.0195 0.0486 0.0112 ...
$ Sdr.n                      : num  9 3 3 6 3 3 3 3 3 6 ...
$ Sdr.min                    : num  1.34 4.81 2.81 1.27 1.19 ...
$ Sdr.max                    : num  3.43 6.67 3.74 3.42 1.5 ...
$ Sdr.mean                   : num  2.49 5.54 3.26 2.56 1.3 ...
$ Sdr.median                 : num  2.77 5.13 3.24 2.83 1.2 ...
$ Sdr.sd                     : num  0.833 0.994 0.466 0.975 0.177 ...
$ Vm.n                       : num  9 3 3 6 3 3 3 3 3 6 ...
$ Vm.min                     : num  0.0401 0.0723 0.0513 0.0521 0.041 ...
$ Vm.max                     : num  0.0988 0.113 0.069 0.0878 0.0597 ...
$ Vm.mean                    : num  0.065 0.0869 0.0602 0.0692 0.0507 ...
$ Vm.median                  : num  0.0606 0.0755 0.0603 0.0655 0.0514 ...
 [list output truncated]
```

Save data

Format name of output file

```
file_out <- "Use-wear_stats"
```

The file will be saved as “~/analysis/summary_stats/.[ext]”.

Write to XLSX

```
write.xlsx(list(spot = spot, tool = tool, raw_material = raw_material,
           wear = wear, use_type = use_type, tool_use = tool_use),
           file = paste0(dir_out, file_out, ".xlsx"))
```

Save R object

```
saveObject(list(spot = spot, tool = tool, raw_material = raw_material, wear = wear, use_type = use_type, tool_use =
tool_use),
        file = paste0(dir_out, file_out, ".Rbin"))
```

---

sessionInfo() and RStudio version

```
sessionInfo()
R version 4.0.2 (2020-06-22)
Platform: x86_64-w64-mingw32/x64 (64-bit)
Running under: Windows 10 x64 (build 19041)

Matrix products: default

locale:
[1] LC_COLLATE=German_Germany.1252  LC_CTYPE=German_Germany.1252
[3] LC_MONETARY=German_Germany.1252 LC_NUMERIC=C
[5] LC_TIME=German_Germany.1252

attached base packages:
[1] tools     stats     graphics  grDevices utils     datasets  methods
[8] base

other attached packages:
[1] doBy_4.6.8        R.utils_2.10.1    R.oo_1.24.0       R.methodsS3_1.8.1
[5] openxlsx_4.2.3

loaded via a namespace (and not attached):
 [1] zip_2.1.1         Rcpp_1.0.6        compiler_4.0.2    pillar_1.4.7
 [5] digest_0.6.27     lattice_0.20-41   evaluate_0.14     lifecycle_0.2.0
 [9] tibble_3.0.6      gtable_0.3.0      pkgconfig_2.0.3   rlang_0.4.10
[13] Matrix_1.2-18     DBI_1.1.1         yaml_2.2.1        xfun_0.20
[17] dplyr_1.0.3       stringr_1.4.0     knitr_1.31        generics_0.1.0
[21] vctrs_0.3.6       grid_4.0.2        tidyselect_1.1.0  glue_1.4.2
[25] R6_2.5.0          rmarkdown_2.6     tidyr_1.1.2       purrr_0.3.4
[29] ggplot2_3.3.3     magrittr_2.0.1    backports_1.2.1   scales_1.1.1
[33] ellipsis_0.3.1    htmltools_0.5.1.1 MASS_7.3-51.6     assertthat_0.2.1
[37] colorspace_2.0-0  Deriv_4.1.2       stringi_1.5.3     munsell_0.5.0
[41] broom_0.7.4       crayon_1.4.0
```

RStudio version 1.3.1073.

END OF SCRIPT

Plots - use-wear archaeology

Lisa Schunk

2021-02-14 16:37:01

Goal of the script

This script plots all variables to see which ones should be used for further analysis.
Scatterplot of each variable will be plotted.

```
dir_in <- "analysis/derived_data/"
dir_out <- "analysis/plots"
```

Raw data must be located in ~/analysis/derived_data/.
Formatted data will be saved in ~/analysis/plots. The knit directory for this script is the project directory.

Load packages

```
library(R.utils)
library(ggplot2)
Warning: package 'ggplot2' was built under R version 4.0.3
library(tools)
library(tidyverse)
Warning: package 'tidyverse' was built under R version 4.0.3
Warning: package 'tibble' was built under R version 4.0.3
Warning: package 'readr' was built under R version 4.0.3
Warning: package 'dplyr' was built under R version 4.0.3
library(patchwork)
Warning: package 'patchwork' was built under R version 4.0.3
library(doBy)
Warning: package 'doBy' was built under R version 4.0.3
library(ggrepel)
Warning: package 'ggrepel' was built under R version 4.0.3
library(openxlsx)
Warning: package 'openxlsx' was built under R version 4.0.3
library(wesanderson)
library(ggfortify)
Warning: package 'ggfortify' was built under R version 4.0.3
```

Get name, path and information of the file

```
data_file <- list.files(dir_in, pattern = "\\.Rbin$", full.names = TRUE)
md5_in <- md5sum(data_file)
info_in <- data.frame(file = basename(names(md5_in)), checksum = md5_in, row.names = NULL)
```

The checksum (MD5 hashes) of the imported file is:

```
          file                         checksum
1 Use-wear.Rbin 558d5b8d978e0d27f0cf6d308b0734de
```

Load data into R object

```
imp_data <- loadObject(data_file)
str(imp_data)
'data.frame':   150 obs. of  57 variables:
 $ Sample              : chr  "MU-232" "MU-232" "MU-232" "MU-003" ...
```

```
$ Site                  : Factor w/ 3 levels "Balve","Buhlen",..: 1 1 1 1 1 1 1 1 1 1 ...
$ Tool.type             : Factor w/ 4 levels "Keilmesser","Pradnik scraper",..: 1 1 1 1 1 1 1 1 1 4 ...
$ Raw.material          : Factor w/ 2 levels "flint","lydite": 2 2 2 2 2 2 2 2 2 2 ...
$ Location              : chr  "B" "B" "B" "D" ...
$ Sublocation           : chr  "2" "2" "2" "1" ...
$ Area                  : chr  "01" "01" "01" "01" ...
$ Spot                  : chr  "a" "b" "c" "a" ...
$ Usewear.type          : Factor w/ 11 levels "A","B","B2","C",..: 9 9 9 2 2 2 4 4 4 3 ...
$ Objective             : Factor w/ 3 levels "20x07","50x075",..: 1 1 1 3 3 3 2 2 2 3 ...
$ Analysis.date         : Date, format: "2020-09-07" "2020-09-07" ...
$ Analysis.time         : 'times' num  0.631 0.631 0.631 0.631 0.632 ...
 ..- attr(*, "format")= chr "h:m:s"
$ Acquisition.date.time   : chr  "07.07.2020 16:58" "07.08.2020 10:35" "07.08.2020 12:10" "07.03.2020 10:44" ...
$ Axis.length.X         : num  255 255 255 255 255 ...
$ Axis.size.X           : num  1198 1198 1198 1198 1198 ...
$ Axis.spacing.X        : num  0.213 0.213 0.213 0.213 0.213 ...
$ Axis.length.Y         : num  255 255 255 255 255 ...
$ Axis.size.Y           : num  1198 1198 1198 1198 1198 ...
$ Axis.spacing.Y        : num  0.213 0.213 0.213 0.213 0.213 ...
$ Axis.length.Z         : num  249564 99661 162726 38576 39610 ...
$ Axis.size.Z           : num  65505 35461 32419 65340 66654 ...
$ Axis.spacing.Z        : num  3.81 2.81 5.019 0.59 0.594 ...
$ NM.points.ratio.Z     : num  0 0 0 0 0 0 0 0 0 0 ...
$ Sq                    : num  3243 2493 4332 1912 1936 ...
$ Ssk                   : num  0.0634 -0.9445 0.1816 -0.058 -0.2928 ...
$ Sku                   : num  3.46 7.36 3.08 3.75 3.47 ...
$ Sp                    : num  10477 7460 12748 6231 5796 ...
$ Sv                    : num  10005 12962 16115 6843 6575 ...
$ Sz                    : num  20482 20422 28864 13075 12371 ...
$ Sa                    : num  2506 1813 3409 1464 1495 ...
$ Smr                   : num  0.551 0.697 0.388 0.784 0.586 ...
$ Smc                   : num  3754 2956 5778 2454 2429 ...
$ Sxp                   : num  6582 4878 7854 3949 4400 ...
$ Sal                   : num  25.9 20.5 23.4 24.4 24.9 ...
$ Str                   : num  0.321 0.215 0.241 0.784 0.767 ...
$ Std                   : num  42.5 93 51 103.7 106.7 ...
$ Sdq                   : num  0.603 0.376 0.557 0.301 0.298 ...
$ Sdr                   : num  9.99 5.11 10.54 4.13 4.09 ...
$ Vm                    : num  0.2094 0.1157 0.2311 0.0944 0.0828 ...
$ Vv                    : num  3.96 3.07 6.01 2.55 2.51 ...
$ Vmp                   : num  0.2094 0.1157 0.2311 0.0944 0.0828 ...
$ Vmc                   : num  2.78 1.82 3.63 1.59 1.6 ...
$ Vvc                   : num  3.56 2.73 5.53 2.31 2.24 ...
$ Vvv                   : num  0.403 0.342 0.48 0.238 0.275 ...
$ Maximum.depth.of.furrows: num  12698 14381 16377 7155 7130 ...
$ Mean.depth.of.furrows   : num  2586 2471 3670 2350 2229 ...
$ Mean.density.of.furrows : num  2987 1790 1901 2032 2098 ...
$ First.direction       : num  44.9809 90.00638 89.98321 0.01527 0.00574 ...
$ Second.direction      : num  26.5 135 63.5 116.5 135 ...
$ Third.direction       : num  63.5 116.4 45 135 90 ...
$ Isotropy              : num  13.5 64.5 14.9 87 86.3 ...
$ epLsar                : num  0.00368 0.0024 0.00301 0.00161 0.00236 ...
$ NewEplsar             : num  0.0181 0.0177 0.0179 0.0171 0.0171 ...
$ Asfc                  : num  12.8 6.85 12.12 5.51 5.36 ...
$ Smfc                  : num  2.51 67.38 48.16 94.68 55.32 ...
$ HAsfc9                : num  0.629 0.444 0.496 0.666 0.75 ...
$ HAsfc81               : num  0.81 2.106 1.515 0.845 0.704 ...
- attr(*, "comment")= Named chr [1:44] "µm" "points" "µm" "µm" ...
 ..- attr(*, "names")= chr [1:44] "Axis length - X" "Axis size - X" "Axis spacing - X" "Axis length - Y" ...
```

The imported file is: "~/analysis/derived_data/Use-wear.Rbin"

Prepare variables

Define numeric variables

```
num.var <- 24:length(imp_data)
```

The following variables will be used:

```
[24] Sq
[25] Ssk
[26] Sku
[27] Sp
[28] Sv
[29] Sz
[30] Sa
[31] Smr
[32] Smc
[33] Sxp
[34] Sal
[35] Str
[36] Std
[37] Sdq
[38] Sdr
[39] Vm
[40] Vv
[41] Vmp
[42] Vmc
[43] Vvc
[44] Vvv
[45] Maximum.depth.of.furrows
[46] Mean.depth.of.furrows
[47] Mean.density.of.furrows
[48] First.direction
[49] Second.direction
[50] Third.direction
[51] Isotropy
[52] epLsar
[53] NewEplsar
[54] Asfc
[55] Smfc
[56] HAsfc9
[57] HAsfc81
```

Plot each of the selected numeric variables

Colour definitions for use-wear types

```
#05100c black
#999999 grey
#52854c green
#c3d7a4 light green
#487bb6 blue
#a6cee3 light blue
#9a0f0f red
#d16103 orange
#fdbf6f apricot
```

```
#ffdb6d yellow
#985633 brown
#134680 dark blue


custom.col <- data.frame(type = levels(imp_data$Usewear.typ),
                         col = c("#999999", "#52854c", "#c3d7a4", "#487bb6", "#9a0f0f",
                                 "#fdbf6f",
                                 "#d16103", "#ffdb6d", "#985633", "#134680", "#05100c"))
```

Plot of all samples with raw material, variables and use-wear type as information

```
# splits the data in the individual 35 samples
imp_data[["Sample_material"]] <- paste(imp_data$Raw.material, imp_data$Sample, sep = "  ")

sp <- split(imp_data, imp_data[["Site"]])

usewear <- levels(imp_data$Usewear.type)



for (i in num.var){

  # gets the min/max range of the data set
  range_var <- range(imp_data[[i]])

   # plot
  p <- vector(mode = "list", length = length(sp))
  names(p) <- names(sp)

  for (j in seq_along(sp)) {
    col_j <- custom.col[custom.col$type %in% levels(factor(sp[[j]][["Usewear.type"]])), "col"]

    p[[j]] <- ggplot(data = sp[[j]], aes_string(x = "Location", y = names(imp_data)[i],
                                               colour = "Usewear.type", shape =
                                              "Sublocation")) +
         # avoids overplotting
         geom_jitter(size = 3,  position = position_jitter(width = 0.4, seed = 1)) +
         coord_cartesian(ylim = range_var) +
         theme_classic() +
         labs(colour = "Use-wear type") +
         facet_wrap(~ Sample_material, nrow = 3) +
         labs(y = gsub("\\.", "  ", names(imp_data)[i])) +
         scale_colour_manual(values = col_j) +
         theme(text = element_text(size = 23)) +
         if(j != 1) ylab(NULL)

  }
  p_all <- wrap_plots(p) + plot_layout(width = c(8/13, 2/13, 3/13), guides = "collect")



  # saves the plots
  file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "_plot_",
                     names(imp_data)[i], ".pdf")
    ggsave(filename = file_out, plot = p_all, path = dir_out, device = "pdf", width = 27,
           height = 35, units = "cm" )
}
Warning: Removed 5 rows containing missing values (geom_point).
Warning: Removed 4 rows containing missing values (geom_point).
```

Boxplot of all the variables combined with the use-wear type (without outliers)

```
# Wes Anderson color palettes Rushmore = c("#E1BD6D", "#EABE94", "#0B775E", "#35274A" ,"#F2300F")
custom.col2 <- data.frame(type = levels(imp_data$Tool.typ),
                          col = c( "#0B775E", "#E1BD6D", "#F2300F", "#35274A"))
imp_data$col <- custom.col2[imp_data$Tool.typ, "col"]


# excludes the outliers
# adds the indices as row numbers
imp_data <- imp_data %>% mutate(id = row_number())
imp_data2 <- imp_data[-c(55, 63, 115, 116), ]


# plot
for (i in num.var){

  p2 <- ggplot(data = imp_data2, aes_string(x = "Usewear.type", y = names(imp_data)[i],
                                            fill = "Tool.type")) +
        geom_boxplot() +
        scale_fill_manual(values = custom.col2$col)+
        theme_classic() +
        labs( x = "use-wear type", title = "  ") +
        labs(y = gsub("\\.", "  ", names(imp_data)[i])) +
        labs(fill = "artefact category")


  # saves the plots
  file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "_boxplot_",
                     names(imp_data)[i], ".pdf")
    ggsave(filename = file_out, plot = p2, path = dir_out, device = "pdf", width = 17,
           height = 25, units = "cm")

}
Warning: Removed 9 rows containing non-finite values (stat_boxplot).
```

Boxplot of all the variables combined with the use-wear type - tool types separated (without outliers)

```
# Keilmesser
# sorts the data according to the technological class
sort_data <- imp_data2[ , ] %>% arrange(Tool.type)
# adds indices as row names
row.names(sort_data) <- 1:nrow(sort_data)
# excludes all other tool types
KM_data <- sort_data [1:107, ]

for (i in num.var){

  KM <- ggplot(data = KM_data, aes_string(x = "Usewear.type", y = names(KM_data)[i],
                                          fill = "Tool.type")) +
        geom_boxplot() +
        theme_classic() +
        labs( x = "use-wear type", title = "  ") +
        labs(y = gsub("\\.", "  ", names(KM_data)[i])) +
        labs(fill = "artefact category") +
        scale_fill_manual(values = "#0B775E")


  # saves the plots
  file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "_KM_boxplot",
```

```r
                    names(KM_data)[i], ".pdf")
   ggsave(filename = file_out, plot = KM, path = dir_out, device = "pdf", width = 17,
          height = 25, units = "cm")

}
Warning: Removed 6 rows containing non-finite values (stat_boxplot).
# Pradnik scraper
# excludes all other tool types
PS_data <- sort_data [108:116, ]

for (i in num.var){

  PS <- ggplot(data = PS_data, aes_string(x = "Usewear.type", y = names(PS_data)[i],
                                          fill = "Tool.type")) +
       geom_boxplot() +
       theme_classic() +
       labs( x = "use-wear type", title = " ") +
       labs(y = gsub("\\.", " ", names(PS_data)[i])) +
       labs(fill = "artefact category") +
       scale_fill_manual(values = "#E1BD6D")



  # saves the plots
  file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "_PS_boxplot",
                    names(PS_data)[i], ".pdf")
   ggsave(filename = file_out, plot = PS, path = dir_out, device = "pdf", width = 17,
          height = 25, units = "cm")

}



# Scraper
# excludes all other tool types
S_data <- sort_data [129:146, ]

for (i in num.var){

  S <- ggplot(data = S_data, aes_string(x = "Usewear.type", y = names(S_data)[i],
                                          fill = "Tool.type")) +
       geom_boxplot() +
       theme_classic() +
       labs( x = "use-wear type", title = " ") +
       labs(y = gsub("\\.", " ", names(S_data)[i])) +
       labs(fill = "artefact category") +
       scale_fill_manual(values = "#35274A")



  # saves the plots
  file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "_S_boxplot",
                    names(S_data)[i], ".pdf")
   ggsave(filename = file_out, plot = S, path = dir_out, device = "pdf", width = 17,
          height = 25, units = "cm")

}
Warning: Removed 3 rows containing non-finite values (stat_boxplot).
# Pradnik spall
# excludes all other tool types
LSS_data <- sort_data [117:128, ]
```

```
for (i in num.var){

  LSS <- ggplot(data = LSS_data, aes_string(x = "Usewear.type", y = names(LSS_data)[i],
                                           fill = "Tool.type")) +
       geom_boxplot() +
       theme_classic() +
       labs( x = "use-wear type", title = "  ") +
       labs(y = gsub("\\.", "  ", names(LSS_data)[i])) +
       labs(fill = "artefact category") +
       scale_fill_manual(values =  "#F2300F")



  # saves the plots
  file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "_LSS_boxplot",
                    names(LSS_data)[i], ".pdf")
   ggsave(filename = file_out, plot = LSS, path = dir_out, device = "pdf", width = 17,
         height = 25, units = "cm")

}
```

Histogram of the use-wear types (without outliers)

```
custom.col <- data.frame(type = levels(imp_data$Usewear.typ),
                        col = c("#999999", "#52854c", "#c3d7a4", "#487bb6", "#9a0f0f",
                                "#fdbf6f",
                                "#d16103", "#ffdb6d", "#985633", "#134680", "#05100c"))

col <- custom.col[custom.col$type %in% levels(imp_data[["Usewear.type"]]), "col"]




# plot
for (i in num.var){



  p_use <- ggplot(data = imp_data2, aes_string(x = names(imp_data)[i])) +
         geom_histogram(bins = 15, aes(fill = Usewear.type)) +
         theme_classic() +
         labs(x = gsub("\\.", "  ", names(imp_data)[i])) +
         labs(fill = "use-wear type", y = NULL) +
         facet_wrap(~Usewear.type)+
         scale_fill_manual(values =  col)



  # saves the plots
  file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "_histogram_UW_Type_",
                    names(imp_data)[i], ".pdf")
   ggsave(filename = file_out, plot = p_use, path = dir_out, device = "pdf")

}
Warning: Removed 9 rows containing non-finite values (stat_bin).
```

Scatterplots of selected variables combined with the use-wear type (without outliers)

```
custom.col <- data.frame(type = levels(imp_data$Usewear.typ),
                        col = c("#999999", "#52854c", "#c3d7a4", "#487bb6", "#9a0f0f",
                                "#fdbf6f",
                                "#d16103", "#ffdb6d", "#985633", "#134680", "#05100c"))

col <- custom.col[custom.col$type %in% levels(imp_data[["Usewear.type"]]), "col"]
```

```
# plot
# plots Sa against Sq
p3 <- ggplot(data = imp_data2) +
      geom_point(mapping = aes(x = Sa, y = Sq, colour = Usewear.type)) +
      theme_classic() +
      labs(colour = "use-wear type") +
      scale_colour_manual(values =  col)


# saves the plot
file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "_SA_scatterplot_", ".pdf")
ggsave(filename = file_out, plot = p3, path = dir_out, device = "pdf")


# plots epLsar against Asfc
p4 <- ggplot(data = imp_data2) +
      geom_point(mapping = aes(x = Asfc, y = epLsar, colour = Usewear.type)) +
      theme_classic() +
      labs(colour = "use-wear type") +
       scale_colour_manual(values =  col)


# saves the plot
file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "_Asfc_scatterplot_", ".pdf")
ggsave(filename = file_out, plot = p4, path = dir_out, device = "pdf")


# plots Sq against Vmc
p5 <- ggplot(data = imp_data2) +
      geom_point(mapping = aes(x = Sq, y = Vmc, colour = Usewear.type)) +
      theme_classic() +
      labs(colour = "use-wear type") +
       scale_colour_manual(values =  col)


# saves the plot
file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "_Sq_scatterplot_", ".pdf")
ggsave(filename = file_out, plot = p5, path = dir_out, device = "pdf")


# plots Mean depth of furrows against mean density of furrows
p6 <- ggplot(data = imp_data2) +
      geom_point(mapping = aes(x = Mean.depth.of.furrows, y = Mean.density.of.furrows,
                           colour = Usewear.type)) +
      theme_classic() +
      labs(colour = "use-wear type") +
       scale_colour_manual(values =  col) +
      labs(x = "Mean depth of furrows", y = "Mean density of furrows")


# saves the plot
file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "_furrows_scatterplot_", ".pdf")
ggsave(filename = file_out, plot = p6, path = dir_out, device = "pdf")
```

Scatterplots of selected variables combined with the two tool types: Keilmesser and Pradnik scraper (without outliers)

```
# selects only Keilmesser and Pradnik scraper
KM_PS <- filter(imp_data2, Tool.type == "Keilmesser" | Tool.type == "Pradnik scraper")
```

```r
custom.col2b <- data.frame(type = unique(KM_PS$Tool.type),
                           col = c("#0B775E", "#E1BD6D"))

col2b <- custom.col2b[custom.col2b$type %in% unique(KM_PS[["Tool.type"]]), "col"]

# plot
# plots Sa against Sq
p7 <- ggplot(data = KM_PS) +
      geom_point(mapping = aes(x = Sa, y = Sq, colour = Tool.type)) +
      theme_classic() +
      labs(colour = "artefact category") +
      scale_colour_manual(values =  col2b)


# saves the plot
file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "_SA_KM.PS_scatterplot_", ".pdf")
ggsave(filename = file_out, plot = p7, path = dir_out, device = "pdf")


# plots epLsar against Asfc
p8 <- ggplot(data = KM_PS) +
      geom_point(mapping = aes(x = Asfc, y = epLsar, colour = Tool.type)) +
      theme_classic() +
      labs(colour = "artefact category") +
      scale_colour_manual(values =  col2b)


# saves the plot
file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "_Asfc_KM.PS_scatterplot_", ".pdf")
ggsave(filename = file_out, plot = p8, path = dir_out, device = "pdf")


# plots Sq against Vmc
p9 <- ggplot(data = KM_PS) +
      geom_point(mapping = aes(x = Sq, y = Vmc, colour = Tool.type)) +
      theme_classic() +
      labs(colour = "artefact category") +
      scale_colour_manual(values =  col2b)


# saves the plot
file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "_Sq_KM.PS_scatterplot_", ".pdf")
ggsave(filename = file_out, plot = p9, path = dir_out, device = "pdf")


# plots Mean depth of furrows against mean density of furrows
p10 <- ggplot(data = KM_PS) +
       geom_point(mapping = aes(x = Mean.depth.of.furrows, y = Mean.density.of.furrows,
                            colour = Tool.type)) +
       theme_classic() +
       labs(colour = "artefact category") +
       scale_colour_manual(values =  col2b) +
       labs(x = "Mean depth of furrows", y = "Mean density of furrows")


# saves the plot
file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "_furrows_KM.PS_scatterplot_",
```

```
                 ".pdf")
ggsave(filename = file_out, plot = p10, path = dir_out, device = "pdf")
```

Principal component analysis

PCA Use-wear type (without outliers)

```
# uses for the PCA only selected variables: Sq, SSK, Vmc, Isotropy, Mean, density of furrows, Asfc, HAsfc9
imp_data.pca <- prcomp(imp_data2[, c(24:25, 42, 47, 51, 54,56)], scale. = TRUE)


custom.col1 <- data.frame(type = levels(imp_data$Usewear.typ),
                      col = c("#999999", "#52854c", "#c3d7a4", "#487bb6", "#9a0f0f", "#fdbf6f",
                             "#d16103", "#ffdb6d", "#985633", "#134680", "#05100c"))
imp_data$col <- custom.col1[imp_data$Usewear.typ, "col"]

# Using ggfortify
a<- autoplot(imp_data.pca, data = imp_data2, colour = "Usewear.type", size = 2,
           loadings = TRUE, loadings.colour = "black", loadings.label = TRUE, loadings.label.colour = "black",
           loadings.label.size  = 4, loadings.label.hjust = 1, loadings.label.vjust = 1,
           frame = TRUE, frame.type = "convex", frame.colour = "Usewear.type",
           frame.alpha = 0) +
           theme_classic() +
           scale_colour_manual(values = custom.col1$col)
Warning: `select_()` is deprecated as of dplyr 0.7.0.
Please use `select()` instead.
This warning is displayed once every 8 hours.
Call `lifecycle::last_warnings()` to see where this warning was generated.
Warning: `group_by_()` is deprecated as of dplyr 0.7.0.
Please use `group_by()` instead.
See vignette('programming') for more help
This warning is displayed once every 8 hours.
Call `lifecycle::last_warnings()` to see where this warning was generated.
# saves the plot
file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "_PCA_usewear_type", ".pdf")
ggsave(filename = file_out, plot = a, path = dir_out, device = "pdf")
```

PCA Tool type (without outliers)

```
# uses for the PCA only selected variables: Sq, SSK, Vmc, Isotropy, Mean density of furrows,
# Asfc, HAsfc9
imp_data.pca <- prcomp(imp_data2[, c(24:25, 42, 47, 51, 54,56)], scale. = TRUE)

# Wes Anderson color palettes Rushmore = c("#E1BD6D", "#EABE94", "#0B775E", "#35274A",
#"#F2300F")
custom.col2 <- data.frame(type = levels(imp_data$Tool.typ),
                      col = c( "#0B775E", "#E1BD6D", "#F2300F", "#35274A"))
imp_data$col <- custom.col2[imp_data$Tool.typ, "col"]

b <- autoplot(imp_data.pca, data = imp_data2, colour = "Tool.type", size = 2,
           loadings = TRUE, loadings.colour = "black", loadings.label = TRUE,
           loadings.label.colour = "black",
           loadings.label.size  = 4, loadings.label.hjust = 1, loadings.label.vjust = 1,
           frame = TRUE, frame.type = "convex", frame.colour = "Tool.type",
           frame.alpha = 0) +
           theme_classic() +
           scale_colour_manual(values = custom.col2$col)


# saves the plot
file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "_PCA_tool_tpye", ".pdf")
ggsave(filename = file_out, plot = b, path = dir_out, device = "pdf")
```

The files will be saved as “~/analysis/plots.[ext]”.

---

sessionInfo() and RStudio version

```
sessionInfo()
R version 4.0.2 (2020-06-22)
Platform: x86_64-w64-mingw32/x64 (64-bit)
Running under: Windows 10 x64 (build 19041)

Matrix products: default

locale:
[1] LC_COLLATE=German_Germany.1252  LC_CTYPE=German_Germany.1252
[3] LC_MONETARY=German_Germany.1252 LC_NUMERIC=C
[5] LC_TIME=German_Germany.1252

attached base packages:
[1] tools     stats     graphics  grDevices utils     datasets  methods
[8] base

other attached packages:
 [1] ggfortify_0.4.11  wesanderson_0.3.6 openxlsx_4.2.3    ggrepel_0.9.1
 [5] doBy_4.6.8        patchwork_1.1.1   forcats_0.5.1     stringr_1.4.0
 [9] dplyr_1.0.3       purrr_0.3.4       readr_1.4.0       tidyr_1.1.2
[13] tibble_3.0.5      tidyverse_1.3.0   ggplot2_3.3.3     R.utils_2.10.1
[17] R.oo_1.24.0       R.methodsS3_1.8.1

loaded via a namespace (and not attached):
 [1] Rcpp_1.0.6        lubridate_1.7.9.2 lattice_0.20-41   assertthat_0.2.1
 [5] digest_0.6.27     R6_2.5.0          cellranger_1.1.0  backports_1.2.0
 [9] reprex_1.0.0      evaluate_0.14     httr_1.4.2        pillar_1.4.7
[13] rlang_0.4.10      readxl_1.3.1      rstudioapi_0.13   Matrix_1.2-18
[17] rmarkdown_2.6     labeling_0.4.2    munsell_0.5.0     broom_0.7.4
[21] compiler_4.0.2    Deriv_4.1.2       modelr_0.1.8      xfun_0.20
[25] pkgconfig_2.0.3   htmltools_0.5.1.1 tidyselect_1.1.0  gridExtra_2.3
[29] crayon_1.4.0      dbplyr_2.0.0      withr_2.4.1       MASS_7.3-53
[33] grid_4.0.2        jsonlite_1.7.2    gtable_0.3.0      lifecycle_0.2.0
[37] DBI_1.1.1         magrittr_2.0.1    scales_1.1.1      zip_2.1.1
[41] cli_2.3.0         stringi_1.5.3     farver_2.0.3      fs_1.5.0
[45] xml2_1.3.2        ellipsis_0.3.1    generics_0.1.0    vctrs_0.3.6
[49] glue_1.4.2        hms_1.0.0         yaml_2.2.1        colorspace_2.0-0
[53] rvest_0.3.6       knitr_1.31        haven_2.3.1
```

RStudio version 1.3.1073.

END OF SCRIPT

Import - Edge angle analysis

Lisa Schunk

2021-02-04 16:45:28

Goal of the script

This script imports and merges all single CSV-files generated with the 'edge angle method'. The data derives from 3D models of artefacts from the three sites Balver Höhle, Buhlen and Ramioul.
The script will:

80. Read in the original CSV-files

81. Combine the data from all samples into one
82. Write an XLSX-file and save an R object ready for further analysis in R

```
dir_in <- "analysis/raw_data"
dir_out <- "analysis/derived_data/"
```

Raw data must be located in "analysis/raw_data".
Formatted data will be saved in "analysis/derived_data/". The knit directory for this script is the project directory.

Load packages

```
library(tidyverse)
Warning: package 'ggplot2' was built under R version 4.0.3
Warning: package 'readr' was built under R version 4.0.3
Warning: package 'dplyr' was built under R version 4.0.3
Warning: package 'forcats' was built under R version 4.0.3
library(R.utils)
library(openxlsx)
Warning: package 'openxlsx' was built under R version 4.0.3
library(tools)
```

List all files and get names of the files

```
# List all CSV files in dir_in
CSV_files <- list.files(dir_in, pattern = "\\.csv$", recursive = TRUE, full.names = TRUE)
```

Merge all files and format the data

```
# Create a list
data_final <- vector(mode = "list", length = length(CSV_files))
names(data_final) <- basename(CSV_files)

# For each sample
for (s in seq_along(data_final)) {

  # Gets sample ID from path names
  ID <- dirname(dirname(dirname(CSV_files[s]))) %>%
        basename()
```

```r
  # Gets name of the site from path names
  site <- basename(dirname(dirname(dirname(dirname(dirname(CSV_files[s])))))) %>%
        gsub("([A-Za-z0-9_]*-)", "", x = .)

  # Gets tool type from path names
  tool_type <- dirname(dirname(dirname(dirname(CSV_files[s])))) %>%
      basename()

  # Gets section from path names
  sec <- basename(CSV_files[s]) %>%
    gsub("^[A-Za-z0-9_-]*_SEC-", "", x = .) %>%
    gsub("_.*\\.csv$", "", x = .) %>%
    as.numeric()

  # Gets edge (E1/E2/E3) from path name
  edge <- basename((dirname(CSV_files[s])))
  edge <- unlist(strsplit(edge, "_"))[3]


 # read the data files
 data_final[[s]] <- read.csv(CSV_files[s]) %>%
                   mutate(Site = site, ID = ID, Tool_type = tool_type, Section = sec,
                   Edge = edge) %>%
                   select(Site, ID, Tool_type, Section, Edge, everything()) %>%
                   select(-section) %>%
                   rename(Angle_number = angel_number,
                          Distance_origin = dist.to.origin.on.curve..mm.,
                          Segment = segment.on.section..mm.,
                          Three_point = angle.1..3.points...degree.,
                          Two_lines = angle.2..2.constructed.lines...degree.,
                          Best_fit = angle.3..2.BestFit.lines...degree.)
}

# rbind all files
data_final <- do.call(rbind, data_final)
# adds indices as row names
row.names(data_final) <- 1:nrow(data_final)
```

Save data

Format name of output file

```r
file_out <- "EdgeAngle"
```

Write to XLSX

```r
write.xlsx(list(data = data_final), file = paste0(dir_out, file_out, ".xlsx"))
```

Save R object

```r
saveObject(data_final, file = paste0(dir_out, file_out, ".Rbin"))
```

Show files information

```r
files_out <- list.files(dir_out, full.names = TRUE)
md5_out <- md5sum(files_out)
info_out <- data.frame(files = basename(names(md5_out)), checksum = md5_out,
                       row.names = NULL)
```

The checksum (MD5 hashes) of the exported files are:

```
          files                         checksum
1 EdgeAngle.Rbin c0fbf0d522d77a70c3a828b8ba7880fc
2 EdgeAngle.xlsx 0596ec4c61d57dfefe809c595c59a2af
```

---

sessionInfo() and RStudio version

```
sessionInfo()
R version 4.0.2 (2020-06-22)
Platform: x86_64-w64-mingw32/x64 (64-bit)
Running under: Windows 10 x64 (build 19041)

Matrix products: default

locale:
[1] LC_COLLATE=German_Germany.1252  LC_CTYPE=German_Germany.1252
[3] LC_MONETARY=German_Germany.1252 LC_NUMERIC=C
[5] LC_TIME=German_Germany.1252

attached base packages:
[1] tools     stats     graphics  grDevices utils     datasets  methods
[8] base

other attached packages:
 [1] openxlsx_4.2.3    R.utils_2.10.1    R.oo_1.24.0       R.methodsS3_1.8.1
 [5] forcats_0.5.1     stringr_1.4.0     dplyr_1.0.3       purrr_0.3.4
 [9] readr_1.4.0       tidyr_1.1.2       tibble_3.0.6      ggplot2_3.3.3
[13] tidyverse_1.3.0

loaded via a namespace (and not attached):
 [1] tidyselect_1.1.0  xfun_0.20         haven_2.3.1       colorspace_2.0-0
 [5] vctrs_0.3.6       generics_0.1.0    htmltools_0.5.1.1 yaml_2.2.1
 [9] rlang_0.4.10      pillar_1.4.7      glue_1.4.2        withr_2.4.1
[13] DBI_1.1.1         dbplyr_2.0.0      modelr_0.1.8      readxl_1.3.1
[17] lifecycle_0.2.0   munsell_0.5.0     gtable_0.3.0      cellranger_1.1.0
[21] zip_2.1.1         rvest_0.3.6       evaluate_0.14     knitr_1.31
[25] broom_0.7.4       Rcpp_1.0.6        scales_1.1.1      backports_1.2.1
[29] jsonlite_1.7.2    fs_1.5.0          hms_1.0.0         digest_0.6.27
[33] stringi_1.5.3     grid_4.0.2        cli_2.3.0         magrittr_2.0.1
[37] crayon_1.4.0      pkgconfig_2.0.3   ellipsis_0.3.1    xml2_1.3.2
[41] reprex_1.0.0      lubridate_1.7.9.2 assertthat_0.2.1  rmarkdown_2.6
[45] httr_1.4.2        rstudioapi_0.13   R6_2.5.0          compiler_4.0.2
```

RStudio version 1.3.1073.

END OF SCRIPT

Summary statistics - Edge angle analysis

Lisa Schunk

2021-02-04 16:51:21

Goal of the script

This script computes standard descriptive statistics for each group.
The groups are based on:

83. Edge (E1/E2/E3)
84. Tool type
85. Site
86. Distance to origin

It computes the following statistics:

87. n (sample size = length): number of measurements
88. smallest value (min)
89. largest value (max)
90. mean
91. median
92. standard deviation (sd)

```
dir_in <- "analysis/derived_data/"
dir_out <- "analysis/summary_stats/"
```

Raw data must be located in ~/analysis/derived_data/.
Formatted data will be saved in ~/analysis/summary_stats/. The knit directory for this script is the project directory. —

Load packages

```
library(openxlsx)
Warning: package 'openxlsx' was built under R version 4.0.3
library(R.utils)
library(tools)
library(doBy)
Warning: package 'doBy' was built under R version 4.0.3
```

Get name, path and information of the file

```
data_file <- list.files(dir_in, pattern = "\\.Rbin$", full.names = TRUE)
md5_in <- md5sum(data_file)
info_in <- data.frame(file = basename(names(md5_in)), checksum = md5_in,
                      row.names = NULL)
```

The checksum (MD5 hashes) of the imported files are:

```
           file                         checksum
1 EdgeAngle.Rbin c0fbf0d522d77a70c3a828b8ba7880fc
```

Load data into R object

```
imp_data <- loadObject(data_file)
str(imp_data)
'data.frame':	58516 obs. of  11 variables:
 $ Site           : chr  "Balve" "Balve" "Balve" "Balve" ...
 $ ID             : chr  "MU-022" "MU-022" "MU-022" "MU-022" ...
 $ Tool_type      : chr  "KM_dex" "KM_dex" "KM_dex" "KM_dex" ...
 $ Section        : num  1 1 1 1 1 1 1 1 1 1 ...
 $ Edge           : chr  "E1" "E1" "E1" "E1" ...
 $ Angle_number   : int  1 2 3 4 5 6 7 8 9 10 ...
 $ Distance_origin: num  1 2 3 4 5 6 7 8 9 10 ...
 $ Segment        : num  2 2 2 2 2 2 2 2 2 2 ...
 $ Three_point    : num  158.6 137.6 124 105.4 89.5 ...
 $ Two_lines      : num  137.9 106.4 71.6 41.4 35.9 ...
 $ Best_fit       : num  138.8 107.7 70.5 42.2 30.8 ...
```

The imported file is: "~/analysis/derived_data/EdgeAngle.Rbin"

Define numeric variables

```
num.var <- 9:length(imp_data)
```

The following variables will be used:

```
[9] Three_point
[10] Two_lines
[11] Best_fit
```

Compute summary statistics

Create function to compute the statistics at once

```
nminmaxmeanmedsd <- function(x){
    y <- x[!is.na(x)]
    n_test <- length(y)
    min_test <- min(y)
    max_test <- max(y)
    mean_test <- mean(y)
    med_test <- median(y)
    sd_test <- sd(y)
    out <- c(n_test, min_test, max_test, mean_test, med_test, sd_test)
    names(out) <- c("n", "min", "max", "mean", "median", "sd")
    return(out)
}
```

Compute the summary statistics in groups

Edge

```
edge <- summaryBy(. ~ Edge+Section+Distance_origin,
                  data = imp_data[c("Edge", "Section", "Distance_origin" ,
                                    names(imp_data)[num.var])],
                  FUN = nminmaxmeanmedsd)
str(edge)
'data.frame':	427 obs. of  21 variables:
 $ Edge              : chr  "E1" "E1" "E1" "E1" ...
 $ Section           : num  1 1 1 1 1 1 1 1 1 1 ...
 $ Distance_origin   : num  1 2 3 4 5 6 7 8 9 10 ...
 $ Three_point.n     : num  225 224 223 220 219 217 213 210 209 204 ...
```

```
 $ Three_point.min   : num  26 21.6 6.1 12.7 14.7 10.1 7.7 7.9 9.2 7.6 ...
 $ Three_point.max   : num  169 153 149 142 133 ...
 $ Three_point.mean  : num  90.9 77.4 69.8 64.4 60.4 ...
 $ Three_point.median: num  88 76.5 68.8 63.5 59.5 ...
 $ Three_point.sd    : num  25.6 25.9 25.5 24.3 23.6 ...
 $ Two_lines.n       : num  225 224 223 220 219 217 213 210 209 204 ...
 $ Two_lines.min     : num  22.2 6.7 2 0 0.1 0.3 0.8 0.1 0.4 0 ...
 $ Two_lines.max     : num  154 139 142 128 115 ...
 $ Two_lines.mean    : num  78.6 60 52 46.9 41.5 ...
 $ Two_lines.median  : num  77.3 57.5 51.5 45 40.5 34.1 30.9 29.3 28.6 26.4 ...
 $ Two_lines.sd      : num  25.8 27.6 26.8 25.9 23.5 ...
 $ Best_fit.n        : num  225 224 223 220 219 217 213 210 209 204 ...
 $ Best_fit.min      : num  11.8 5.3 0.3 0.2 0 0.9 0.8 0.2 0.2 0 ...
 $ Best_fit.max      : num  170 143 169 167 170 ...
 $ Best_fit.mean     : num  82.1 60.4 54.6 48.5 43.8 ...
 $ Best_fit.median   : num  77.5 56.6 52.3 44.5 41.7 ...
 $ Best_fit.sd       : num  23 28.1 29.5 28.5 27.3 ...
```

Tool type + section

```
tool_sec <- summaryBy(. ~ Tool_type+Edge+Section,
                  data = imp_data[c("Tool_type", "Edge", "Section",
                                 names(imp_data)[num.var])],
                  FUN = nminmaxmeanmedsd)
str(tool_sec)
'data.frame':   306 obs. of  21 variables:
 $ Tool_type         : chr  "flakes" "flakes" "flakes" "flakes" ...
 $ Edge              : chr  "E1" "E1" "E1" "E1" ...
 $ Section           : num  1 2 3 4 5 6 7 8 9 10 ...
 $ Three_point.n     : num  20 22 20 21 22 21 22 21 11 12 ...
 $ Three_point.min   : num  22 42.6 54.3 37.3 47.6 49.1 45.1 48.9 60.5 91.9 ...
 $ Three_point.max   : num  115.8 92.7 104.7 75 97.9 ...
 $ Three_point.mean  : num  59.4 58.3 69.4 51.8 59.5 ...
 $ Three_point.median: num  58.8 56.1 63.8 49.7 54.9 ...
 $ Three_point.sd    : num  21.3 13 14.2 11.1 12.6 ...
 $ Two_lines.n       : num  20 22 20 21 22 21 22 21 11 12 ...
 $ Two_lines.min     : num  0.5 23.1 37.6 26.1 37.8 33 38.2 31.9 47.7 54.5 ...
 $ Two_lines.max     : num  87.2 80.2 91.3 65.5 80.8 ...
 $ Two_lines.mean    : num  39.5 43.3 53 46.2 46.8 ...
 $ Two_lines.median  : num  42.5 39.5 48.9 43.9 42.9 ...
 $ Two_lines.sd      : num  21.5 14.1 14.9 12.6 10.4 ...
 $ Best_fit.n        : num  20 22 20 21 22 21 22 21 11 12 ...
 $ Best_fit.min      : num  2.3 19.5 37.7 26.5 38.7 28.4 37.7 30.9 47.2 54.2 ...
 $ Best_fit.max      : num  76.2 75.6 90.9 68 78.6 ...
 $ Best_fit.mean     : num  39.6 43.2 53.1 46.8 46.8 ...
 $ Best_fit.median   : num  41.1 39.5 48.5 41.7 43 ...
 $ Best_fit.sd       : num  19.7 14.4 15.1 13.1 10.7 ...
```

Tool type + distance to origin

```
tool_dist <- summaryBy(. ~ Tool_type+Edge+Distance_origin,
                  data = imp_data[c("Tool_type", "Edge", "Distance_origin",
                                 names(imp_data)[num.var])],
                  FUN = nminmaxmeanmedsd)
str(tool_dist)
'data.frame':   400 obs. of  21 variables:
 $ Tool_type         : chr  "flakes" "flakes" "flakes" "flakes" ...
 $ Edge              : chr  "E1" "E1" "E1" "E1" ...
 $ Distance_origin   : num  1 2 3 4 5 6 7 8 9 10 ...
 $ Three_point.n     : num  19 18 18 18 18 18 18 18 18 17 ...
 $ Three_point.min   : num  49.7 49.1 45.8 43 42.2 40.5 34.1 29.7 22 38.5 ...
 $ Three_point.max   : num  120 109 107 105 107 ...
 $ Three_point.mean  : num  90.6 78.2 70.6 65.7 62.2 ...
```

```
 $ Three_point.median: num  89 79.5 71.2 65.3 61.5 ...
 $ Three_point.sd    : num  18.6 14.8 13.7 13.5 13.8 ...
 $ Two_lines.n       : num  19 18 18 18 18 18 18 18 18 17 ...
 $ Two_lines.min     : num  49.9 43.9 34.1 26.6 14.2 0.5 4.4 24 33.1 24.8 ...
 $ Two_lines.max     : num  111.4 99.9 101.5 106.8 109.9 ...
 $ Two_lines.mean    : num  80.6 61.7 53.7 50.2 48 ...
 $ Two_lines.median  : num  80.8 58.4 51 47.5 47.5 ...
 $ Two_lines.sd      : num  16.1 13.5 15 16.1 18.3 ...
 $ Best_fit.n        : num  19 18 18 18 18 18 18 18 18 17 ...
 $ Best_fit.min      : num  62 41.7 31.9 25.5 20.2 8.2 2.3 23.1 33.1 25.4 ...
 $ Best_fit.max      : num  112 96 100 111 109 ...
 $ Best_fit.mean     : num  81.5 60.9 53.6 49.9 48.4 ...
 $ Best_fit.median   : num  76.4 59 50.8 47.1 46.9 ...
 $ Best_fit.sd       : num  14.8 13.1 15.2 17.2 17.4 ...
```

Tool type + section + distance to origin

```
tool_sec_dist <- summaryBy(. ~ Tool_type+Edge+Section++Distance_origin,
                data = imp_data[c("Tool_type", "Edge", "Section", "Distance_origin",
                                  names(imp_data)[num.var])],
                FUN = nminmaxmeanmedsd)
str(tool_sec_dist)
'data.frame':   3554 obs. of  22 variables:
 $ Tool_type         : chr  "flakes" "flakes" "flakes" "flakes" ...
 $ Edge              : chr  "E1" "E1" "E1" "E1" ...
 $ Section           : num  1 1 1 1 1 1 1 1 1 1 ...
 $ Distance_origin   : num  1 2 3 4 5 6 7 8 9 10 ...
 $ Three_point.n     : num  2 2 2 2 2 2 2 2 2 1 ...
 $ Three_point.min   : num  81.4 72.7 59.8 53.1 46.5 40.5 34.1 29.7 22 52.5 ...
 $ Three_point.max   : num  115.8 86.1 76.8 69.3 63.8 ...
 $ Three_point.mean  : num  98.6 79.4 68.3 61.2 55.1 ...
 $ Three_point.median: num  98.6 79.4 68.3 61.2 55.1 ...
 $ Three_point.sd    : num  24.32 9.48 12.02 11.46 12.23 ...
 $ Two_lines.n       : num  2 2 2 2 2 2 2 2 2 1 ...
 $ Two_lines.min     : num  74.1 49.1 34.1 26.6 14.2 0.5 4.4 24 33.1 24.8 ...
 $ Two_lines.max     : num  87.2 59.5 54 45.4 46.4 50.2 47.2 39.7 49.5 24.8 ...
 $ Two_lines.mean    : num  80.7 54.3 44 36 30.3 ...
 $ Two_lines.median  : num  80.7 54.3 44 36 30.3 ...
 $ Two_lines.sd      : num  9.26 7.35 14.07 13.29 22.77 ...
 $ Best_fit.n        : num  2 2 2 2 2 2 2 2 2 1 ...
 $ Best_fit.min      : num  72.3 50 31.9 25.5 20.2 8.2 2.3 23.1 33.1 25.4 ...
 $ Best_fit.max      : num  76.2 59 54.9 43.6 46.1 51.8 47.3 38.6 55.3 25.4 ...
 $ Best_fit.mean     : num  74.2 54.5 43.4 34.5 33.1 ...
 $ Best_fit.median   : num  74.2 54.5 43.4 34.5 33.1 ...
 $ Best_fit.sd       : num  2.76 6.36 16.26 12.8 18.31 ...
```

Sample

```
ID <- summaryBy(. ~ ID+Tool_type+Edge+Section+Distance_origin,
                data = imp_data[c("ID", "Tool_type", "Edge", "Section",
                                  "Distance_origin", names(imp_data)[num.var])],
                FUN = nminmaxmeanmedsd)
str(ID)
'data.frame':   58516 obs. of  23 variables:
 $ ID                : chr  "BU-001" "BU-001" "BU-001" "BU-001" ...
 $ Tool_type         : chr  "KM_dex" "KM_dex" "KM_dex" "KM_dex" ...
 $ Edge              : chr  "E1" "E1" "E1" "E1" ...
 $ Section           : num  1 1 1 1 1 1 1 1 1 1 ...
 $ Distance_origin   : num  1 2 3 4 5 6 7 8 9 10 ...
 $ Three_point.n     : num  1 1 1 1 1 1 1 1 1 1 ...
 $ Three_point.min   : num  100 85.7 71.8 71.6 75.9 70.6 66.8 61.2 59.2 57.5 ...
 $ Three_point.max   : num  100 85.7 71.8 71.6 75.9 70.6 66.8 61.2 59.2 57.5 ...
 $ Three_point.mean  : num  100 85.7 71.8 71.6 75.9 70.6 66.8 61.2 59.2 57.5 ...
```

```
 $ Three_point.median: num  100 85.7 71.8 71.6 75.9 70.6 66.8 61.2 59.2 57.5 ...
 $ Three_point.sd    : num  NA NA NA NA NA NA NA NA NA NA ...
 $ Two_lines.n       : num  1 1 1 1 1 1 1 1 1 1 ...
 $ Two_lines.min     : num  87.3 58.6 58.3 85.8 69.9 46.4 35.2 35 44.1 33.2 ...
 $ Two_lines.max     : num  87.3 58.6 58.3 85.8 69.9 46.4 35.2 35 44.1 33.2 ...
 $ Two_lines.mean    : num  87.3 58.6 58.3 85.8 69.9 46.4 35.2 35 44.1 33.2 ...
 $ Two_lines.median  : num  87.3 58.6 58.3 85.8 69.9 46.4 35.2 35 44.1 33.2 ...
 $ Two_lines.sd      : num  NA NA NA NA NA NA NA NA NA NA ...
 $ Best_fit.n        : num  1 1 1 1 1 1 1 1 1 1 ...
 $ Best_fit.min      : num  90.8 57 53.9 94.7 69.3 43.3 35.6 35.9 44.8 31 ...
 $ Best_fit.max      : num  90.8 57 53.9 94.7 69.3 43.3 35.6 35.9 44.8 31 ...
 $ Best_fit.mean     : num  90.8 57 53.9 94.7 69.3 43.3 35.6 35.9 44.8 31 ...
 $ Best_fit.median   : num  90.8 57 53.9 94.7 69.3 43.3 35.6 35.9 44.8 31 ...
 $ Best_fit.sd       : num  NA NA NA NA NA NA NA NA NA NA ...
```

Distance origin

```
dist <- summaryBy(. ~ ID+Tool_type+Edge+Distance_origin,
                  data = imp_data[c("ID", "Tool_type", "Edge", "Distance_origin",
                                    names(imp_data)[num.var])],
                  FUN = nminmaxmeanmedsd)
str(dist)
'data.frame':   6302 obs. of  22 variables:
 $ ID                : chr  "BU-001" "BU-001" "BU-001" "BU-001" ...
 $ Tool_type         : chr  "KM_dex" "KM_dex" "KM_dex" "KM_dex" ...
 $ Edge              : chr  "E1" "E1" "E1" "E1" ...
 $ Distance_origin   : num  1 2 3 4 5 6 7 8 9 10 ...
 $ Three_point.n     : num  10 10 10 10 10 10 10 10 10 10 ...
 $ Three_point.min   : num  76 67.2 62 58.2 56 54.5 53.6 53.2 52.5 50.8 ...
 $ Three_point.max   : num  131.8 97.7 90.3 85.3 81.6 ...
 $ Three_point.mean  : num  94.5 80.8 74 70.4 67.9 ...
 $ Three_point.median: num  93.8 80.2 71.9 68 64.2 ...
 $ Three_point.sd    : num  15.36 9.15 8.92 9.24 9.15 ...
 $ Two_lines.n       : num  10 10 10 10 10 10 10 10 10 10 ...
 $ Two_lines.min     : num  69.6 53.6 47.8 41.6 44 32.2 31 16.2 1.6 3.8 ...
 $ Two_lines.max     : num  98.2 89.1 78 85.8 73 62.6 64.4 56.7 48.8 46.5 ...
 $ Two_lines.mean    : num  82 64.7 60.5 59.3 56.6 ...
 $ Two_lines.median  : num  81.6 63 57.5 55 53.6 ...
 $ Two_lines.sd      : num  8.8 10.6 11.3 13.3 11.8 ...
 $ Best_fit.n        : num  10 10 10 10 10 10 10 10 10 10 ...
 $ Best_fit.min      : num  68 52.6 43.3 42.6 40 30 29.9 12.8 0.3 4.3 ...
 $ Best_fit.max      : num  92.8 93.5 79.6 94.7 76.3 63.8 68.6 56.1 47.9 46.8 ...
 $ Best_fit.mean     : num  80.3 64.8 59.8 59.7 56.5 ...
 $ Best_fit.median   : num  78.6 61.7 54.6 54.7 52.9 ...
 $ Best_fit.sd       : num  7.76 11.8 12.13 15.28 12.99 ...
```

Section

```
sec <- summaryBy(. ~ ID+Tool_type+Edge+Section,
                 data = imp_data[c("ID", "Tool_type", "Edge", "Section",
                                   names(imp_data)[num.var])],
                 FUN = nminmaxmeanmedsd)
str(sec)
'data.frame':   5400 obs. of  22 variables:
 $ ID                : chr  "BU-001" "BU-001" "BU-001" "BU-001" ...
 $ Tool_type         : chr  "KM_dex" "KM_dex" "KM_dex" "KM_dex" ...
 $ Edge              : chr  "E1" "E1" "E1" "E1" ...
 $ Section           : num  1 2 3 4 5 6 7 8 9 10 ...
 $ Three_point.n     : num  11 11 11 11 11 11 10 11 11 11 ...
 $ Three_point.min   : num  54.2 54 51.3 55.7 52.8 49.5 56.7 47.1 50.5 54.6 ...
 $ Three_point.max   : num  100 99.3 79.4 90.3 94.7 ...
 $ Three_point.mean  : num  70.4 68 58.2 63.9 68.2 ...
 $ Three_point.median: num  70.6 64.9 54.5 60.5 66.2 ...
```

```
 $ Three_point.sd    : num  13.4 12.36 8.51 9.86 14.06 ...
 $ Two_lines.n       : num  11 11 11 11 11 11 10 11 11 11 ...
 $ Two_lines.min     : num  31.4 16 41.5 40.7 31 33.1 38.1 8.8 1.6 10.9 ...
 $ Two_lines.max     : num  87.3 80.7 69.6 73.6 84.1 72.6 82.4 80.2 98.2 91.2 ...
 $ Two_lines.mean    : num  53.2 50.9 49.9 53.9 51.2 ...
 $ Two_lines.median  : num  46.4 54.9 48.5 53.6 46.5 42.4 51.2 47.9 60.4 54.7 ...
 $ Two_lines.sd      : num  20.54 18.36 7.13 9.56 18.64 ...
 $ Best_fit.n        : num  11 11 11 11 11 11 10 11 11 11 ...
 $ Best_fit.min      : num  31 16.6 44.6 41.6 30 32.7 38.2 8.4 0.3 11.2 ...
 $ Best_fit.max      : num  94.7 75.1 68 76 82.3 74.5 78.7 78.5 92.8 93.5 ...
 $ Best_fit.mean     : num  53.5 50.3 50.3 54.3 51.4 ...
 $ Best_fit.median   : num  44.8 53.6 48.4 53.5 46.2 40 50.7 48.1 62.8 55.3 ...
 $ Best_fit.sd       : num  22.67 17.79 6.34 10.28 18.71 ...
```

Site

```
site <- summaryBy(. ~ Site+ID+Tool_type+Edge+Section+Distance_origin,
                  data = imp_data[c("Site", "ID", "Tool_type", "Edge", "Section",
                                    "Distance_origin",
                                    names(imp_data)[num.var])],
                 FUN = nminmaxmeanmedsd)
str(site)
'data.frame':   58516 obs. of  24 variables:
 $ Site              : chr  "Balve" "Balve" "Balve" "Balve" ...
 $ ID                : chr  "MU-003" "MU-003" "MU-003" "MU-003" ...
 $ Tool_type         : chr  "KM+LSS_sin" "KM+LSS_sin" "KM+LSS_sin" "KM+LSS_sin" ...
 $ Edge              : chr  "E1" "E1" "E1" "E1" ...
 $ Section           : num  1 1 1 1 1 1 1 1 1 1 ...
 $ Distance_origin   : num  1 2 3 4 5 6 7 8 9 10 ...
 $ Three_point.n     : num  1 1 1 1 1 1 1 1 1 1 ...
 $ Three_point.min   : num  113.9 101.4 94.6 85.7 79.9 ...
 $ Three_point.max   : num  113.9 101.4 94.6 85.7 79.9 ...
 $ Three_point.mean  : num  113.9 101.4 94.6 85.7 79.9 ...
 $ Three_point.median: num  113.9 101.4 94.6 85.7 79.9 ...
 $ Three_point.sd    : num  NA NA NA NA NA NA NA NA NA NA ...
 $ Two_lines.n       : num  1 1 1 1 1 1 1 1 1 1 ...
 $ Two_lines.min     : num  102.3 85.2 69.8 59.1 51.2 ...
 $ Two_lines.max     : num  102.3 85.2 69.8 59.1 51.2 ...
 $ Two_lines.mean    : num  102.3 85.2 69.8 59.1 51.2 ...
 $ Two_lines.median  : num  102.3 85.2 69.8 59.1 51.2 ...
 $ Two_lines.sd      : num  NA NA NA NA NA NA NA NA NA NA ...
 $ Best_fit.n        : num  1 1 1 1 1 1 1 1 1 1 ...
 $ Best_fit.min      : num  98 86.4 70.2 59.1 51.8 34.3 25.7 19.3 18.8 12.6 ...
 $ Best_fit.max      : num  98 86.4 70.2 59.1 51.8 34.3 25.7 19.3 18.8 12.6 ...
 $ Best_fit.mean     : num  98 86.4 70.2 59.1 51.8 34.3 25.7 19.3 18.8 12.6 ...
 $ Best_fit.median   : num  98 86.4 70.2 59.1 51.8 34.3 25.7 19.3 18.8 12.6 ...
 $ Best_fit.sd       : num  NA NA NA NA NA NA NA NA NA NA ...
```

Save data

Format name of output file

```
file_out <- "EdgeAngle_stats"
```

The file will be saved as "~/analysis/summary_stats/.[ext]".

Write to XLSX

```
write.xlsx(list(edge = edge, tool_sec = tool_sec, tool_dist = tool_dist, tool_sec_dist =
           tool_sec_dist, ID = ID, dist = dist, sec =sec, site = site),
           file = paste0(dir_out, file_out, ".xlsx"))
```

Save R object

```
saveObject(list(edge = edge, tool_sec = tool_sec, tool_dist = tool_dist, ID = ID, dist =
           dist, sec =sec, site = site),
           file = paste0(dir_out, file_out, ".Rbin"))
```

---

sessionInfo() and RStudio version

```
sessionInfo()
R version 4.0.2 (2020-06-22)
Platform: x86_64-w64-mingw32/x64 (64-bit)
Running under: Windows 10 x64 (build 19041)

Matrix products: default

locale:
[1] LC_COLLATE=German_Germany.1252  LC_CTYPE=German_Germany.1252
[3] LC_MONETARY=German_Germany.1252 LC_NUMERIC=C
[5] LC_TIME=German_Germany.1252

attached base packages:
[1] tools     stats     graphics  grDevices utils     datasets  methods
[8] base

other attached packages:
[1] doBy_4.6.8        R.utils_2.10.1    R.oo_1.24.0       R.methodsS3_1.8.1
[5] openxlsx_4.2.3

loaded via a namespace (and not attached):
 [1] zip_2.1.1         Rcpp_1.0.6        compiler_4.0.2    pillar_1.4.7
 [5] digest_0.6.27     lattice_0.20-41   evaluate_0.14     lifecycle_0.2.0
 [9] tibble_3.0.6      gtable_0.3.0      pkgconfig_2.0.3   rlang_0.4.10
[13] Matrix_1.2-18     DBI_1.1.1         yaml_2.2.1        xfun_0.20
[17] dplyr_1.0.3       stringr_1.4.0     knitr_1.31        generics_0.1.0
[21] vctrs_0.3.6       grid_4.0.2        tidyselect_1.1.0  glue_1.4.2
[25] R6_2.5.0          rmarkdown_2.6     tidyr_1.1.2       purrr_0.3.4
[29] ggplot2_3.3.3     magrittr_2.0.1    backports_1.2.1   scales_1.1.1
[33] ellipsis_0.3.1    htmltools_0.5.1.1 MASS_7.3-51.6     assertthat_0.2.1
[37] colorspace_2.0-0  Deriv_4.1.2       stringi_1.5.3     munsell_0.5.0
[41] broom_0.7.4       crayon_1.4.0
```

RStudio version 1.3.1073.

END OF SCRIPT

Plots - Edge angle analysis

Lisa Schunk

2021-02-14 16:31:51

Goal of the script

This script plots the data from the edge angle analysis (archaeology) in order to visualizes the measurements. The plots will also visualize the differences between the three methods.

```
dir_in <- "analysis/derived_data/"
dir_out <- "analysis/plots"
```

Raw data must be located in ~/analysis/derived_data/.
Formatted data will be saved in ~/analysis/plots. The knit directory for this script is the project directory.

Load packages

```
library(R.utils)
library(ggplot2)
Warning: package 'ggplot2' was built under R version 4.0.3
library(tools)
library(tidyverse)
Warning: package 'tidyverse' was built under R version 4.0.3
Warning: package 'tibble' was built under R version 4.0.3
Warning: package 'readr' was built under R version 4.0.3
Warning: package 'dplyr' was built under R version 4.0.3
library(patchwork)
Warning: package 'patchwork' was built under R version 4.0.3
library(doBy)
Warning: package 'doBy' was built under R version 4.0.3
library(ggrepel)
Warning: package 'ggrepel' was built under R version 4.0.3
library(openxlsx)
Warning: package 'openxlsx' was built under R version 4.0.3
```

Get name, path and information of the file

```
data_file <- list.files(dir_in, pattern = "\\.Rbin$", full.names = TRUE)
md5_in <- md5sum(data_file)
info_in <- data.frame(file = basename(names(md5_in)), checksum = md5_in, row.names = NULL)
```

The checksum (MD5 hashes) of the imported file is:

```
           file                         checksum
1 EdgeAngle.Rbin c0fbf0d522d77a70c3a828b8ba7880fc
```

Load data into R object

```
imp_data <- loadObject(data_file)
str(imp_data)
'data.frame':   58516 obs. of  11 variables:
 $ Site          : chr  "Balve" "Balve" "Balve" "Balve" ...
 $ ID            : chr  "MU-022" "MU-022" "MU-022" "MU-022" ...
 $ Tool_type     : chr  "KM_dex" "KM_dex" "KM_dex" "KM_dex" ...
 $ Section       : num  1 1 1 1 1 1 1 1 1 1 ...
```

```
 $ Edge           : chr  "E1" "E1" "E1" "E1" ...
 $ Angle_number   : int  1 2 3 4 5 6 7 8 9 10 ...
 $ Distance_origin: num  1 2 3 4 5 6 7 8 9 10 ...
 $ Segment        : num  2 2 2 2 2 2 2 2 2 2 ...
 $ Three_point    : num  158.6 137.6 124 105.4 89.5 ...
 $ Two_lines      : num  137.9 106.4 71.6 41.4 35.9 ...
 $ Best_fit       : num  138.8 107.7 70.5 42.2 30.8 ...
```

The imported file is: "~/analysis/derived_data/EdgeAngle.Rbin"

Define numeric variables

```
num.var <- 9:length(imp_data)
```

Plot edge angle measurements

Plots showing the angles as lines

```
# splits the data in the individual 227 samples
sp <- split(imp_data, imp_data[["ID"]])

for (j in seq_along(sp)) {
  p <- vector(mode = "list", length = length(num.var))
  names(p) <- names(sp[[j]])[num.var]

  for (i in seq_along(num.var)){
    p[[i]] <- ggplot(data = sp[[j]], aes_string(y = "Section",
              x = names(sp[[j]])[num.var[i]], colour = "Angle_number")) +
              geom_line(aes(group = Angle_number), orientation = "y") +
              geom_hline(yintercept = c(2, 9), linetype = "dashed") +
              facet_wrap(~ Edge) +
              scale_colour_continuous(trans = "reverse") +
              scale_y_continuous(breaks=1:10, trans = "reverse") +
              labs(y = "Section") +
              labs(colour = "Dis. origin (mm)") +
              labs(x = gsub("_", " ", names(sp[[j]])[num.var[i]])) +
              scale_x_continuous(n.breaks = 3) +
                theme_classic()
  }

wp <- wrap_plots(p) + plot_annotation(title = names(sp)[j]) +
      plot_layout(guides = "collect")


  # save to PDF
  file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "_EA_plot_", names(sp)[j],
                     ".pdf")
  ggsave(filename = file_out, plot = wp, path = dir_out,
         device = "pdf", width = 260, height = 170, units = "mm")
}
```

The files will be saved as "~/analysis/plots.[ext]".

---

sessionInfo() and RStudio version

```
sessionInfo()
R version 4.0.2 (2020-06-22)
Platform: x86_64-w64-mingw32/x64 (64-bit)
```

```
Running under: Windows 10 x64 (build 19041)

Matrix products: default

locale:
[1] LC_COLLATE=German_Germany.1252  LC_CTYPE=German_Germany.1252
[3] LC_MONETARY=German_Germany.1252 LC_NUMERIC=C
[5] LC_TIME=German_Germany.1252

attached base packages:
[1] tools     stats     graphics  grDevices utils     datasets  methods
[8] base

other attached packages:
 [1] openxlsx_4.2.3    ggrepel_0.9.1     doBy_4.6.8        patchwork_1.1.1
 [5] forcats_0.5.1     stringr_1.4.0     dplyr_1.0.3       purrr_0.3.4
 [9] readr_1.4.0       tidyr_1.1.2       tibble_3.0.5      tidyverse_1.3.0
[13] ggplot2_3.3.3     R.utils_2.10.1    R.oo_1.24.0       R.methodsS3_1.8.1

loaded via a namespace (and not attached):
 [1] Rcpp_1.0.6        lubridate_1.7.9.2 lattice_0.20-41   assertthat_0.2.1
 [5] digest_0.6.27     R6_2.5.0          cellranger_1.1.0  backports_1.2.0
 [9] reprex_1.0.0      evaluate_0.14     httr_1.4.2        pillar_1.4.7
[13] rlang_0.4.10      readxl_1.3.1      rstudioapi_0.13   Matrix_1.2-18
[17] rmarkdown_2.6     labeling_0.4.2    munsell_0.5.0     broom_0.7.4
[21] compiler_4.0.2    Deriv_4.1.2       modelr_0.1.8      xfun_0.20
[25] pkgconfig_2.0.3   htmltools_0.5.1.1 tidyselect_1.1.0  crayon_1.4.0
[29] dbplyr_2.0.0      withr_2.4.1       MASS_7.3-53       grid_4.0.2
[33] jsonlite_1.7.2    gtable_0.3.0      lifecycle_0.2.0   DBI_1.1.1
[37] magrittr_2.0.1    scales_1.1.1      zip_2.1.1         cli_2.3.0
[41] stringi_1.5.3     farver_2.0.3      fs_1.5.0          xml2_1.3.2
[45] ellipsis_0.3.1    generics_0.1.0    vctrs_0.3.6       glue_1.4.2
[49] hms_1.0.0         yaml_2.2.1        colorspace_2.0-0  rvest_0.3.6
[53] knitr_1.31        haven_2.3.1
```

RStudio version 1.3.1073.

END OF SCRIPT

Initial experiment - sensor recording

João Marreiros & Lisa Schunk

2021-02-14

Goal of the script

This script reads the CSV files generated with the sensors (SMARTTESTER) during an initaial experiment in order to check the functionality of the sensors.
The script will:

93. Read in the original CSV files, combines them and organise the data
94. Plot the data
95. Write an XLSX-file and save an R object ready for further analysis in R

```
dir_in <- "analysis/raw_data/"
dir_out <- "analysis/plots"
```

Raw data must be located in ~/analysis/raw_data/.
Formatted data will be saved in ~/analysis/plots. The knit directory for this script is the project directory.

Load packages

```
library(ggplot2)
Warning: package 'ggplot2' was built under R version 4.0.3
library(readr)
Warning: package 'readr' was built under R version 4.0.3
library(reshape2)
Warning: package 'reshape2' was built under R version 4.0.3
library(ggpubr)
Warning: package 'ggpubr' was built under R version 4.0.3
library(magrittr)
Warning: package 'magrittr' was built under R version 4.0.3
library(wesanderson)
library(tools)
library(chron)
```

Get name, path and information of the file

```
data_file <- list.files(dir_in, pattern = "\\.csv$", full.names = TRUE)
md5_in <- md5sum(data_file)
info_in <- data.frame(files = basename(names(md5_in)), checksum = md5_in,
                      row.names = NULL)
```

The checksum (MD5 hashes) of the imported files are:

```
         files                         checksum
1    force.csv dbd0e66dcda6cbd5974e09cf37e6ff21
2 friction.csv 619972f50049e2d4d2ee7365d9f58023
3   length.csv 02e8b95bd84378fc0010d435d6bb01bf
4 messung3.csv 43b2968677a1737470175d0406188513
5 velocity.csv 4ff510dd57430747ab2ffac2565061f3
```

Read in original data

```
# the data contains information about force, friction, length and velocity

force <- read_table2(data_file[1])
Warning: 1 parsing failure.
row col   expected    actual                         file
 11  -- 51 columns 7 columns 'analysis/raw_data/force.csv'
friction <- read_table2(data_file[2])
Warning: 1 parsing failure.
row col   expected    actual                            file
 11  -- 51 columns 7 columns 'analysis/raw_data/friction.csv'
length <- read_table2(data_file[3])
Warning: 1 parsing failure.
row col   expected    actual                          file
 11  -- 51 columns 7 columns 'analysis/raw_data/length.csv'
depth <- read_table2(data_file[4])
Warning: 1 parsing failure.
row col   expected    actual                             file
 11  -- 51 columns 7 columns 'analysis/raw_data/messung3.csv'
velocity <- read_table2(data_file[5])
Warning: 1 parsing failure.
row col   expected    actual                             file
 11  -- 51 columns 7 columns 'analysis/raw_data/velocity.csv'
```

Organise the data

```
# fills empty fields

# force
data_force <- as.data.frame(force)
data_force <- melt(data_force, id = "steps")

# friction
data_friction <- as.data.frame(friction)
data_friction <- melt(data_friction, id = "steps")

# length
data_length <- as.data.frame(length)
data_length[is.na(data_length)] <- 0
data_lenght <- melt(data_length, id = "steps")

# depth
data_depth <- as.data.frame(depth)
data_depth <- melt(data_depth, id = "steps")

# velocity
data_velocity <- as.data.frame(velocity)
data_velocity[is.na(data_velocity)] <- 0
data_velocity <- melt(data_velocity, id = "steps")
```

Plot the data

```
# force
forceplot <- ggplot(data_force, aes(x = steps, y = value, colour = variable)) +
        geom_line(alpha = 0.3) +
        theme_classic() +
        labs(x = "distance [mm]", y = "force [N]",
        title = " ") +
        theme(legend.position = "none") +
```

```
        scale_colour_manual(values = wes_palette(n = 50, name =
        "Moonrise2", type = "continuous"))

# friction
frictionplot <- ggplot(data_friction, aes(x = steps, y = value, colour =
          variable)) + geom_line(alpha = 0.3) +
          theme_classic() +
          labs(x = "distance [mm]",
          y = "force [N]", title = "", colour = "Strokes") +
          theme(legend.position = "none") +
          scale_colour_manual(values = wes_palette(n = 50, name =
          "Moonrise2", type = "continuous"))

# velocity
velocityplot <- ggplot(data_velocity, aes(x = steps, y = value, colour =
          variable)) + geom_line(alpha=0.3) +
          theme_classic() +
          geom_line(alpha = 0.3) +
          labs(x = "distance [mm]", y = "velocity [mm/s]",                 title = "", colour = "Strokes") +
          theme(legend.position = "none") +
          scale_colour_manual(values = wes_palette(n = 50, name =
          "Moonrise2", type = "continuous"))

# depth
depthplot <- ggplot(data_depth, aes(x = steps, y = value, colour = variable)) +
        geom_line(alpha = 0.3) +
        theme_classic() +
        labs(x = "distance [mm]", y = "depth [mm]",
        title = "", colour = "Strokes") + theme(legend.position = "none") +
        scale_colour_manual(values = wes_palette(n = 50, name =
        "Moonrise2", type = "continuous"))

# plot all together
all <- ggarrange(forceplot, frictionplot,  velocityplot, depthplot,
    labels = c("Force", "Friction", "Velocity", "Depth"),
    ncol = 2, nrow = 2)
Warning: Removed 45 row(s) containing missing values (geom_path).

Warning: Removed 45 row(s) containing missing values (geom_path).

Warning: Removed 45 row(s) containing missing values (geom_path).
file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "all", ".pdf")
ggsave(filename = file_out, plot = all, path = dir_out, device = "pdf")
```

---

sessionInfo() and RStudio version

```
sessionInfo()
R version 4.0.2 (2020-06-22)
Platform: x86_64-w64-mingw32/x64 (64-bit)
Running under: Windows 10 x64 (build 19041)

Matrix products: default

locale:
[1] LC_COLLATE=German_Germany.1252  LC_CTYPE=German_Germany.1252
[3] LC_MONETARY=German_Germany.1252 LC_NUMERIC=C
[5] LC_TIME=German_Germany.1252
```

```
attached base packages:
[1] tools     stats     graphics  grDevices utils     datasets  methods  
[8] base     

other attached packages:
[1] chron_2.3-56      wesanderson_0.3.6 magrittr_2.0.1    ggpubr_0.4.0     
[5] reshape2_1.4.4    readr_1.4.0       ggplot2_3.3.3    

loaded via a namespace (and not attached):
 [1] tidyselect_1.1.0  xfun_0.20         purrr_0.3.4       haven_2.3.1      
 [5] carData_3.0-4     colorspace_2.0-0  vctrs_0.3.6       generics_0.1.0   
 [9] htmltools_0.5.1.1 yaml_2.2.1        rlang_0.4.10      pillar_1.4.7     
[13] foreign_0.8-81    glue_1.4.2        withr_2.4.1       DBI_1.1.1        
[17] readxl_1.3.1      lifecycle_0.2.0   plyr_1.8.6        stringr_1.4.0    
[21] munsell_0.5.0     ggsignif_0.6.0    gtable_0.3.0      cellranger_1.1.0 
[25] zip_2.1.1         evaluate_0.14     labeling_0.4.2    knitr_1.31       
[29] rio_0.5.16        forcats_0.5.1     curl_4.3          broom_0.7.4      
[33] Rcpp_1.0.6        scales_1.1.1      backports_1.2.0   abind_1.4-5      
[37] farver_2.0.3      hms_1.0.0         digest_0.6.27     stringi_1.5.3    
[41] openxlsx_4.2.3    rstatix_0.6.0     dplyr_1.0.3       cowplot_1.1.1    
[45] grid_4.0.2        cli_2.3.0         tibble_3.0.5      crayon_1.4.0     
[49] tidyr_1.1.2       car_3.0-10        pkgconfig_2.0.3   ellipsis_0.3.1   
[53] data.table_1.13.6 rstudioapi_0.13   assertthat_0.2.1  rmarkdown_2.6    
[57] R6_2.5.0          compiler_4.0.2   
```

RStudio version 1.3.1056.

END OF SCRIPT

Import SMARTTESTER datasets - artificial VS natural experiment

Ivan Calandra & Lisa Schunk

2021-02-04 15:35:31

Goal of the script

This script imports and merges all single TXT-files (strokes + sensors) produced with the Inotec Smarttester during the 'artificial VS natural' - experiment'. The experiment involved 24 samples (12 flint, 12 lydite) which have been used in four cycles (0-2000 strokes) respectively. The script will:

96. Read in the original TXT-files

97. Format and merge the data for each sample
98. Combines the data from the 24 samples into one
99. Write an XLSX-file and save an R object ready for further analysis in R

```
dir_in <- "E:/Sync/EXPERIMENTS/contact_material-experiment/DATA/INOTEC/R/raw_data"
dir_out <- "analysis/derived_data/"
```

Raw data must be located in "E:/Sync/EXPERIMENTS/contact_material-experiment/DATA/INOTEC/R/raw_data". Formatted data will be saved in "analysis/derived_data/". The knit directory for this script is the project directory.

Load packages

```
library(tidyverse)
Warning: package 'tidyverse' was built under R version 4.0.3
Warning: package 'ggplot2' was built under R version 4.0.3
Warning: package 'tibble' was built under R version 4.0.3
Warning: package 'readr' was built under R version 4.0.3
Warning: package 'dplyr' was built under R version 4.0.3
library(R.utils)
library(openxlsx)
Warning: package 'openxlsx' was built under R version 4.0.3
library(tools)
```

List all files and get names of the files

```
# List all CSV files in dir_in
TXT_files <- list.files(dir_in, pattern = "\\.txt$", recursive = TRUE, full.names = TRUE)

# Extract sample names from paths
samples_names <- dirname(dirname(dirname(TXT_files))) %>% # Path of folder 3 levels higher
             basename() %>%                 # Name of folder 3 levels higher
             unique()                       # Unique names
```

Define sensors

```
sensors <- data.frame(mess = paste0("Messung", 1:5),
                meas = c("Force", "Friction", "Depth", "Position", "Velocity"),
                unit = c("N", "N", "mm", "mm", "mm/s"))
```

Merge all files and format the data

```r
# Create named list, 1 element for each sample
sampl <- vector(mode = "list", length = length(samples_names))
names(sampl) <- samples_names

# For each sample
for (s in seq_along(samples_names)) {

  # Gets information through the path name and defines the cycle, raw material and
  # contact material
  folder <- paste0(samples_names[s], "/") %>%
           grep(TXT_files, value = TRUE) %>%
           dirname() %>%
           dirname() %>%
           unique() %>%
           basename() %>%
           strsplit(., "_")

  cycles <- sapply(folder, FUN = function(x) x[[3]])
  # Defines the number of the first stroke per cycle based on the name from the folders
  cycle_start <- gsub("-.*$", "", x = cycles) %>%
               # Converts into numeric
               as.numeric()

  # Orders the cycles
  order_cycles <- order(cycle_start)
  cycle_start <- cycle_start[order_cycles]
  cycle_start[1] <- 1
  cycles <- cycles[order_cycles]

  # Takes the information about the contact material
  cont_mat <- sapply(folder, FUN = function(x) x[[2]]) %>%
            unique()

  # Takes the information about the raw material
  raw_mat <- ifelse(grepl("FLT", names(sampl)[s]), "Flint", "Lydite")


  # Create named list, 1 element for each sensor ("Messung")
  sampl[[s]] <- vector(mode = "list", length = nrow(sensors))
  names(sampl[[s]]) <- sensors [["meas"]]

  # For each sensor ("Messung")
  for (m in seq_along(sampl[[s]])) {

    # Extract file names of all strokes for the given sensor
    # Paste sample name and slash to avoid partial matching
    s_m <- paste0(samples_names[[s]], "/") %>%
         # Extract sample "s" from all files
         grep(TXT_files, value = TRUE) %>%
         # Extract sensor "m" from sample "s"
         grep(sensors[["mess"]][m], ., value = TRUE)

    # Create named list, 1 element for each stroke bin
    sampl[[s]][[m]] <- vector(mode = "list", length = length(cycles))
    names(sampl[[s]][[m]]) <- cycles

    # For each cycle
    for (cy in seq_along(sampl[[s]][[m]])) {
```

```r
      # Extract file names of all strokes for each cycle
      s_m_cy <- grep(cycles[cy], s_m, value = TRUE)

      # Create named list, 1 element for each stroke
      sampl[[s]][[m]][[cy]] <- vector(mode = "list", length = length(s_m_cy))
      names(sampl[[s]][[m]][[cy]]) <- paste0("Stroke", seq_along(s_m_cy))

      # For each stroke
      for (st in seq_along(s_m_cy)) {

        # Read in TXT file
        sampl[[s]][[m]][[cy]][[st]] <- read.table(s_m_cy[st], skip = 4, sep = ";") %>%

          # Add columns Step based on V2 and Stroke based on "st"
          mutate(Step = V2/100000+1, Stroke = st -1 + cycle_start[cy]) %>%

          # Select columns stroke, step, V1
          select(Stroke, Step, V1)

        # Rename column V1 based on "m"
        names(sampl[[s]][[m]][[cy]][[st]])[3] <- sensors[m, "meas"]
      }

      # rbind all files per cycle
      sampl[[s]][[m]][[cy]] <- do.call(rbind, sampl[[s]][[m]][[cy]])
    }

    # rbind all cycles per sensor
    sampl[[s]][[m]] <- do.call(rbind, sampl[[s]][[m]])
  }

  # rbind all sensors per sample
  sampl[[s]] <- full_join(sampl[[s]][[1]], sampl[[s]][[2]]) %>%
    full_join(sampl[[s]][[3]]) %>%
    full_join(sampl[[s]][[4]]) %>%
    full_join(sampl[[s]][[5]]) %>%
    mutate(Sample = names(sampl)[s], Raw_material = raw_mat,
           Contact_material = cont_mat) %>%

    select(Sample, Raw_material, Contact_material, everything())
}

# rbind all samples
sampl <- do.call(rbind, sampl)
```

Save data

Format name of output file

```r
file_out <- "aVSn_inotec"
```

Write to XLSX

```r
write.xlsx(list(data = sampl, units = sensors), file = paste0(dir_out, file_out, ".xlsx"))
```

Save R object

```r
saveObject(sampl, file = paste0(dir_out, file_out, ".Rbin"))
```

sessionInfo() and RStudio version

```
sessionInfo()
R version 4.0.2 (2020-06-22)
Platform: x86_64-w64-mingw32/x64 (64-bit)
Running under: Windows 10 x64 (build 19041)

Matrix products: default

locale:
[1] LC_COLLATE=German_Germany.1252  LC_CTYPE=German_Germany.1252
[3] LC_MONETARY=German_Germany.1252 LC_NUMERIC=C
[5] LC_TIME=German_Germany.1252

attached base packages:
[1] tools     stats     graphics  grDevices utils     datasets  methods
[8] base

other attached packages:
 [1] openxlsx_4.2.3    R.utils_2.10.1    R.oo_1.24.0       R.methodsS3_1.8.1
 [5] forcats_0.5.1     stringr_1.4.0     dplyr_1.0.3       purrr_0.3.4
 [9] readr_1.4.0       tidyr_1.1.2       tibble_3.0.5      ggplot2_3.3.3
[13] tidyverse_1.3.0

loaded via a namespace (and not attached):
 [1] tidyselect_1.1.0  xfun_0.20         haven_2.3.1       colorspace_2.0-0
 [5] vctrs_0.3.6       generics_0.1.0    htmltools_0.5.1.1 yaml_2.2.1
 [9] rlang_0.4.10      pillar_1.4.7      glue_1.4.2        withr_2.4.1
[13] DBI_1.1.1         dbplyr_2.0.0      modelr_0.1.8      readxl_1.3.1
[17] lifecycle_0.2.0   munsell_0.5.0     gtable_0.3.0      cellranger_1.1.0
[21] zip_2.1.1         rvest_0.3.6       evaluate_0.14     knitr_1.31
[25] broom_0.7.4       Rcpp_1.0.6        scales_1.1.1      backports_1.2.0
[29] jsonlite_1.7.2    fs_1.5.0          hms_1.0.0         digest_0.6.27
[33] stringi_1.5.3     grid_4.0.2        cli_2.3.0         magrittr_2.0.1
[37] crayon_1.4.0      pkgconfig_2.0.3   ellipsis_0.3.1    xml2_1.3.2
[41] reprex_1.0.0      lubridate_1.7.9.2 assertthat_0.2.1  rmarkdown_2.6
[45] httr_1.4.2        rstudioapi_0.13   R6_2.5.0          compiler_4.0.2
```

RStudio version 1.3.1073.

END OF SCRIPT

Plots_aVSn-Inotec

Lisa Schunk
2021-02-14 15:51:28

Goal of the script

This script plots a sensor data in order to visualizes the measurements recorded throughout the tool function experiment.
Variables of interest are: * Penetration depth

```
dir_in <- "analysis/derived_data/aVSn/"
dir_out <- "analysis/plots"
```

Raw data must be located in ~/analysis/derived_data/aVSn/.
Formatted data will be saved in ~/analysis/plots. The knit directory for this script is the project directory.

Load packages

```
library(R.utils)
library(ggplot2)
Warning: package 'ggplot2' was built under R version 4.0.3
library(tools)
library(tidyverse)
Warning: package 'tidyverse' was built under R version 4.0.3
Warning: package 'tibble' was built under R version 4.0.3
Warning: package 'readr' was built under R version 4.0.3
Warning: package 'dplyr' was built under R version 4.0.3
library(patchwork)
Warning: package 'patchwork' was built under R version 4.0.3
library(doBy)
Warning: package 'doBy' was built under R version 4.0.3
library(ggrepel)
Warning: package 'ggrepel' was built under R version 4.0.3
library(openxlsx)
Warning: package 'openxlsx' was built under R version 4.0.3
```

Get name, path and information of the file

```
data_file <- list.files(dir_in, pattern = "\\.Rbin$", full.names = TRUE)
md5_in <- md5sum(data_file)
info_in <- data.frame(file = basename(names(md5_in)), checksum = md5_in, row.names = NULL)
```

The checksum (MD5 hashes) of the imported file is:

```
             file                         checksum
1 aVSn_inotec.Rbin e359eceee825bfc7e75789bce69e0db2
```

Load data into R object

```
imp_data <- loadObject(data_file)
str(imp_data)
'data.frame':   723904 obs. of  10 variables:
 $ Sample         : chr  "FLT4-10" "FLT4-10" "FLT4-10" "FLT4-10" ...
```

```
 $ Raw_material    : chr  "Flint" "Flint" "Flint" "Flint" ...
 $ Contact_material: chr  "bone-plate" "bone-plate" "bone-plate" "bone-plate" ...
 $ Stroke          : num  1 1 1 1 1 1 1 1 1 1 ...
 $ Step            : num  1 2 3 4 5 6 7 8 9 10 ...
 $ Force           : num  -69.1 -69 -66.8 -69.3 -69.3 ...
 $ Friction        : num  -4.7 -4.7 -23.2 -23.8 -25.2 ...
 $ Depth           : num  3.03 3.03 3.13 3.25 3.24 ...
 $ Position        : num  145 146 177 235 295 ...
 $ Velocity        : num  -2.62e-04 6.84e+01 4.61e+02 5.94e+02 6.00e+02 ...
```

The imported file is: "~/analysis/derived_data/aVSn/aVSn_inotec.Rbin"

Plot each of the selected numeric variable

Plots showing the strokes as lines

```
# plots all 2000 strokes per sample divided by 40
# splits the data in the individual 24 samples
sp <- split(imp_data, imp_data[["Sample"]])


for (i in seq_along(sp)) {
  # creates a sequence of every ~ 50th strokes
  seq_st <- seq(1, length(unique(sp[[i]][["Stroke"]])), by = 40) %>%
           c(max(unique(sp[[i]][["Stroke"]])))
  dat_i_all <- sp[[i]] %>%
             filter(Stroke %in% seq_st)
  range_depth <- range(dat_i_all[["Depth"]])
  p1 <- ggplot(data = dat_i_all, aes(x = Step, y = Depth, colour = Stroke)) +
        geom_line(aes(group = Stroke), alpha = 0.3) +
        labs(x = "Step", y = "Depth (mm)") + ylab(NULL) +
        # reverses the legend starting with 0 going to 2000 strokes
        scale_colour_continuous(trans = "reverse") +
        coord_cartesian(ylim = range_depth) +
        # changes the 'Step-number' in the x-legend
        scale_x_continuous(breaks=c(1, 4, 7, 10)) +
          theme_classic()

# plots only the first 50 strokes per sample
  dat_i_50 <- sp[[i]] %>%
            # takes only the first 50 strokes per sample
            filter(Stroke %in% 1:50)
  p2 <- ggplot(data = dat_i_50) +
        geom_line(aes(x = Step, y = Depth, colour = Stroke, group = Stroke), alpha = 0.3) +
        labs(x = "Step", y = "Depth (mm)") +
        scale_colour_continuous(trans = "reverse") +
        coord_cartesian(ylim = range_depth) +
        scale_x_continuous(breaks=c(1, 4, 7, 10)) +
          theme_classic()
  # patchwork plot
  p <- p2 + p1 + plot_annotation(title = names(sp)[i])

  # save to PDF
  file_out <- paste0(file_path_sans_ext(info_in[["file"]]),
                    "_aVSn_plot_",
                     names(sp)[i], ".pdf")
  ggsave(filename = file_out, plot = p, path = dir_out,
       device = "pdf")
}
Warning: Removed 9 row(s) containing missing values (geom_path).
```

Plot showing the absolut penetration depths

Plot of all samples

```
# calculates the absolute depths reached per sample
abs.depth <- function(x) {
  noNA <- x[!is.na(x)]
  out <- abs(min(noNA) - max(noNA))
}

# Define grouping variable and compute the summary statistics
depth <- summaryBy(Depth ~ Sample+Raw_material+Contact_material,
                   data=imp_data,
                   FUN=abs.depth)

str(depth)
'data.frame':   24 obs. of  4 variables:
 $ Sample          : chr  "FLT4-10" "FLT4-11" "FLT4-12" "FLT4-13" ...
 $ Raw_material    : chr  "Flint" "Flint" "Flint" "Flint" ...
 $ Contact_material: chr  "bone-plate" "skin-pad" "skin-pad" "skin-pad" ...
 $ Depth.abs.depth : num  1.37 1.69 1.54 1.31 3.65 ...
depth[["Contact_material"]] <- factor(depth[["Contact_material"]])
# GrandBudapest1 = c("#F1BB7B", "#FD6467", "#5B1A18", "#D67236")
custom.col3 <- data.frame(type = levels(depth$Contact_material),
                          col = c("#F1BB7B", "#FD6467", "#5B1A18", "#D67236"))
depth$col <- custom.col3[depth$Contact_material, "col"]


# plots all depth points in one facet plot (contact material together)
p3 <- ggplot(data = depth, aes(x = Contact_material,
                               y = Depth.abs.depth, colour =
                                 Contact_material)) +
       geom_point() + labs(y = "Absolute depth (mm)") +
       scale_colour_manual(values = custom.col3$col) +
       facet_wrap(~Raw_material, strip.position = "bottom") +
       # avoids overplotting of the labels (sample IDs)
       geom_text_repel(aes(label=Sample), size = 2,
                       nudge_x = -0.4,
                       segment.size = 0.1, force = 2,
                       seed = 123) +
       scale_y_continuous(trans = "reverse") +
       scale_x_discrete(position="top") +
       # removes the "_" between "Contact_material in the legend
       labs(x = "Contact material") +
         theme_classic() +
       theme(legend.position = "none")


# save to PDF
file_out <- paste0(file_path_sans_ext(info_in[["file"]]),
                   "_aVSn_P3_depth_plot_", ".pdf")
ggsave(filename = file_out, plot = p3, path = dir_out,
       device = "pdf",
       width = 25, height = 17, units = "cm")


depth[["Raw_material"]] <- factor(depth[["Raw_material"]])
#Royal1 = c("#899DA4", "#C93312", "#FAEFD1", "#DC863B")
custom.col7 <- data.frame(type = levels(depth$Raw_material),
                          col = c("#899DA4", "#DC863B"))
depth$col <- custom.col7[depth$Raw_material, "col"]
```

```r
# plots all depth points in one facet plot (contact material separated)
p4 <- ggplot(data = depth, aes(x = Contact_material,
                              y = Depth.abs.depth, colour =
                               Raw_material)) +
      geom_point() + labs(y = "Absolute depth (mm)") +
      scale_colour_manual(values = custom.col7$col) +
      facet_wrap(~Contact_material, strip.position = "bottom") +
      # avoids overplotting of the labels (sample IDs)
      geom_text_repel(aes(label=Sample), size = 2,
                      nudge_x = -0.4,
                      segment.size = 0.1, force = 2,
                      seed = 123) +
      scale_y_continuous(trans = "reverse") +
      scale_x_discrete(position="top") +
      # removes the "_" between "Contact_material in the legend
      labs(x = "Contact material") +
        theme_classic() +
      theme(axis.text.x = element_blank(), axis.ticks = element_blank()) +
      theme(legend.position = "none")

# save to PDF
file_out <- paste0(file_path_sans_ext(info_in[["file"]]),
                   "_aVSn_P4_depth_plot_", ".pdf")
ggsave(filename = file_out, plot = p4, path = dir_out,
      device = "pdf",
      width = 25, height = 17, units = "cm")
```

The files will be saved as "~/analysis/plots.[ext]".

Show plot files information

```r
info_out <- list.files(path = dir_out, pattern = "\\.pdf$",
                      full.names = TRUE) %>%
           md5sum()
```

The checksum (MD5 hashes) of the exported files are:

```
analysis/plots/aVSn_inotec_aVSn_P3_depth_plot_.pdf
              "578b9c4f793a8ade0581eb55b0cf4204"
analysis/plots/aVSn_inotec_aVSn_P4_depth_plot_.pdf
              "ee495bac76d9d90a4f2696809330373c"
  analysis/plots/aVSn_inotec_aVSn_plot_FLT4-10.pdf
              "7e2a5ea62d1612b70c66a7f870c08130"
  analysis/plots/aVSn_inotec_aVSn_plot_FLT4-11.pdf
              "25c5a4b05a165f93b96358e53fb4ebca"
  analysis/plots/aVSn_inotec_aVSn_plot_FLT4-12.pdf
              "a6828c8723294ea9eb5fc6e6296de3cb"
  analysis/plots/aVSn_inotec_aVSn_plot_FLT4-13.pdf
              "31f7eff8e9194175908e7502653a14dc"
  analysis/plots/aVSn_inotec_aVSn_plot_FLT4-14.pdf
              "a1cf3d6abac46448c9c4d47a2e7efcb2"
  analysis/plots/aVSn_inotec_aVSn_plot_FLT4-15.pdf
              "34aecfd2480ca39762f3f713d21aaf36"
   analysis/plots/aVSn_inotec_aVSn_plot_FLT4-4.pdf
              "49be9d766a0252a8ed1325d4607c72aa"
   analysis/plots/aVSn_inotec_aVSn_plot_FLT4-5.pdf
              "b9d1fe3cd75675cf984343c7bea81192"
   analysis/plots/aVSn_inotec_aVSn_plot_FLT4-6.pdf
              "3bcf520863416f90c40844c4d8276d05"
```

analysis/plots/aVSn_inotec_aVSn_plot_FLT4-7.pdf
"a9dcd826cdaf5d3daa39afdd3c2add1b"
analysis/plots/aVSn_inotec_aVSn_plot_FLT4-8.pdf
"1d7f8b29dac1861d160408f351fe71d0"
analysis/plots/aVSn_inotec_aVSn_plot_FLT4-9.pdf
"f18f74d2dfcd0fe5c93e4747529c1d88"
analysis/plots/aVSn_inotec_aVSn_plot_LYDIT4-1.pdf
"faa2ecda757325c999af29beb5c9fa0d"
analysis/plots/aVSn_inotec_aVSn_plot_LYDIT4-10.pdf
"78f5bc2c241955f1e90c319e3c21f183"
analysis/plots/aVSn_inotec_aVSn_plot_LYDIT4-11.pdf
"ed284520441e4dedad5e2b2e12677ea4"
analysis/plots/aVSn_inotec_aVSn_plot_LYDIT4-12.pdf
"38d04a43fc76e512ecdf5523096b436f"
analysis/plots/aVSn_inotec_aVSn_plot_LYDIT4-2.pdf
"074722ce2494f383d6de4cfce501ddbd"
analysis/plots/aVSn_inotec_aVSn_plot_LYDIT4-3.pdf
"7025c3114c14fc0d6e7286abcfcf7daf"
analysis/plots/aVSn_inotec_aVSn_plot_LYDIT4-4.pdf
"1d88c1e75794057ca0489434db736123"
analysis/plots/aVSn_inotec_aVSn_plot_LYDIT4-5.pdf
"b153abe3d6334f0005d0c17514442083"
analysis/plots/aVSn_inotec_aVSn_plot_LYDIT4-6.pdf
"006cb6d344e0423879df29fd281d8ba2"
analysis/plots/aVSn_inotec_aVSn_plot_LYDIT4-7.pdf
"00a66f28cb97efc5de7fcfedc15e9ed5"
analysis/plots/aVSn_inotec_aVSn_plot_LYDIT4-8.pdf
"f72fac56bce31f1a30f3be4c3b9bb21b"
analysis/plots/aVSn_inotec_aVSn_plot_LYDIT4-9.pdf
"042c2f60a7eb586b274ce883717f8e97"
analysis/plots/aVSn_inotec_P3_depth_plot.pdf
"3da906dae4635c7209e14e67f9e833d7"
analysis/plots/aVSn_inotec_P4_depth_plot.pdf
"3da906dae4635c7209e14e67f9e833d7"
analysis/plots/TFE_inotec_P3_depth_plot.pdf
"0814b442a4177230be87ae4ca7f3a279"
analysis/plots/TFE_inotec_P4_depth_plot.pdf
"925a84d760ece763e501a74bc58d1a5a"
analysis/plots/TFE_inotec_plot_FLT8-1.pdf
"2e11ffd5bb061002c579d659f5900f37"
analysis/plots/TFE_inotec_plot_FLT8-10.pdf
"844c49e67400c56b52ede77d08a8d960"
analysis/plots/TFE_inotec_plot_FLT8-11.pdf
"f3cb6430cedc040e4b2504d7be0ff736"
analysis/plots/TFE_inotec_plot_FLT8-12.pdf
"5b8d2632ecce009afa338dec3a1b3038"
analysis/plots/TFE_inotec_plot_FLT8-2.pdf
"a682d96c68117f70075c88c622004a7f"
analysis/plots/TFE_inotec_plot_FLT8-3.pdf
"c9aeb8f9f015f960c5c3677c41065bd9"
analysis/plots/TFE_inotec_plot_FLT8-4.pdf
"e5f31cb4c22dedadee08b4b6d58a71c7"
analysis/plots/TFE_inotec_plot_FLT8-5.pdf
"53222cf7a5a2d204c2e523aa4d9ac796"
analysis/plots/TFE_inotec_plot_FLT8-6.pdf
"43773551a81710efb3c6ed8191485661"
analysis/plots/TFE_inotec_plot_FLT8-7.pdf
"2e88961092c5ce0a9c07764b0834b01b"
analysis/plots/TFE_inotec_plot_FLT8-8.pdf
"5fd05d4c131c1f0ee080f700e6c86692"
analysis/plots/TFE_inotec_plot_FLT8-9.pdf

```
        "1b9cf37ea13ced927cc96e8b80ffc31c"
 analysis/plots/TFE_inotec_plot_LYDIT5-10.pdf
        "a642ad9b558f60597592c0c26080b83d"
 analysis/plots/TFE_inotec_plot_LYDIT5-11.pdf
        "116ee13ff0f44e9e657b4c4260e565da"
 analysis/plots/TFE_inotec_plot_LYDIT5-12.pdf
        "a4dc9ac9d8edcfe407bd07121c49d511"
 analysis/plots/TFE_inotec_plot_LYDIT5-13.pdf
        "935c35e03c71b5d770e96bc1c9e539e4"
  analysis/plots/TFE_inotec_plot_LYDIT5-2.pdf
        "57c084396c3e1cebb6ea52d2fa536ad0"
  analysis/plots/TFE_inotec_plot_LYDIT5-3.pdf
        "005f048a73e4568737daa13c542308a0"
  analysis/plots/TFE_inotec_plot_LYDIT5-4.pdf
        "628c34d00fe5087b516d9da6057ae9b3"
  analysis/plots/TFE_inotec_plot_LYDIT5-5.pdf
        "ed613efc636032e446378112c3735d26"
  analysis/plots/TFE_inotec_plot_LYDIT5-6.pdf
        "bff0fc0414e095379ef55ab59d1ee59c"
  analysis/plots/TFE_inotec_plot_LYDIT5-7.pdf
        "793860886f9ed409efa20a81599ddb8f"
  analysis/plots/TFE_inotec_plot_LYDIT5-8.pdf
        "4eb2a9d6ac929f232ad3b817eedec240"
  analysis/plots/TFE_inotec_plot_LYDIT5-9.pdf
        "8c8b7468fd9db5d4db790728ff166f66"
```

---

sessionInfo() and RStudio version

```
sessionInfo()
R version 4.0.2 (2020-06-22)
Platform: x86_64-w64-mingw32/x64 (64-bit)
Running under: Windows 10 x64 (build 19041)

Matrix products: default

locale:
[1] LC_COLLATE=German_Germany.1252  LC_CTYPE=German_Germany.1252
[3] LC_MONETARY=German_Germany.1252 LC_NUMERIC=C
[5] LC_TIME=German_Germany.1252

attached base packages:
[1] tools     stats     graphics  grDevices utils     datasets  methods
[8] base

other attached packages:
 [1] openxlsx_4.2.3    ggrepel_0.9.1     doBy_4.6.8        patchwork_1.1.1
 [5] forcats_0.5.1     stringr_1.4.0     dplyr_1.0.3       purrr_0.3.4
 [9] readr_1.4.0       tidyr_1.1.2       tibble_3.0.5      tidyverse_1.3.0
[13] ggplot2_3.3.3     R.utils_2.10.1    R.oo_1.24.0       R.methodsS3_1.8.1

loaded via a namespace (and not attached):
 [1] Rcpp_1.0.6        lubridate_1.7.9.2 lattice_0.20-41   assertthat_0.2.1
 [5] digest_0.6.27     R6_2.5.0          cellranger_1.1.0  backports_1.2.0
 [9] reprex_1.0.0      evaluate_0.14     httr_1.4.2        pillar_1.4.7
[13] rlang_0.4.10      readxl_1.3.1      rstudioapi_0.13   Matrix_1.2-18
[17] rmarkdown_2.6     labeling_0.4.2    munsell_0.5.0     broom_0.7.4
[21] compiler_4.0.2    Deriv_4.1.2       modelr_0.1.8      xfun_0.20
[25] pkgconfig_2.0.3   htmltools_0.5.1.1 tidyselect_1.1.0  crayon_1.4.0
[29] dbplyr_2.0.0      withr_2.4.1       MASS_7.3-53       grid_4.0.2
```

```
[33] jsonlite_1.7.2    gtable_0.3.0      lifecycle_0.2.0   DBI_1.1.1
[37] magrittr_2.0.1    scales_1.1.1      zip_2.1.1         cli_2.3.0
[41] stringi_1.5.3     farver_2.0.3      fs_1.5.0          xml2_1.3.2
[45] ellipsis_0.3.1    generics_0.1.0    vctrs_0.3.6       glue_1.4.2
[49] hms_1.0.0         yaml_2.2.1        colorspace_2.0-0  rvest_0.3.6
[53] knitr_1.31        haven_2.3.1
```

RStudio version 1.3.1073.

END OF SCRIPT

Import CSV from ConfoMap ISO25178 - 'artificial VS natural' - experiment

Lisa Schunk

2021-02-04 17:18:08

Goal of the script

This script formats the output of the resulting CSV-file from applying a template computing ISO 25178 parameters in ConfoMap. The script will:

100. Read in the original CSV-file

101. Format the data

102. Write an XLSX-file and save an R object ready for further analysis in R

```
dir_in <- "analysis/raw_data"
dir_out <- "analysis/derived_data/"
```

Raw data must be located in ~/analysis/raw_data.
Formatted data will be saved in ~/analysis/derived_data/.

The knit directory for this script is the project directory.

Load packages

```
library(openxlsx)
Warning: package 'openxlsx' was built under R version 4.0.3
library(tools)
library(R.utils)
library(chron)
```

Get names, path and information of the file

```
data_file <- list.files(dir_in, pattern = "\\.csv$", full.names = TRUE)
md5_in <- md5sum(data_file)
info_in <- data.frame(file = basename(names(md5_in)), checksum = md5_in, row.names = NULL)
```

The checksum (MD5 hashes) of the imported file are:

```
          file                         checksum
1 AvsN_pro.csv 2146aa42863f079e7aa558deabdf7f20
```

Read in original CSV-file

```
imp_data <- read.csv(data_file, header = FALSE, stringsAsFactors = FALSE,
                     na.strings = "*****")
str(imp_data)
'data.frame':   63 obs. of  100 variables:
 $ V1  : chr  "#" "#" "#" "17.08.2020" ...
 $ V2  : chr  "#" "#" "#" "14:48:58" ...
 $ V3  : chr  "#" "#" "#" "C:\\Users\\schunk\\Documents\\USE-
```

```
WEAR\\experiment\\artificail_VS_natural\\ConfoMap\\AvsN_pro --- AvsN_50x_res "| __truncated__ ...
 $ V4  : chr  "OPERATOR:1" "X-axis rotation angle" "°" "-0.937506084" ...
 $ V5  : chr  "OPERATOR:1" "Y-axis rotation angle" "°" "-5.006628584" ...
 $ V6  : chr  "OPERATOR:2" "a0" "nm" "-109.4976081" ...
 $ V7  : chr  "OPERATOR:2" "ax" "nm" "1.061666448" ...
 $ V8  : chr  "OPERATOR:2" "ax2" "nm" "-0.000560662" ...
 $ V9  : chr  "OPERATOR:2" "ax3" "nm" "-2.47E-07" ...
 $ V10 : chr  "OPERATOR:2" "ay" "nm" "-0.891326241" ...
 $ V11 : chr  "OPERATOR:2" "axy" "nm" "-0.001559154" ...
 $ V12 : chr  "OPERATOR:2" "ax2y" "nm" "1.24E-06" ...
 $ V13 : chr  "OPERATOR:2" "ay2" "nm" "0.002241266" ...
 $ V14 : chr  "OPERATOR:2" "axy2" "nm" "-5.34E-08" ...
 $ V15 : chr  "OPERATOR:2" "ay3" "nm" "-1.09E-06" ...
 $ V16 : chr  "6" "Name" "<no unit>" "AvsN_50x_res --- FLT4-12 - 2000_strokes - FLT4-12_2000_B1-01-
a_50x09_LSM_Topo" ...
 $ V17 : chr  "6" "Created on" "<no unit>" "7/20/2020 2:39:46 PM" ...
 $ V18 : chr  "6" "Studiable type" "<no unit>" "Surface" ...
 $ V19 : chr  "6" "Axis name - X" "<no unit>" "X" ...
 $ V20 : chr  "6" "Axis length - X" "µm" "255.4748056" ...
 $ V21 : chr  "6" "Axis size - X" "points" "1198" ...
 $ V22 : chr  "6" "Axis spacing - X" "µm" "0.213429245" ...
 $ V23 : chr  "6" "Axis name - Y" "<no unit>" "Y" ...
 $ V24 : chr  "6" "Axis length - Y" "µm" "255.4748056" ...
 $ V25 : chr  "6" "Axis size - Y" "points" "1198" ...
 $ V26 : chr  "6" "Axis spacing - Y" "µm" "0.213429245" ...
 $ V27 : chr  "6" "Axis name - Z" "<no unit>" "Z" ...
 $ V28 : chr  "6" "Layer type - Z" "<no unit>" "Topography" ...
 $ V29 : chr  "6" "Axis length - Z" "nm" "27287.04725" ...
 $ V30 : chr  "6" "Axis size - Z" "digits" "63694" ...
 $ V31 : chr  "6" "Axis spacing - Z" "nm" "0.428408441" ...
 $ V32 : chr  "6" "NM-points ratio - Z" "%" "0" ...
 $ V33 : chr  "8" "Name" "<no unit>" "AvsN_50x_res --- FLT4-12 - 2000_strokes - FLT4-12-2000-B1-01-
a_50x09_LSM_Topo > Leveled (LS-plane)" ...
 $ V34 : chr  "8" "Created on" "<no unit>" "7/20/2020 2:39:46 PM" ...
 $ V35 : chr  "8" "Studiable type" "<no unit>" "Surface" ...
 $ V36 : chr  "8" "Axis name - X" "<no unit>" "X" ...
 $ V37 : chr  "8" "Axis length - X" "µm" "255.4748056" ...
 $ V38 : chr  "8" "Axis size - X" "points" "1198" ...
 $ V39 : chr  "8" "Axis spacing - X" "µm" "0.213429245" ...
 $ V40 : chr  "8" "Axis name - Y" "<no unit>" "Y" ...
 $ V41 : chr  "8" "Axis length - Y" "µm" "255.4748056" ...
 $ V42 : chr  "8" "Axis size - Y" "points" "1198" ...
 $ V43 : chr  "8" "Axis spacing - Y" "µm" "0.213429245" ...
 $ V44 : chr  "8" "Axis name - Z" "<no unit>" "Z" ...
 $ V45 : chr  "8" "Layer type - Z" "<no unit>" "Topography" ...
 $ V46 : chr  "8" "Axis length - Z" "nm" "9299.462032" ...
 $ V47 : chr  "8" "Axis size - Z" "digits" "21707" ...
 $ V48 : chr  "8" "Axis spacing - Z" "nm" "0.428408441" ...
 $ V49 : chr  "8" "NM-points ratio - Z" "%" "0" ...
 $ V50 : chr  "15" "Name" "<no unit>" "AvsN_50x_res --- FLT4-12 - 2000_strokes - FLT4-12-2000-B1-01-
a_50x09_LSM_Topo > Leveled (LS-plane) > Form remov"| __truncated__ ...
 $ V51 : chr  "15" "Created on" "<no unit>" "7/20/2020 2:39:46 PM" ...
 $ V52 : chr  "15" "Studiable type" "<no unit>" "Surface" ...
 $ V53 : chr  "15" "Axis name - X" "<no unit>" "X" ...
 $ V54 : chr  "15" "Axis length - X" "µm" "255.4748056" ...
 $ V55 : chr  "15" "Axis size - X" "points" "1198" ...
 $ V56 : chr  "15" "Axis spacing - X" "µm" "0.213429245" ...
 $ V57 : chr  "15" "Axis name - Y" "<no unit>" "Y" ...
 $ V58 : chr  "15" "Axis length - Y" "µm" "255.4748056" ...
 $ V59 : chr  "15" "Axis size - Y" "points" "1198" ...
 $ V60 : chr  "15" "Axis spacing - Y" "µm" "0.213429245" ...
```

```
 $ V61 : chr  "15" "Axis name - Z" "<no unit>" "Z" ...
 $ V62 : chr  "15" "Layer type - Z" "<no unit>" "Topography" ...
 $ V63 : chr  "15" "Axis length - Z" "nm" "1869.720096" ...
 $ V64 : chr  "15" "Axis size - Z" "digits" "436434" ...
 $ V65 : chr  "15" "Axis spacing - Z" "nm" "0.004284084" ...
 $ V66 : chr  "15" "NM-points ratio - Z" "%" "0" ...
 $ V67 : chr  "17" "Sq" "nm" "160.4154563" ...
 $ V68 : chr  "17" "Ssk" "<no unit>" "-0.019911014" ...
 $ V69 : chr  "17" "Sku" "<no unit>" "6.207775635" ...
 $ V70 : chr  "17" "Sp" "nm" "1153.339785" ...
 $ V71 : chr  "17" "Sv" "nm" "716.3803112" ...
 $ V72 : chr  "17" "Sz" "nm" "1869.720096" ...
 $ V73 : chr  "17" "Sa" "nm" "115.8251049" ...
 $ V74 : chr  "17" "Smr (c = 1000 nm below highest peak)" "%" "12.72158775" ...
 $ V75 : chr  "17" "Smc (p = 10.00%)" "nm" "176.6360143" ...
 $ V76 : chr  "17" "Sxp (p = 50.00%  q = 97.50%)" "nm" "361.6088233" ...
 $ V77 : chr  "17" "Sal (s = 0.2000)" "µm" "5.942806298" ...
 $ V78 : chr  "17" "Str (s = 0.2000)" "<no unit>" "0.074639606" ...
 $ V79 : chr  "17" "Std (Reference angle = 0.000°)" "°" "169.9923278" ...
 $ V80 : chr  "17" "Sdq" "<no unit>" "0.101921542" ...
 $ V81 : chr  "17" "Sdr" "%" "0.513152846" ...
 $ V82 : chr  "17" "Vm (p = 10.00%)" "µm³/µm²" "0.010292594" ...
 $ V83 : chr  "17" "Vv (p = 10.00%)" "µm³/µm²" "0.186930291" ...
 $ V84 : chr  "17" "Vmp (p = 10.00%)" "µm³/µm²" "0.010292594" ...
 $ V85 : chr  "17" "Vmc (p = 10.00%  q = 80.00%)" "µm³/µm²" "0.118834303" ...
 $ V86 : chr  "17" "Vvc (p = 10.00%  q = 80.00%)" "µm³/µm²" "0.163649655" ...
 $ V87 : chr  "17" "Vvv (p = 80.00%)" "µm³/µm²" "0.023280636" ...
 $ V88 : chr  "18" "Maximum depth of furrows" "nm" "905.167059" ...
 $ V89 : chr  "18" "Mean depth of furrows" "nm" "256.5225098" ...
 $ V90 : chr  "18" "Mean density of furrows" "cm/cm2" "3081.213006" ...
 $ V91 : chr  "19" "First direction" "°" "168.8479242" ...
 $ V92 : chr  "19" "Second direction" "°" "179.9943855" ...
 $ V93 : chr  "19" "Third direction" "°" "134.9997734" ...
 $ V94 : chr  "20" "Isotropy" "%" "6.160986338" ...
 $ V95 : chr  "21" "Length-scale anisotropy (Sfrax) (epLsar)" "<no unit>" "0.003555407" ...
 $ V96 : chr  "21" "Length-scale anisotropy (NewEplsar)" "<no unit>" "0.0187295" ...
 $ V97 : chr  "22" "Fractal complexity (Asfc)" "<no unit>" "1.144764694" ...
 $ V98 : chr  "22" "Scale of max complexity (Smfc)" "µm²" "3.08161037" ...
 $ V99 : chr  "22" "HAsfc9 (HAsfc9)" "<no unit>" "0.200797063" ...
  [list output truncated]
```

Format data

Keep only interesting columns and rows

```r
# keeps only the columns and rows of interest for the analysis
data_keep_col <- c(1:2, 16:17, 20:22, 24:26, 29:32, 67:100)
data_keep_rows <- which(imp_data[[1]] != "#")
data_keep <- imp_data[data_keep_rows, data_keep_col]
```

Add headers

```r
head_data_keep <- unlist(imp_data[2, data_keep_col])
colnames(data_keep) <- gsub("\\.+", "\\.", make.names(head_data_keep))
colnames(data_keep) <- gsub("\\.$", "", colnames(data_keep))
```

Identify results using frame numbers

```r
# combines the results from the different analysis based on the column numbers
# (ID from MountainsMAp)
frames <- as.numeric(unlist(imp_data[1, data_keep_col]))
```

```
Warning: NAs introduced by coercion
ID <- which(frames == 6)[-(1:2)]
ISO <- which(frames == 17)
furrow <- which(frames == 18)
diriso <- which(frames %in% 19:20)
SSFA <- which(frames %in% 21:22)
```

Shorten the names for parameters

```
# keeps only the important information of the headers
colnames(data_keep)[ISO] <- sapply(strsplit(names(data_keep)[ISO], ".", fixed = TRUE),
                                   `[[`, 1)
colnames(data_keep)[SSFA] <- gsub("^([A-Za-z0-9]+\\.)+", "", colnames(data_keep)[SSFA])
```

Save units

```
# takes the units which were part of the headers and separates them; creates a data frame
var_num <- c(ID, ISO, furrow, diriso, SSFA)
# extracts 'unit' line for considered columns
units_var <- unlist(imp_data[3, data_keep_col])[var_num]
# gets names associated to the units
names(units_var) <- head_data_keep[var_num]
# puts all of it into a data.frame
units_var_table <- data.frame(variable = names(units_var), unit = units_var)
```

Convert to numeric

```
for (i in var_num) data_keep[[i]] <- as.numeric(data_keep[[i]])
```

Split the column ‘Name’ into several columns

```
# these lines extract the artefact ID out of the path name
stud_name <- gsub("^([A-Za-z0-9_]+( --- ))+", "", data_keep[["Name"]])
stud_name <- gsub("([A-Za-z0-9_-]*( - ))+", "", stud_name)
split_name <- do.call(rbind, strsplit(stud_name, "_"))[, 1:4]
split_loc <- do.call(rbind, strsplit(split_name[, 3], "-"))

# splits the ID in the separat information
data_final <- data.frame(split_name[, -3], split_loc, data_keep[-3],
                         stringsAsFactors = FALSE)
colnames(data_final)[1:9] <- c("Sample", "Cycle","Objective", "Location", "Area", "Spot",
                               "Analysis.date", "Analysis.time", "Acquisition.date.time")

# orders the the column cycle so that 'before' comes before '2000'
data_final[["Cycle"]] <- factor(data_final[["Cycle"]], labels=c("before","2000"))
```

Format date and time columns

```
data_final[["Analysis.date"]] <- as.Date(data_final[["Analysis.date"]],
                                         format = "%d.%m.%Y")
data_final[["Analysis.time"]] <- times(data_final[["Analysis.time"]])
```

The column `data_final[["Acquisition.date.time"]]` includes several formats and is therefore left as `character` without convertion to `POSIXct`.

Add columns about site, contact material and correct 50x objectives’ NAs

```
# extracts the raw material based on the ID
data_final[grep("FLT4-", data_final[["Sample"]]), "Raw.material"] <- "flint"
data_final[grep("LYDIT4-", data_final[["Sample"]]), "Raw.material"] <- "lydite"
data_final[["Raw.material"]] <- factor(data_final[["Raw.material"]])

# adds the contact/worked material
data_final[grep("LYDIT4-1", data_final[["Sample"]]), "Contact.material"] <- "pork skin"
data_final[grep("LYDIT4-2", data_final[["Sample"]]), "Contact.material"] <- "bone plate"
```

```r
data_final[grep("LYDIT4-5", data_final[["Sample"]]), "Contact.material"] <- "bos scapula"
data_final[grep("LYDIT4-9", data_final[["Sample"]]), "Contact.material"] <- "skin pad"

data_final[grep("FLT4-4", data_final[["Sample"]]), "Contact.material"] <- "pork skin"
data_final[grep("FLT4-5", data_final[["Sample"]]), "Contact.material"] <- "bone plate"
data_final[grep("FLT4-15", data_final[["Sample"]]), "Contact.material"] <- "bos scapula"
data_final[grep("FLT4-12", data_final[["Sample"]]), "Contact.material"] <- "skin pad"

# corrects information about the used objectives
data_final[data_final[["Objective"]] == "50x09", "Objective"] <- "50x095"
data_final[data_final[["Objective"]] == "50x07", "Objective"] <- "50x075"
data_final[["Objective"]] <- factor(data_final[["Objective"]])
```

Ignore some columns and reorder columns

```r
data_final <- data_final[c(1:2, 4:6, 3, 54:55, 7:9, 10:53)]
```

Add units as comment()

```r
comment(data_final) <- units_var
```

Type comment(data_final) to check the units of the columns.

Check the result

```r
str(data_final)
'data.frame':   60 obs. of  55 variables:
 $ Sample               : chr  "FLT4-12" "FLT4-12" "FLT4-12" "FLT4-12" ...
 $ Cycle                : Factor w/ 2 levels "before","2000": 1 1 1 2 2 2 1 1 1 1 ...
 $ Location             : chr  "B1" "B1" "B1" "B1" ...
 $ Area                 : chr  "01" "01" "01" "01" ...
 $ Spot                 : chr  "a" "b" "c" "a" ...
 $ Objective            : Factor w/ 2 levels "50x075","50x095": 2 2 2 2 2 2 1 1 1 1 ...
 $ Raw.material         : Factor w/ 2 levels "flint","lydite": 1 1 1 1 1 1 1 1 1 1 ...
 $ Contact.material     : chr  "skin pad" "skin pad" "skin pad" "skin pad" ...
 $ Analysis.date        : Date, format: "2020-08-17" "2020-08-17" ...
 $ Analysis.time        : 'times' num  14:48:58 14:49:34 14:50:09 14:50:43 14:51:18 ...
  ..- attr(*, "format")= chr "h:m:s"
 $ Acquisition.date.time : chr  "7/20/2020 2:39:46 PM" "7/20/2020 2:55:08 PM" "7/20/2020 3:12:51 PM" "7/20/2020 3:29:51 PM" ...
 $ Axis.length.X        : num  255 255 255 255 255 ...
 $ Axis.size.X          : num  1198 1198 1198 1198 1198 ...
 $ Axis.spacing.X       : num  0.213 0.213 0.213 0.213 0.213 ...
 $ Axis.length.Y        : num  255 255 255 255 255 ...
 $ Axis.size.Y          : num  1198 1198 1198 1198 1198 ...
 $ Axis.spacing.Y       : num  0.213 0.213 0.213 0.213 0.213 ...
 $ Axis.length.Z        : num  27287 27231 26655 13395 13291 ...
 $ Axis.size.Z          : num  63694 65201 63762 65466 65538 ...
 $ Axis.spacing.Z       : num  0.428 0.418 0.418 0.205 0.203 ...
 $ NM.points.ratio.Z    : num  0 0 0 0 0 0 0 0 0 0 ...
 $ Sq                   : num  160 151 196 227 160 ...
 $ Ssk                  : num  -0.0199 4.1704 2.0253 2.2084 2.0238 ...
 $ Sku                  : num  6.21 37.01 10.42 11.22 9.9 ...
 $ Sp                   : num  1153 1693 1606 1740 1174 ...
 $ Sv                   : num  716 594 406 473 321 ...
 $ Sz                   : num  1870 2286 2013 2212 1496 ...
 $ Sa                   : num  115.8 84.7 138.7 154.4 111.9 ...
 $ Smr                  : num  12.722 0.832 1.59 1.645 10.656 ...
 $ Smc                  : num  177 111 232 250 184 ...
 $ Sxp                  : num  362 192 211 245 175 ...
 $ Sal                  : num  5.94 7.73 8.18 12.2 8.71 ...
 $ Str                  : num  0.0746 0.669 0.226 0.6994 0.1989 ...
 $ Std                  : num  170 133 50.5 101 81.5 ...
```

```
 $ Sdq                   : num  0.1019 0.0833 0.1177 0.1378 0.1048 ...
 $ Sdr                   : num  0.513 0.337 0.68 0.916 0.54 ...
 $ Vm                    : num  0.0103 0.0176 0.0206 0.0263 0.0175 ...
 $ Vv                    : num  0.187 0.128 0.252 0.276 0.202 ...
 $ Vmp                   : num  0.0103 0.0176 0.0206 0.0263 0.0175 ...
 $ Vmc                   : num  0.119 0.073 0.133 0.143 0.106 ...
 $ Vvc                   : num  0.164 0.115 0.241 0.262 0.192 ...
 $ Vvv                   : num  0.0233 0.0128 0.0112 0.0138 0.0092 ...
 $ Maximum.depth.of.furrows: num  905 865 814 881 640 ...
 $ Mean.depth.of.furrows   : num  257 174 386 409 311 ...
 $ Mean.density.of.furrows : num  3081 3318 3101 3225 3191 ...
 $ First.direction         : num  1.69e+02 1.35e+02 8.76e-03 9.00e+01 9.00e+01 ...
 $ Second.direction        : num  180 90 135 135 45 ...
 $ Third.direction         : num  135 45 117 116 135 ...
 $ Isotropy                : num  6.16 66.63 52.93 77.77 55.86 ...
 $ epLsar                  : num  0.00356 0.00393 0.00189 0.00195 0.00041 ...
 $ NewEplsar               : num  0.0187 0.0188 0.0179 0.0179 0.0175 ...
 $ Asfc                    : num  1.145 0.703 1.494 2.067 1.207 ...
 $ Smfc                    : num  3.08 3.3 2.88 2.52 2.52 ...
 $ HAsfc9                  : num  0.201 0.636 0.191 0.512 0.239 ...
 $ HAsfc81                 : num  0.264 0.939 0.388 0.722 0.386 ...
 - attr(*, "comment")= Named chr [1:44] "µm" "points" "µm" "µm" ...
  ..- attr(*, "names")= chr [1:44] "Axis length - X" "Axis size - X" "Axis spacing - X" "Axis length - Y" ...
head(data_final)
   Sample  Cycle Location Area Spot Objective Raw.material Contact.material
4 FLT4-12 before       B1   01    a   50x095        flint         skin pad
5 FLT4-12 before       B1   01    b   50x095        flint         skin pad
6 FLT4-12 before       B1   01    c   50x095        flint         skin pad
7 FLT4-12   2000       B1   01    a   50x095        flint         skin pad
8 FLT4-12   2000       B1   01    b   50x095        flint         skin pad
9 FLT4-12   2000       B1   01    c   50x095        flint         skin pad
  Analysis.date Analysis.time Acquisition.date.time Axis.length.X Axis.size.X
4    2020-08-17      14:48:58  7/20/2020 2:39:46 PM      255.4748        1198
5    2020-08-17      14:49:34  7/20/2020 2:55:08 PM      255.4748        1198
6    2020-08-17      14:50:09  7/20/2020 3:12:51 PM      255.4748        1198
7    2020-08-17      14:50:43  7/20/2020 3:29:51 PM      255.4748        1198
8    2020-08-17      14:51:18  7/20/2020 3:39:33 PM      255.4748        1198
9    2020-08-17      14:51:52  7/20/2020 3:47:55 PM      255.4748        1198
  Axis.spacing.X Axis.length.Y Axis.size.Y Axis.spacing.Y Axis.length.Z
4      0.2134292      255.4748        1198      0.2134292      27287.05
5      0.2134292      255.4748        1198      0.2134292      27231.39
6      0.2134292      255.4748        1198      0.2134292      26655.09
7      0.2134292      255.4748        1198      0.2134292      13395.19
8      0.2134292      255.4748        1198      0.2134292      13291.26
9      0.2134292      255.4748        1198      0.2134292      14244.97
  Axis.size.Z Axis.spacing.Z NM.points.ratio.Z       Sq         Ssk       Sku
4       63694      0.4284084                 0 160.4155 -0.01991101  6.207776
5       65201      0.4176529                 0 151.4683  4.17044767 37.011718
6       63762      0.4180403                 0 196.2226  2.02532876 10.418268
7       65466      0.2046129                 0 226.8631  2.20835172 11.223360
8       65538      0.2028023                 0 159.8090  2.02383168  9.901026
9       64645      0.2203569                 0 189.9887  2.29069771 13.111004
        Sp       Sv       Sz        Sa        Smr      Smc      Sxp       Sal
4 1153.340 716.3803 1869.720 115.82510 12.7215877 176.6360 361.6088  5.942806
5 1692.538 593.9024 2286.441  84.67852  0.8316469 110.5102 192.3170  7.726396
6 1606.249 406.3645 2012.613 138.74817  1.5897119 231.7261 210.6213  8.177532
7 1739.966 472.5125 2212.479 154.38278  1.6447061 249.7198 244.7967 12.198919
8 1174.225 321.2997 1495.525 111.90571 10.6558448 184.0793 174.7748  8.708922
9 1622.598 467.6635 2090.262 130.13572  1.4040062 207.7138 211.0431 11.074442
         Str       Std        Sdq       Sdr         Vm        Vv        Vmp
4 0.07463961 169.99233 0.10192154 0.5131528 0.01029259 0.1869303 0.01029259
```

```
5 0.66904293 132.99310 0.08330742 0.3365565 0.01755343 0.1280688 0.01755343
6 0.22601928  50.49950 0.11769041 0.6803618 0.02061169 0.2523372 0.02061169
7 0.69940075 100.99736 0.13782886 0.9161613 0.02629832 0.2760144 0.02629832
8 0.19892219  81.50622 0.10479757 0.5401652 0.01752015 0.2015934 0.01752015
9 0.67826780  94.24986 0.13054918 0.8284018 0.02059551 0.2283117 0.02059551
         Vmc       Vvc         Vvv Maximum.depth.of.furrows
4 0.11883430 0.1636497 0.023280636                905.1671
5 0.07299844 0.1152377 0.012831053                865.2933
6 0.13337955 0.2411010 0.011236180                814.2276
7 0.14301616 0.2622196 0.013794788                880.9403
8 0.10613643 0.1923885 0.009204862                639.8412
9 0.12526862 0.2165270 0.011784722                717.2838
  Mean.depth.of.furrows Mean.density.of.furrows First.direction
4              256.5225                3081.213    1.688479e+02
5              174.1921                3317.619    1.349866e+02
6              385.6325                3100.987    8.755264e-03
7              409.4052                3224.859    9.000996e+01
8              311.0101                3191.041    8.999201e+01
9              340.8053                3283.305    9.001552e+01
  Second.direction Third.direction  Isotropy      epLsar  NewEplsar      Asfc
4     179.99438550       134.99977  6.160986 0.003555407 0.01872950 1.1447647
5      90.02579777        45.01357 66.627363 0.003931972 0.01881458 0.7029939
6     134.98022360       116.51112 52.929462 0.001892460 0.01793799 1.4940819
7     134.98616910       116.49202 77.769348 0.001947934 0.01791490 2.0674634
8      45.02479864       134.98957 55.864679 0.000409770 0.01749798 1.2071761
9       0.03831368       135.01351 74.247076 0.001553346 0.01782690 1.9125832
      Smfc    HAsfc9   HAsfc81
4 3.081610 0.2007971 0.2639337
5 3.295669 0.6356309 0.9393985
6 2.881455 0.1906289 0.3875291
7 2.519302 0.5120017 0.7218524
8 2.519302 0.2392387 0.3856592
9 2.694300 0.2599328 0.3448180
```

Save data

Format name of output file

```
file_out <- "AvsN_use-wear"
```

The files will be saved as "~/AvsN_use-wear.[ext]".

Write to XLSX

```
write.xlsx(list(data = data_final, units = units_var_table),
           file = paste0(dir_out, file_out, ".xlsx"))
```

Save R object

```
saveObject(data_final, file = paste0(dir_out, file_out, ".Rbin"))
```

---

sessionInfo() and RStudio version

```
sessionInfo()
R version 4.0.2 (2020-06-22)
Platform: x86_64-w64-mingw32/x64 (64-bit)
Running under: Windows 10 x64 (build 19041)

Matrix products: default
```

```
locale:
[1] LC_COLLATE=German_Germany.1252  LC_CTYPE=German_Germany.1252
[3] LC_MONETARY=German_Germany.1252 LC_NUMERIC=C
[5] LC_TIME=German_Germany.1252

attached base packages:
[1] tools     stats     graphics  grDevices utils     datasets  methods
[8] base

other attached packages:
[1] chron_2.3-56      R.utils_2.10.1    R.oo_1.24.0       R.methodsS3_1.8.1
[5] openxlsx_4.2.3

loaded via a namespace (and not attached):
 [1] Rcpp_1.0.6        digest_0.6.27     magrittr_2.0.1    evaluate_0.14
 [5] zip_2.1.1         rlang_0.4.10      stringi_1.5.3     rmarkdown_2.6
 [9] stringr_1.4.0     xfun_0.20         yaml_2.2.1        compiler_4.0.2
[13] htmltools_0.5.1.1 knitr_1.31
```

RStudio version 1.3.1073.

END OF SCRIPT

Summary statistics - ‘artificial VS natural’ -experiment

Lisa Schunk

2021-02-04 17:25:40

Goal of the script

This script computes standard descriptive statistics for each group.
The groups are based on:

103. Raw material
104. Cycle
105. Spots (replicas)

It computes the following statistics:

106. n (sample size = length): number of measurements
107. smallest value (min)
108. largest value (max)
109. mean
110. median
111. standard deviation (sd)

```
dir_in <- "analysis/derived_data/"
dir_out <- "analysis/summary_stats/"
```

Raw data must be located in ~/analysis/derived_data/.
Formatted data will be saved in ~/analysis/summary_stats/. The knit directory for this script is the project directory. —

Load packages

```
library(openxlsx)
Warning: package 'openxlsx' was built under R version 4.0.3
library(R.utils)
library(tools)
library(doBy)
Warning: package 'doBy' was built under R version 4.0.3
```

Get names, path and information of all files

```
data_file <- list.files(dir_in, pattern = "\\.Rbin$", full.names = TRUE)
md5_in <- md5sum(data_file)
info_in <- data.frame(file = basename(names(md5_in)), checksum = md5_in, row.names = NULL)
```

The checksum (MD5 hashes) of the imported files are:

```
                file                         checksum
1 AvsN_use-wear.Rbin 0bbb6fa72fc579f481ad716752f28d5d
```

Load data into R object

```
imp_data <- loadObject(data_file)
str(imp_data)
'data.frame':	60 obs. of  55 variables:
 $ Sample                  : chr  "FLT4-12" "FLT4-12" "FLT4-12" "FLT4-12" ...
 $ Cycle                   : Factor w/ 2 levels "before","2000": 1 1 1 2 2 2 1 1 1 1 ...
 $ Location                : chr  "B1" "B1" "B1" "B1" ...
 $ Area                    : chr  "01" "01" "01" "01" ...
 $ Spot                    : chr  "a" "b" "c" "a" ...
 $ Objective               : Factor w/ 2 levels "50x075","50x095": 2 2 2 2 2 2 1 1 1 1 ...
 $ Raw.material            : Factor w/ 2 levels "flint","lydite": 1 1 1 1 1 1 1 1 1 1 ...
 $ Contact.material        : chr  "skin pad" "skin pad" "skin pad" "skin pad" ...
 $ Analysis.date           : Date, format: "2020-08-17" "2020-08-17" ...
 $ Analysis.time           : 'times' num  0.617 0.618 0.618 0.619 0.619 ...
  ..- attr(*, "format")= chr "h:m:s"
 $ Acquisition.date.time   : chr  "7/20/2020 2:39:46 PM" "7/20/2020 2:55:08 PM" "7/20/2020 3:12:51 PM" "7/20/2020 
3:29:51 PM" ...
 $ Axis.length.X           : num  255 255 255 255 255 ...
 $ Axis.size.X             : num  1198 1198 1198 1198 1198 ...
 $ Axis.spacing.X          : num  0.213 0.213 0.213 0.213 0.213 ...
 $ Axis.length.Y           : num  255 255 255 255 255 ...
 $ Axis.size.Y             : num  1198 1198 1198 1198 1198 ...
 $ Axis.spacing.Y          : num  0.213 0.213 0.213 0.213 0.213 ...
 $ Axis.length.Z           : num  27287 27231 26655 13395 13291 ...
 $ Axis.size.Z             : num  63694 65201 63762 65466 65538 ...
 $ Axis.spacing.Z          : num  0.428 0.418 0.418 0.205 0.203 ...
 $ NM.points.ratio.Z       : num  0 0 0 0 0 0 0 0 0 0 ...
 $ Sq                      : num  160 151 196 227 160 ...
 $ Ssk                     : num  -0.0199 4.1704 2.0253 2.2084 2.0238 ...
 $ Sku                     : num  6.21 37.01 10.42 11.22 9.9 ...
 $ Sp                      : num  1153 1693 1606 1740 1174 ...
 $ Sv                      : num  716 594 406 473 321 ...
 $ Sz                      : num  1870 2286 2013 2212 1496 ...
 $ Sa                      : num  115.8 84.7 138.7 154.4 111.9 ...
 $ Smr                     : num  12.722 0.832 1.59 1.645 10.656 ...
 $ Smc                     : num  177 111 232 250 184 ...
 $ Sxp                     : num  362 192 211 245 175 ...
 $ Sal                     : num  5.94 7.73 8.18 12.2 8.71 ...
 $ Str                     : num  0.0746 0.669 0.226 0.6994 0.1989 ...
 $ Std                     : num  170 133 50.5 101 81.5 ...
 $ Sdq                     : num  0.1019 0.0833 0.1177 0.1378 0.1048 ...
 $ Sdr                     : num  0.513 0.337 0.68 0.916 0.54 ...
 $ Vm                      : num  0.0103 0.0176 0.0206 0.0263 0.0175 ...
 $ Vv                      : num  0.187 0.128 0.252 0.276 0.202 ...
 $ Vmp                     : num  0.0103 0.0176 0.0206 0.0263 0.0175 ...
 $ Vmc                     : num  0.119 0.073 0.133 0.143 0.106 ...
 $ Vvc                     : num  0.164 0.115 0.241 0.262 0.192 ...
 $ Vvv                     : num  0.0233 0.0128 0.0112 0.0138 0.0092 ...
 $ Maximum.depth.of.furrows: num  905 865 814 881 640 ...
 $ Mean.depth.of.furrows   : num  257 174 386 409 311 ...
 $ Mean.density.of.furrows : num  3081 3318 3101 3225 3191 ...
 $ First.direction         : num  1.69e+02 1.35e+02 8.76e-03 9.00e+01 9.00e+01 ...
 $ Second.direction        : num  180 90 135 135 45 ...
 $ Third.direction         : num  135 45 117 116 135 ...
 $ Isotropy                : num  6.16 66.63 52.93 77.77 55.86 ...
 $ epLsar                  : num  0.00356 0.00393 0.00189 0.00195 0.00041 ...
 $ NewEplsar               : num  0.0187 0.0188 0.0179 0.0179 0.0175 ...
 $ Asfc                    : num  1.145 0.703 1.494 2.067 1.207 ...
 $ Smfc                    : num  3.08 3.3 2.88 2.52 2.52 ...
 $ HAsfc9                  : num  0.201 0.636 0.191 0.512 0.239 ...
 $ HAsfc81                 : num  0.264 0.939 0.388 0.722 0.386 ...
```

```
 - attr(*, "comment")= Named chr [1:44] "µm" "points" "µm" "µm" ...
  ..- attr(*, "names")= chr [1:44] "Axis length - X" "Axis size - X" "Axis spacing - X" "Axis length - Y" ...
```

The imported file is: "~/analysis/derived_data/AvsN_use-wear.Rbin"

Define numeric variables

```
num.var <- 22:length(imp_data)
```

The following variables will be used:

```
[22] Sq
[23] Ssk
[24] Sku
[25] Sp
[26] Sv
[27] Sz
[28] Sa
[29] Smr
[30] Smc
[31] Sxp
[32] Sal
[33] Str
[34] Std
[35] Sdq
[36] Sdr
[37] Vm
[38] Vv
[39] Vmp
[40] Vmc
[41] Vvc
[42] Vvv
[43] Maximum.depth.of.furrows
[44] Mean.depth.of.furrows
[45] Mean.density.of.furrows
[46] First.direction
[47] Second.direction
[48] Third.direction
[49] Isotropy
[50] epLsar
[51] NewEplsar
[52] Asfc
[53] Smfc
[54] HAsfc9
[55] HAsfc81
```

Compute summary statistics

Create function to compute the statistics at once

```
nminmaxmeanmedsd <- function(x){
  y <- x[!is.na(x)]
  n_test <- length(y)
  min_test <- min(y)
  max_test <- max(y)
  mean_test <- mean(y)
  med_test <- median(y)
  sd_test <- sd(y)
  out <- c(n_test, min_test, max_test, mean_test, med_test, sd_test)
```

```r
  names(out) <- c("n", "min", "max", "mean", "median", "sd")
  return(out)
}
```

Compute the summary statistics in groups

Spots

```r
spot <- summaryBy(.~ Sample + Location + Area,
          data = imp_data[c("Sample","Location","Area" , names(imp_data)[num.var])],
          FUN = nminmaxmeanmedsd)
str(spot)
'data.frame':   10 obs. of  207 variables:
 $ Sample             : chr  "FLT4-12" "FLT4-15" "FLT4-15" "FLT4-4" ...
 $ Location           : chr  "B1" "B1" "D1" "B1" ...
 $ Area               : chr  "01" "03" "01" "01" ...
 $ Sq.n               : num  6 6 6 6 6 6 6 6 6 6
 $ Sq.min             : num  151 395 162 373 1131 ...
 $ Sq.max             : num  227 797 635 6312 3110 ...
 $ Sq.mean            : num  181 544 379 2104 1784 ...
 $ Sq.median          : num  175 521 347 460 1516 ...
 $ Sq.sd              : num  28.8 160.6 231.1 2665.2 722 ...
 $ Ssk.n              : num  6 6 6 6 6 6 6 6 6 6
 $ Ssk.min            : num  -0.0199 -0.8753 1.2672 0.5893 1.1846 ...
 $ Ssk.max            : num  4.17 2.33 4.05 1.14 3.64 ...
 $ Ssk.mean           : num  2.116 0.82 2.01 0.881 2.521 ...
 $ Ssk.median         : num  2.117 0.785 1.607 0.934 2.455 ...
 $ Ssk.sd             : num  1.33 1.04 1.061 0.221 0.852 ...
 $ Sku.n              : num  6 6 6 6 6 6 6 6 6 6
 $ Sku.min            : num  6.21 4.48 7.31 3.34 8.32 ...
 $ Sku.max            : num  37.01 15.93 29.53 8.86 31.49 ...
 $ Sku.mean           : num  14.65 7.56 14.15 6 20.77 ...
 $ Sku.median         : num  10.82 6.26 10.25 5.55 20.42 ...
 $ Sku.sd             : num  11.19 4.23 8.78 1.93 9.27 ...
 $ Sp.n               : num  6 6 6 6 6 6 6 6 6 6
 $ Sp.min             : num  1153 2063 1099 2024 11622 ...
 $ Sp.max             : num  1740 6501 4888 28679 18610 ...
 $ Sp.mean            : num  1498 3030 2827 10334 13749 ...
 $ Sp.median          : num  1614 2320 2391 2339 13190 ...
 $ Sp.sd              : num  264 1722 1807 12679 2545 ...
 $ Sv.n               : num  6 6 6 6 6 6 6 6 6 6
 $ Sv.min             : num  321 1132 679 938 3505 ...
 $ Sv.max             : num  716 3628 2397 26653 8667 ...
 $ Sv.mean            : num  496 2116 1240 8415 5774 ...
 $ Sv.median          : num  470 1997 986 1191 5097 ...
 $ Sv.sd              : num  140 832 658 11577 2280 ...
 $ Sz.n               : num  6 6 6 6 6 6 6 6 6 6
 $ Sz.min             : num  1496 3542 1778 2962 15825 ...
 $ Sz.max             : num  2286 8613 7285 55332 27123 ...
 $ Sz.mean            : num  1995 5145 4066 18749 19523 ...
 $ Sz.median          : num  2051 4528 3702 3507 18168 ...
 $ Sz.sd              : num  285 1906 2316 24229 4197 ...
 $ Sa.n               : num  6 6 6 6 6 6 6 6 6 6
 $ Sa.min             : num  84.7 286.6 114.5 279.1 668.6 ...
 $ Sa.max             : num  154 521 409 4188 2088 ...
 $ Sa.mean            : num  123 384 239 1411 1101 ...
 $ Sa.median          : num  123 374 219 358 923 ...
 $ Sa.sd              : num  24.2 96.3 131.6 1731.4 518.8 ...
 $ Smr.n              : num  6 6 6 6 6 6 6 6 6 6
 $ Smr.min            : num  0.8316 0.2624 0.3152 0.0556 0.1019 ...
 $ Smr.max            : num  12.72 2.31 20.4 2.1 0.45 ...
 $ Smr.mean           : num  4.808 1.417 4.894 1.037 0.172 ...
```

```
 $ Smr.median                  : num  1.617 1.368 1.784 1.113 0.117 ...
 $ Smr.sd                      : num  5.377 0.73 7.766 0.858 0.137 ...
 $ Smc.n                       : num  6 6 6 6 6 6 6 6 6 6
 $ Smc.min                     : num  111 429 171 467 833 ...
 $ Smc.max                     : num  250 850 524 4666 2349 ...
 $ Smc.mean                    : num  193 617 315 1891 1243 ...
 $ Smc.median                  : num  196 605 290 599 1055 ...
 $ Smc.sd                      : num  49.2 162.1 147.3 2099.4 554.4 ...
 $ Sxp.n                       : num  6 6 6 6 6 6 6 6 6 6
 $ Sxp.min                     : num  175 591 247 553 2077 ...
 $ Sxp.max                     : num  362 1432 1305 12014 6175 ...
 $ Sxp.mean                    : num  233 955 600 3720 3147 ...
 $ Sxp.median                  : num  211 924 408 648 2666 ...
 $ Sxp.sd                      : num  67.4 343.4 440.7 5003.7 1518.7 ...
 $ Sal.n                       : num  6 6 6 6 6 6 6 6 6 6
 $ Sal.min                     : num  5.94 11.46 8.22 7.85 14.14 ...
 $ Sal.max                     : num  12.2 16.9 20.2 23.6 27.6 ...
 $ Sal.mean                    : num  8.97 14.84 15.48 12.6 20.49 ...
 $ Sal.median                  : num  8.44 15.25 15.21 9.14 19.86 ...
 $ Sal.sd                      : num  2.29 2.04 4.21 6.54 5.29 ...
 $ Str.n                       : num  6 6 6 4 4 6 6 4 5 5
 $ Str.min                     : num  0.0746 0.2662 0.145 0.1212 0.2222 ...
 $ Str.max                     : num  0.699 0.769 0.74 0.501 0.728 ...
 $ Str.mean                    : num  0.424 0.483 0.374 0.248 0.487 ...
 $ Str.median                  : num  0.448 0.441 0.34 0.186 0.498 ...
 $ Str.sd                      : num  0.287 0.176 0.222 0.173 0.26 ...
 $ Std.n                       : num  6 6 6 6 6 6 6 6 6 6
 $ Std.min                     : num  50.5 159.3 32.3 102 39.2 ...
 $ Std.max                     : num  170 163.3 42.7 153.5 99 ...
 $ Std.mean                    : num  105 161.3 36 133.8 79.4 ...
 $ Std.median                  : num  97.6 161.4 36.1 147.9 81.9 ...
 $ Std.sd                      : num  41.62 2.02 3.8 24.33 21.74 ...
 $ Sdq.n                       : num  6 6 6 6 6 6 6 6 6 6
 $ Sdq.min                     : num  0.0833 0.2169 0.1096 0.2052 0.2588 ...
 $ Sdq.max                     : num  0.138 0.323 0.218 1.339 0.474 ...
 $ Sdq.mean                    : num  0.113 0.268 0.157 0.499 0.314 ...
 $ Sdq.median                  : num  0.111 0.265 0.16 0.238 0.284 ...
 $ Sdq.sd                      : num  0.0201 0.039 0.0417 0.4649 0.0811 ...
 $ Sdr.n                       : num  6 6 6 6 6 6 6 6 6 6
 $ Sdr.min                     : num  0.337 2.237 0.589 2.032 2.869 ...
 $ Sdr.max                     : num  0.916 4.365 2.171 21.441 6.269 ...
 $ Sdr.mean                    : num  0.636 3.309 1.227 7.007 3.704 ...
 $ Sdr.median                  : num  0.61 3.24 1.21 2.69 3.21 ...
 $ Sdr.sd                      : num  0.215 0.825 0.596 7.869 1.3 ...
 $ Vm.n                        : num  6 6 6 6 6 6 6 6 6 6
 $ Vm.min                      : num  0.0103 0.0284 0.0141 0.0282 0.1187 ...
 $ Vm.max                      : num  0.0263 0.0797 0.0903 0.805 0.3764 ...
 $ Vm.mean                     : num  0.0188 0.0461 0.0438 0.2363 0.2175 ...
 $ Vm.median                   : num  0.0191 0.0411 0.04 0.0352 0.172 ...
 $ Vm.sd                       : num  0.00526 0.01833 0.03238 0.33205 0.10698 ...
  [list output truncated]
```

Cycle (before & after 2000 strokes)

```
cycle <- summaryBy(.~ Cycle + Contact.material,
                   data = imp_data[c("Cycle", "Contact.material",
                                     names(imp_data)[num.var])],
                   FUN=nminmaxmeanmedsd)
str(cycle)
'data.frame':   8 obs. of  206 variables:
 $ Cycle                       : Factor w/ 2 levels "before","2000": 1 1 1 1 2 2 2 2
 $ Contact.material            : chr  "bone plate" "bos scapula" "pork skin" "skin pad" ...
```

```
$ Sq.n                    : num  6 9 9 6 6 9 9 6
$ Sq.min                  : num  868 162 461 151 882 ...
$ Sq.max                  : num  3463 3403 6312 5833 2906 ...
$ Sq.mean                 : num  1799 1145 2464 1349 1647 ...
$ Sq.median               : num  1706 500 1797 470 1624 ...
$ Sq.sd                   : num  949 1254 1897 2226 752 ...
$ Ssk.n                   : num  6 9 9 6 6 9 9 6
$ Ssk.min                 : num  0.0348 0.4052 0.4579 -3.5705 -2.2103 ...
$ Ssk.max                 : num  3.07 4.05 3.21 4.17 2.81 ...
$ Ssk.mean                : num  0.963 1.544 1.457 1.24 1.296 ...
$ Ssk.median              : num  0.693 1.298 1.185 1.392 1.837 ...
$ Ssk.sd                  : num  1.086 1.12 0.968 2.906 1.903 ...
$ Sku.n                   : num  6 9 9 6 6 9 9 6
$ Sku.min                 : num  4.11 4.48 3.34 6.21 8.31 ...
$ Sku.max                 : num  15.6 29.5 30.8 42.9 13.9 ...
$ Sku.mean                : num  6.38 11.17 11.42 23.21 11.57 ...
$ Sku.median              : num  4.56 7.98 8.32 22.66 12.21 ...
$ Sku.sd                  : num  4.53 8.13 8.57 16.77 2.18 ...
$ Sp.n                    : num  6 9 9 6 6 9 9 6
$ Sp.min                  : num  4421 1310 2076 1153 5895 ...
$ Sp.max                  : num  11358 14701 28679 27412 12214 ...
$ Sp.mean                 : num  7184 6091 13914 7582 9076 ...
$ Sp.median               : num  6875 4880 12059 2436 10002 ...
$ Sp.sd                   : num  2301 5026 8587 10321 2534 ...
$ Sv.n                    : num  6 9 9 6 6 9 9 6
$ Sv.min                  : num  1830 759 1194 406 1448 ...
$ Sv.max                  : num  11396 12495 26653 26381 17743 ...
$ Sv.mean                 : num  5727 3884 9533 6471 6435 ...
$ Sv.median               : num  5837 1881 8513 2016 4178 ...
$ Sv.sd                   : num  3394 4372 8455 10116 6195 ...
$ Sz.n                    : num  6 9 9 6 6 9 9 6
$ Sz.min                  : num  7126 2069 3270 1870 7342 ...
$ Sz.max                  : num  22754 24943 55332 53793 29957 ...
$ Sz.mean                 : num  12910 9975 23447 14053 15511 ...
$ Sz.median               : num  13009 5862 19639 6439 14180 ...
$ Sz.sd                   : num  5578 9089 16618 20116 8359 ...
$ Sa.n                    : num  6 9 9 6 6 9 9 6
$ Sa.min                  : num  526.6 114.5 370.2 84.7 574.5 ...
$ Sa.max                  : num  2609 2489 4188 3552 1469 ...
$ Sa.mean                 : num  1293 802 1618 817 1010 ...
$ Sa.median               : num  1195 312 1118 280 1048 ...
$ Sa.sd                   : num  740 904 1254 1355 375 ...
$ Smr.n                   : num  6 9 9 6 6 9 9 6
$ Smr.min                 : num  0.1932 0.1734 0.0556 0.1044 0.1404 ...
$ Smr.max                 : num  0.974 4.633 2.1 12.722 0.308 ...
$ Smr.mean                : num  0.453 1.329 0.395 2.673 0.219 ...
$ Smr.median              : num  0.385 0.315 0.121 0.651 0.219 ...
$ Smr.sd                  : num  0.2761 1.5375 0.6745 4.95 0.0596 ...
$ Smc.n                   : num  6 9 9 6 6 9 9 6
$ Smc.min                 : num  738 171 627 111 811 ...
$ Smc.max                 : num  3691 4354 4666 3888 2206 ...
$ Smc.mean                : num  2159 1265 2176 986 1490 ...
$ Smc.median              : num  2102 514 1551 470 1524 ...
$ Smc.sd                  : num  1086 1485 1517 1451 566 ...
$ Sxp.n                   : num  6 9 9 6 6 9 9 6
$ Sxp.min                 : num  684 259 652 192 630 ...
$ Sxp.max                 : num  7857 6666 12014 11116 10902 ...
$ Sxp.mean                : num  3289 2016 4262 2380 3338 ...
$ Sxp.median              : num  2909 730 2574 497 2198 ...
$ Sxp.sd                  : num  2533 2417 3699 4320 3847 ...
$ Sal.n                   : num  6 9 9 6 6 9 9 6
```

```
 $ Sal.min            : num  13.84 11.46 8.47 5.94 12.22 ...
 $ Sal.max            : num  35.6 28 23.6 15.7 20.4 ...
 $ Sal.mean           : num  21.8 18.2 16.6 10.6 15.9 ...
 $ Sal.median         : num  20.3 16.3 16.9 10.7 15.3 ...
 $ Sal.sd             : num  8.56 5.46 4.48 3.87 2.86 ...
 $ Str.n              : num  5 8 7 6 5 9 7 5
 $ Str.min            : num  0.2505 0.178 0.2169 0.0746 0.1123 ...
 $ Str.max            : num  0.53 0.803 0.691 0.669 0.29 ...
 $ Str.mean           : num  0.414 0.481 0.426 0.35 0.218 ...
 $ Str.median         : num  0.431 0.396 0.437 0.267 0.229 ...
 $ Str.sd             : num  0.118 0.251 0.167 0.241 0.065 ...
 $ Std.n              : num  6 9 9 6 6 9 9 6
 $ Std.min            : num  16.7 32.3 39.2 50.5 3.5 ...
 $ Std.max            : num  173.7 167.5 153.5 170 86.2 ...
 $ Std.mean           : num  83.2 117.9 102.1 103.2 40.5 ...
 $ Std.median         : num  47.5 159.3 102 99 35.2 ...
 $ Std.sd             : num  70.1 62.1 32.7 44.1 39.3 ...
 $ Sdq.n              : num  6 9 9 6 6 9 9 6
 $ Sdq.min            : num  0.3258 0.1096 0.2456 0.0833 0.3318 ...
 $ Sdq.max            : num  0.519 0.701 1.339 0.851 0.668 ...
 $ Sdq.mean           : num  0.394 0.3 0.483 0.284 0.469 ...
 $ Sdq.median         : num  0.368 0.272 0.315 0.192 0.469 ...
 $ Sdq.sd             : num  0.0735 0.1856 0.3598 0.2907 0.1271 ...
 $ Sdr.n              : num  6 9 9 6 6 9 9 6
 $ Sdr.min            : num  4.431 0.589 2.874 0.337 4.363 ...
 $ Sdr.max            : num  10.2 16.3 21.4 17.9 13.1 ...
 $ Sdr.mean           : num  6.31 4.6 6.75 4.36 8.2 ...
 $ Sdr.median         : num  5.52 3.45 4 1.89 8.29 ...
 $ Sdr.sd             : num  2.26 4.9 6.07 6.8 3.55 ...
 $ Vm.n               : num  6 9 9 6 6 9 9 6
 $ Vm.min             : num  0.0697 0.0141 0.0282 0.0103 0.1226 ...
 $ Vm.max             : num  0.263 0.332 0.805 0.847 0.24 ...
 $ Vm.mean            : num  0.153 0.11 0.282 0.171 0.169 ...
 $ Vm.median          : num  0.1351 0.062 0.1947 0.0325 0.1685 ...
 $ Vm.sd              : num  0.0651 0.1201 0.2411 0.3323 0.0439 ...
 $ Vv.n               : num  6 9 9 6 6 9 9 6
  [list output truncated]
```

Cycle combined with contact and raw material

```
cycle_material <- summaryBy(.~ Cycle + Raw.material + Contact.material,
                            data = imp_data[c("Cycle", "Raw.material",
                            "Contact.material", names(imp_data)[num.var])], FUN=nminmaxmeanmedsd)
str(cycle_material)
'data.frame':	16 obs. of  207 variables:
 $ Cycle              : Factor w/ 2 levels "before","2000": 1 1 1 1 1 1 1 1 2 2 ...
 $ Raw.material       : Factor w/ 2 levels "flint","lydite": 1 1 1 1 2 2 2 2 1 1 ...
 $ Contact.material   : chr  "bone plate" "bos scapula" "pork skin" "skin pad" ...
 $ Sq.n               : num  3 6 6 3 3 3 3 3 3 6 ...
 $ Sq.min             : num  868 162 461 151 941 ...
 $ Sq.max             : num  1784 797 6312 196 3463 ...
 $ Sq.mean            : num  1426 414 2873 169 2172 ...
 $ Sq.median          : num  1627 414 2348 160 2113 ...
 $ Sq.sd              : num  490.2 230.8 2259.1 23.7 1261.8 ...
 $ Ssk.n              : num  3 6 6 3 3 3 3 3 3 6 ...
 $ Ssk.min            : num  0.3148 0.7198 0.5893 -0.0199 0.0348 ...
 $ Ssk.max            : num  3.07 4.05 3.21 4.17 0.98 ...
 $ Ssk.mean           : num  1.31 1.78 1.48 2.06 0.62 ...
 $ Ssk.median         : num  0.54 1.372 1.013 2.025 0.847 ...
 $ Ssk.sd             : num  1.527 1.247 1.074 2.095 0.511 ...
 $ Sku.n              : num  3 6 6 3 3 3 3 3 3 6 ...
 $ Sku.min            : num  4.92 4.48 3.34 6.21 4.11 ...
```

```
 $ Sku.max          : num  15.56 29.53 30.81 37.01 4.19 ...
 $ Sku.mean         : num  8.59 12.54 13.07 17.88 4.16 ...
 $ Sku.median       : num  5.3 9.87 8.59 10.42 4.17 ...
 $ Sku.sd           : num  6.0389 9.3362 10.2224 16.7024 0.0457 ...
 $ Sp.n             : num  3 6 6 3 3 3 3 3 3 6 ...
 $ Sp.min           : num  6117 1310 2076 1153 4421 ...
 $ Sp.max           : num  7456 6501 28679 1693 11358 ...
 $ Sp.mean          : num  6811 3041 16425 1484 7556 ...
 $ Sp.median        : num  6861 2105 15595 1606 6888 ...
 $ Sp.sd            : num  671 2144 9598 290 3516 ...
 $ Sv.n             : num  3 6 6 3 3 3 3 3 3 6 ...
 $ Sv.min           : num  1830 759 1194 406 2705 ...
 $ Sv.max           : num  6757 2112 26653 716 11396 ...
 $ Sv.mean          : num  4760 1411 11381 572 6694 ...
 $ Sv.median        : num  5692 1365 8590 594 5981 ...
 $ Sv.sd            : num  2592 567 9761 156 4389 ...
 $ Sz.n             : num  3 6 6 3 3 3 3 3 3 6 ...
 $ Sz.min           : num  7947 2069 3270 1870 7126 ...
 $ Sz.max           : num  13618 8613 55332 2286 22754 ...
 $ Sz.mean          : num  11571 4452 27806 2056 14250 ...
 $ Sz.median        : num  13148 3917 24185 2013 12870 ...
 $ Sz.sd            : num  3147 2452 19028 212 7905 ...
 $ Sa.n             : num  3 6 6 3 3 3 3 3 3 6 ...
 $ Sa.min           : num  526.6 114.5 370.2 84.7 710.6 ...
 $ Sa.max           : num  1244 521 4188 139 2609 ...
 $ Sa.mean          : num  972 281 1869 113 1614 ...
 $ Sa.median        : num  1145 301 1496 116 1522 ...
 $ Sa.sd            : num  388.9 146.2 1504.3 27.1 952.7 ...
 $ Smr.n            : num  3 6 6 3 3 3 3 3 3 6 ...
 $ Smr.min          : num  0.2888 0.2624 0.0556 0.8316 0.1932 ...
 $ Smr.max          : num  0.432 4.633 2.1 12.722 0.974 ...
 $ Smr.mean         : num  0.353 1.883 0.43 5.048 0.554 ...
 $ Smr.median       : num  0.339 1.84 0.111 1.59 0.494 ...
 $ Smr.sd           : num  0.0727 1.6353 0.819 6.6566 0.3939 ...
 $ Smc.n            : num  3 6 6 3 3 3 3 3 3 6 ...
 $ Smc.min          : num  738 171 627 111 1302 ...
 $ Smc.max          : num  2251 850 4666 232 3691 ...
 $ Smc.mean         : num  1647 435 2339 173 2671 ...
 $ Smc.median       : num  1953 434 1687 177 3020 ...
 $ Smc.sd           : num  801.2 247.8 1852.6 60.7 1232.3 ...
 $ Sxp.n            : num  3 6 6 3 3 3 3 3 3 6 ...
 $ Sxp.min          : num  684 259 652 192 1383 ...
 $ Sxp.max          : num  3996 1204 12014 362 7857 ...
 $ Sxp.mean         : num  2509 600 5232 255 4070 ...
 $ Sxp.median       : num  2847 553 4374 211 2970 ...
 $ Sxp.sd           : num  1681.9 344.8 4289.7 92.9 3374.2 ...
 $ Sal.n            : num  3 6 6 3 3 3 3 3 3 6 ...
 $ Sal.min          : num  14.35 11.46 8.47 5.94 13.84 ...
 $ Sal.max          : num  26.25 19.14 23.64 8.18 35.62 ...
 $ Sal.mean         : num  18.95 15.3 17.27 7.28 24.57 ...
 $ Sal.median       : num  16.25 15.21 18.59 7.73 24.26 ...
 $ Sal.sd           : num  6.4 2.51 5.32 1.18 10.89 ...
 $ Str.n            : num  3 6 4 3 2 2 3 3 3 6 ...
 $ Str.min          : num  0.2505 0.178 0.2169 0.0746 0.3444 ...
 $ Str.max          : num  0.514 0.769 0.691 0.669 0.53 ...
 $ Str.mean         : num  0.399 0.44 0.408 0.323 0.437 ...
 $ Str.median       : num  0.431 0.343 0.362 0.226 0.437 ...
 $ Str.sd           : num  0.135 0.253 0.231 0.309 0.132 ...
 $ Std.n            : num  3 6 6 3 3 3 3 3 3 6 ...
 $ Std.min          : num  42.5 32.3 39.2 50.5 16.7 ...
 $ Std.max          : num  47.8 159.8 153.5 170 173.7 ...
```

```
 $ Std.mean          : num  45.8 97.7 96.4 117.8 120.6 ...
 $ Std.median        : num  47.3 101 100.5 133 171.3 ...
 $ Std.sd            : num  2.9 67.8 37 61.2 89.9 ...
 $ Sdq.n             : num  3 6 6 3 3 3 3 3 3 6 ...
 $ Sdq.min           : num  0.3258 0.1096 0.2456 0.0833 0.3434 ...
 $ Sdq.max           : num  0.39 0.323 1.339 0.118 0.519 ...
 $ Sdq.mean          : num  0.354 0.203 0.566 0.101 0.433 ...
 $ Sdq.median        : num  0.346 0.199 0.394 0.102 0.438 ...
 $ Sdq.sd            : num  0.0329 0.0883 0.4255 0.0172 0.0877 ...
 $ Sdr.n             : num  3 6 6 3 3 3 3 3 3 6 ...
 $ Sdr.min           : num  4.431 0.589 2.874 0.337 5.087 ...
 $ Sdr.max           : num  5.96 4.37 21.44 0.68 10.19 ...
 $ Sdr.mean          : num  4.95 2.15 8.04 0.51 7.67 ...
 $ Sdr.median        : num  4.472 1.932 5.027 0.513 7.727 ...
 $ Sdr.sd            : num  0.868 1.584 7.25 0.172 2.552 ...
 $ Vm.n              : num  3 6 6 3 3 3 3 3 3 6 ...
 $ Vm.min            : num  0.13 0.0141 0.0282 0.0103 0.0697 ...
 $ Vm.max            : num  0.1391 0.0797 0.805 0.0206 0.2625 ...
 $ Vm.mean           : num  0.1334 0.0405 0.3344 0.0162 0.1726 ...
 $ Vm.median         : num  0.1311 0.0347 0.2856 0.0176 0.1857 ...
 $ Vm.sd             : num  0.005 0.0259 0.2847 0.0053 0.0971 ...
  [list output truncated]
```

Save data

Format name of output file

```
file_out <- "AvsN_stats"
```

The file will be saved as "~/analysis/summary_stats/.[ext]".

Write to XLSX

```
write.xlsx(list(spot = spot, cycle= cycle, cycle_material = cycle_material),
           file = paste0(dir_out, file_out, ".xlsx"))
```

Save R object

```
saveObject(list(spot = spot, cycle = cycle, cycle_material = cycle_material),
           file = paste0(dir_out, file_out, ".Rbin"))
```

---

sessionInfo() and RStudio version

```
sessionInfo()
R version 4.0.2 (2020-06-22)
Platform: x86_64-w64-mingw32/x64 (64-bit)
Running under: Windows 10 x64 (build 19041)

Matrix products: default

locale:
[1] LC_COLLATE=German_Germany.1252  LC_CTYPE=German_Germany.1252
[3] LC_MONETARY=German_Germany.1252 LC_NUMERIC=C
[5] LC_TIME=German_Germany.1252

attached base packages:
[1] tools     stats     graphics  grDevices utils     datasets  methods
[8] base
```

```
other attached packages:
[1] doBy_4.6.8        R.utils_2.10.1    R.oo_1.24.0       R.methodsS3_1.8.1
[5] openxlsx_4.2.3

loaded via a namespace (and not attached):
 [1] zip_2.1.1         Rcpp_1.0.6        compiler_4.0.2    pillar_1.4.7
 [5] digest_0.6.27     lattice_0.20-41   evaluate_0.14     lifecycle_0.2.0
 [9] tibble_3.0.6      gtable_0.3.0      pkgconfig_2.0.3   rlang_0.4.10
[13] Matrix_1.2-18     DBI_1.1.1         yaml_2.2.1        xfun_0.20
[17] dplyr_1.0.3       stringr_1.4.0     knitr_1.31        generics_0.1.0
[21] vctrs_0.3.6       grid_4.0.2        tidyselect_1.1.0  glue_1.4.2
[25] R6_2.5.0          rmarkdown_2.6     tidyr_1.1.2       purrr_0.3.4
[29] ggplot2_3.3.3     magrittr_2.0.1    backports_1.2.1   scales_1.1.1
[33] ellipsis_0.3.1    htmltools_0.5.1.1 MASS_7.3-51.6     assertthat_0.2.1
[37] colorspace_2.0-0  Deriv_4.1.2       stringi_1.5.3     munsell_0.5.0
[41] broom_0.7.4       crayon_1.4.0
```

RStudio version 1.3.1073.

END OF SCRIPT

Plots - ‘artificial VS natural’ -experiment

Ivan Calandra & Lisa Schunk

2021-02-14 16:29:28

Goal of the script

This script plots all variables to see which ones should be used for further analysis.
Scatterplot of each variable will be plotted.

```
dir_in <- "analysis/derived_data/"
dir_out <- "analysis/plots"
```

Raw data must be located in ~/analysis/derived_data/.
Formatted data will be saved in ~/analysis/plots.

The knit directory for this script is the project directory.

Load packages

```
library(R.utils)
library(ggplot2)
Warning: package 'ggplot2' was built under R version 4.0.3
library(tools)
library(tidyverse)
Warning: package 'tidyverse' was built under R version 4.0.3
Warning: package 'tibble' was built under R version 4.0.3
Warning: package 'readr' was built under R version 4.0.3
Warning: package 'dplyr' was built under R version 4.0.3
library(patchwork)
Warning: package 'patchwork' was built under R version 4.0.3
library(ggsci)
library(ggfortify)
Warning: package 'ggfortify' was built under R version 4.0.3
library(wesanderson)
library(doBy)
Warning: package 'doBy' was built under R version 4.0.3
library(ggfortify)
```

Get name, path and information of the file

```
data_file <- list.files(dir_in, pattern = "\\.Rbin$", full.names = TRUE)
md5_in <- md5sum(data_file)
info_in <- data.frame(file = basename(names(md5_in)), checksum = md5_in, row.names = NULL)
```

The checksum (MD5 hashes) of the imported file is:

```
               file                         checksum
1 AvsN_use-wear.Rbin 0bbb6fa72fc579f481ad716752f28d5d
```

Load data into R object

```
imp_data <- loadObject(data_file)
str(imp_data)
```

```
'data.frame':   60 obs. of  55 variables:
 $ Sample                  : chr  "FLT4-12" "FLT4-12" "FLT4-12" "FLT4-12" ...
 $ Cycle                   : Factor w/ 2 levels "before","2000": 1 1 1 2 2 2 1 1 1 1 ...
 $ Location                : chr  "B1" "B1" "B1" "B1" ...
 $ Area                    : chr  "01" "01" "01" "01" ...
 $ Spot                    : chr  "a" "b" "c" "a" ...
 $ Objective               : Factor w/ 2 levels "50x075","50x095": 2 2 2 2 2 2 1 1 1 1 ...
 $ Raw.material            : Factor w/ 2 levels "flint","lydite": 1 1 1 1 1 1 1 1 1 1 ...
 $ Contact.material        : chr  "skin pad" "skin pad" "skin pad" "skin pad" ...
 $ Analysis.date           : Date, format: "2020-08-17" "2020-08-17" ...
 $ Analysis.time           : 'times' num  0.617 0.618 0.618 0.619 0.619 ...
  ..- attr(*, "format")= chr "h:m:s"
 $ Acquisition.date.time   : chr  "7/20/2020 2:39:46 PM" "7/20/2020 2:55:08 PM" "7/20/2020 3:12:51 PM" "7/20/2020 3:29:51 PM" ...
 $ Axis.length.X           : num  255 255 255 255 255 ...
 $ Axis.size.X             : num  1198 1198 1198 1198 1198 ...
 $ Axis.spacing.X          : num  0.213 0.213 0.213 0.213 0.213 ...
 $ Axis.length.Y           : num  255 255 255 255 255 ...
 $ Axis.size.Y             : num  1198 1198 1198 1198 1198 ...
 $ Axis.spacing.Y          : num  0.213 0.213 0.213 0.213 0.213 ...
 $ Axis.length.Z           : num  27287 27231 26655 13395 13291 ...
 $ Axis.size.Z             : num  63694 65201 63762 65466 65538 ...
 $ Axis.spacing.Z          : num  0.428 0.418 0.418 0.205 0.203 ...
 $ NM.points.ratio.Z       : num  0 0 0 0 0 0 0 0 0 0 ...
 $ Sq                      : num  160 151 196 227 160 ...
 $ Ssk                     : num  -0.0199 4.1704 2.0253 2.2084 2.0238 ...
 $ Sku                     : num  6.21 37.01 10.42 11.22 9.9 ...
 $ Sp                      : num  1153 1693 1606 1740 1174 ...
 $ Sv                      : num  716 594 406 473 321 ...
 $ Sz                      : num  1870 2286 2013 2212 1496 ...
 $ Sa                      : num  115.8 84.7 138.7 154.4 111.9 ...
 $ Smr                     : num  12.722 0.832 1.59 1.645 10.656 ...
 $ Smc                     : num  177 111 232 250 184 ...
 $ Sxp                     : num  362 192 211 245 175 ...
 $ Sal                     : num  5.94 7.73 8.18 12.2 8.71 ...
 $ Str                     : num  0.0746 0.669 0.226 0.6994 0.1989 ...
 $ Std                     : num  170 133 50.5 101 81.5 ...
 $ Sdq                     : num  0.1019 0.0833 0.1177 0.1378 0.1048 ...
 $ Sdr                     : num  0.513 0.337 0.68 0.916 0.54 ...
 $ Vm                      : num  0.0103 0.0176 0.0206 0.0263 0.0175 ...
 $ Vv                      : num  0.187 0.128 0.252 0.276 0.202 ...
 $ Vmp                     : num  0.0103 0.0176 0.0206 0.0263 0.0175 ...
 $ Vmc                     : num  0.119 0.073 0.133 0.143 0.106 ...
 $ Vvc                     : num  0.164 0.115 0.241 0.262 0.192 ...
 $ Vvv                     : num  0.0233 0.0128 0.0112 0.0138 0.0092 ...
 $ Maximum.depth.of.furrows: num  905 865 814 881 640 ...
 $ Mean.depth.of.furrows   : num  257 174 386 409 311 ...
 $ Mean.density.of.furrows : num  3081 3318 3101 3225 3191 ...
 $ First.direction         : num  1.69e+02 1.35e+02 8.76e-03 9.00e+01 9.00e+01 ...
 $ Second.direction        : num  180 90 135 135 45 ...
 $ Third.direction         : num  135 45 117 116 135 ...
 $ Isotropy                : num  6.16 66.63 52.93 77.77 55.86 ...
 $ epLsar                  : num  0.00356 0.00393 0.00189 0.00195 0.00041 ...
 $ NewEplsar               : num  0.0187 0.0188 0.0179 0.0179 0.0175 ...
 $ Asfc                    : num  1.145 0.703 1.494 2.067 1.207 ...
 $ Smfc                    : num  3.08 3.3 2.88 2.52 2.52 ...
 $ HAsfc9                  : num  0.201 0.636 0.191 0.512 0.239 ...
 $ HAsfc81                 : num  0.264 0.939 0.388 0.722 0.386 ...
 - attr(*, "comment")= Named chr [1:44] "µm" "points" "µm" "µm" ...
  ..- attr(*, "names")= chr [1:44] "Axis length - X" "Axis size - X" "Axis spacing - X" "Axis length - Y" ...
```

The imported file is: "~/analysis/derived_data/AvsN_use-wear.Rbin"

Prepare variables

Define numeric variables

```
num.var <- 22:length(imp_data)
```

The following variables will be used:

```
[22] Sq
[23] Ssk
[24] Sku
[25] Sp
[26] Sv
[27] Sz
[28] Sa
[29] Smr
[30] Smc
[31] Sxp
[32] Sal
[33] Str
[34] Std
[35] Sdq
[36] Sdr
[37] Vm
[38] Vv
[39] Vmp
[40] Vmc
[41] Vvc
[42] Vvv
[43] Maximum.depth.of.furrows
[44] Mean.depth.of.furrows
[45] Mean.density.of.furrows
[46] First.direction
[47] Second.direction
[48] Third.direction
[49] Isotropy
[50] epLsar
[51] NewEplsar
[52] Asfc
[53] Smfc
[54] HAsfc9
[55] HAsfc81
```

Plot each of the selected numeric variable (facet plot = 1 plot for flint, 1 plot for lydite)

```
for (i in num.var){
  #plot
 range_var <- range(imp_data[[i]]) # gets the min/max range of the data set

  p_lydite <- ggplot(data = imp_data[grep("LYDIT", imp_data[["Sample"]]), ],
                     aes_string(x = "Cycle", y = names(imp_data)[i],
                                colour = "Spot")) +
        # avoids overplotting
        geom_point(size = 3) +
        geom_line(aes(group = Spot)) +
```

```
             facet_wrap(Sample+Location ~ Contact.material, nrow = 2) +
               coord_cartesian(ylim = range_var) +
             ylab(names(imp_data)[i]) + xlab(NULL) +
             labs(y = gsub("\\.", " ", names(imp_data)[i])) +
             scale_colour_futurama() +
             theme_classic()

    p_flint <- ggplot(data = imp_data[grep("FLT", imp_data[["Sample"]]), ],
                      aes_string(x = "Cycle", y = names(imp_data)[i],
                                 colour = "Spot")) +
               geom_point(size = 3) +
               geom_line(aes(group = Spot)) +
               facet_wrap(Sample+Location ~ Contact.material, nrow = 2) +
               coord_cartesian(ylim = range_var) +
               ylab(names(imp_data)[i]) + xlab(NULL) +
               labs(y = gsub("\\.", " ", names(imp_data)[i])) +
               scale_colour_futurama() +
               theme_classic()

    # combines the flint and the lydite plots
  p <- p_flint + p_lydite + plot_layout(width = c(3/5, 2/5), guides = 'collect')



#save to PDF
    file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "_plot_", names(imp_data)[i], ".pdf")
    ggsave(filename = file_out, plot = p, path = dir_out, device = "pdf")

}
Warning: Removed 4 rows containing missing values (geom_point).

Warning: Removed 4 rows containing missing values (geom_point).
Warning: Removed 1 row(s) containing missing values (geom_path).
Warning: Removed 1 rows containing missing values (geom_point).
Warning: Removed 2 rows containing missing values (geom_point).
Warning: Removed 1 row(s) containing missing values (geom_path).
```

Plot each of the selected numeric variable in one scatter plot

```
# excludes the outliers
# adds the indices as row numbers
imp_data <- imp_data %>% mutate(id = row_number())
imp_data2 <- imp_data[-c(10:12,16:18,19, 20, 58), ]

# adds a column that combines sample and location
sample_data <- unite(imp_data2, sample_location, c(Sample, Location), remove = FALSE)
# computes the mean of the three spots per sample
sample_spot <- summaryBy(.~sample_location+Cycle+Contact.material+Raw.material,
                         data = sample_data, FUN = mean)
# num.var needs to be defined new since the number of columns changed
new.num.var <- num.var - 7

sample_spot[["Contact.material"]] <- factor(sample_spot[["Contact.material"]])
# GrandBudapest1 = c("#F1BB7B", "#FD6467", "#5B1A18", "#D67236")
custom.col3 <- data.frame(type = levels(sample_spot$Contact.material),
                         col = c("#F1BB7B", "#FD6467", "#5B1A18", "#D67236"))
sample_spot$col <- custom.col3[sample_spot$Contact.material, "col"]



for (i in new.num.var){
```

```r
  p_all <- ggplot(data = sample_spot, aes_string(x = "Cycle", y = names(sample_spot)[i],
          colour = "Contact.material", shape = "Raw.material")) +
          geom_point(size = 3) +
          geom_line(aes(group = sample_location)) +
          ylab(names(sample_spot)[i]) + xlab(NULL) +
          labs(y = gsub("\\.", " ", names(sample_spot)[i])) +
          labs(colour = "Contact material", shape = "Raw material") +
          scale_colour_manual(values = custom.col3$col) +
          theme_classic()

#save to PDF
  file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "_VS_plot_", names(sample_spot)[i], ".pdf")
  ggsave(filename = file_out, plot = p_all, path = dir_out, device = "pdf")

}
Warning: Removed 8 rows containing missing values (geom_point).
Warning: Removed 8 row(s) containing missing values (geom_path).
Warning: Removed 3 rows containing missing values (geom_point).
Warning: Removed 3 row(s) containing missing values (geom_path).
```

Principal component analysis

PCA contact material

```r
# removes rows with na values
data_pca <- na.omit(imp_data2)
# uses for the PCA only selected variables: Sq, SSK, Vmc, Isotropy, Mean density of furrows,
# Asfc, HAsfc9
imp_data.pca <- prcomp(data_pca[, c(22:23, 40, 45, 49, 52, 54)], scale. = TRUE)
# converts the data into factor
data_pca[["Contact.material"]] <- factor(data_pca[["Contact.material"]])



# GrandBudapest1 = c("#F1BB7B", "#FD6467", "#5B1A18", "#D67236")
custom.col3 <- data.frame(type = levels(data_pca$Contact.material),
                    col = c("#F1BB7B", "#FD6467", "#5B1A18", "#D67236"))
data_pca$col <- custom.col3[data_pca$Contact.material, "col"]

# Using ggfortify
PCA<- autoplot(imp_data.pca, data = data_pca, colour = "Contact.material", size = 2,
          loadings = TRUE, loadings.colour = "black", loadings.label = TRUE,
          loadings.label.colour = "black",
          loadings.label.size  = 4, loadings.label.repel = TRUE,
          frame = TRUE, frame.type = "convex", frame.colour = "Contact.material",
          frame.alpha = 0) +
          theme_classic() +
          scale_colour_manual(values = custom.col3$col)
Warning: `select_()` is deprecated as of dplyr 0.7.0.
Please use `select()` instead.
This warning is displayed once every 8 hours.
Call `lifecycle::last_warnings()` to see where this warning was generated.
Warning: `group_by_()` is deprecated as of dplyr 0.7.0.
Please use `group_by()` instead.
See vignette('programming') for more help
This warning is displayed once every 8 hours.
Call `lifecycle::last_warnings()` to see where this warning was generated.
# saves the plot
file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "_PCA_contact", ".pdf")
ggsave(filename = file_out, plot = PCA, path = dir_out, device = "pdf")
```

PCA before and after

```
#  Cavalcanti1 = c("#D8B70A", "#02401B", "#A2A475", "#81A88D", "#972D15")
custom.col6 <- data.frame(type = levels(data_pca$Cycle),
                          col = c("#D8B70A", "#02401B"))
data_pca$col <- custom.col6[data_pca$Cycle, "col"]

# Using ggfortify
PCA2<- autoplot(imp_data.pca, data = data_pca, colour = "Cycle", size = 2,
         loadings = TRUE, loadings.colour = "black", loadings.label = TRUE, loadings.label.colour = "black",
         loadings.label.size  = 4, loadings.label.repel = TRUE,
         frame = TRUE, frame.type = "convex", frame.colour = "Cycle", frame.alpha = 0) +
         theme_classic() +
         scale_colour_manual(values = custom.col6$col)


# saves the plot
file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "_PCA_cycle", ".pdf")
ggsave(filename = file_out, plot = PCA2, path = dir_out, device = "pdf")
```

---

sessionInfo() and RStudio version

```
sessionInfo()
R version 4.0.2 (2020-06-22)
Platform: x86_64-w64-mingw32/x64 (64-bit)
Running under: Windows 10 x64 (build 19041)

Matrix products: default

locale:
[1] LC_COLLATE=German_Germany.1252  LC_CTYPE=German_Germany.1252
[3] LC_MONETARY=German_Germany.1252 LC_NUMERIC=C
[5] LC_TIME=German_Germany.1252

attached base packages:
[1] tools     stats     graphics  grDevices utils     datasets  methods
[8] base

other attached packages:
 [1] doBy_4.6.8         wesanderson_0.3.6 ggfortify_0.4.11  ggsci_2.9
 [5] patchwork_1.1.1    forcats_0.5.1     stringr_1.4.0     dplyr_1.0.3
 [9] purrr_0.3.4        readr_1.4.0       tidyr_1.1.2       tibble_3.0.5
[13] tidyverse_1.3.0    ggplot2_3.3.3     R.utils_2.10.1    R.oo_1.24.0
[17] R.methodsS3_1.8.1

loaded via a namespace (and not attached):
 [1] ggrepel_0.9.1      Rcpp_1.0.6        lubridate_1.7.9.2 lattice_0.20-41
 [5] assertthat_0.2.1   digest_0.6.27     R6_2.5.0          cellranger_1.1.0
 [9] backports_1.2.0    reprex_1.0.0      evaluate_0.14     httr_1.4.2
[13] pillar_1.4.7       rlang_0.4.10      readxl_1.3.1      rstudioapi_0.13
[17] Matrix_1.2-18      rmarkdown_2.6     labeling_0.4.2    munsell_0.5.0
[21] broom_0.7.4        compiler_4.0.2    Deriv_4.1.2       modelr_0.1.8
[25] xfun_0.20          pkgconfig_2.0.3   htmltools_0.5.1.1 tidyselect_1.1.0
[29] gridExtra_2.3      crayon_1.4.0      dbplyr_2.0.0      withr_2.4.1
[33] MASS_7.3-53        grid_4.0.2        jsonlite_1.7.2    gtable_0.3.0
[37] lifecycle_0.2.0    DBI_1.1.1         magrittr_2.0.1    scales_1.1.1
[41] cli_2.3.0          stringi_1.5.3     farver_2.0.3      fs_1.5.0
[45] xml2_1.3.2         ellipsis_0.3.1    generics_0.1.0    vctrs_0.3.6
```

```
[49] glue_1.4.2        hms_1.0.0         yaml_2.2.1        colorspace_2.0-0
[53] rvest_0.3.6       knitr_1.31        haven_2.3.1
```

RStudio version 1.3.1073.

END OF SCRIPT

Import SMARTTESTER datasets - tool function experiment

Lisa Schunk & Ivan Calandra

2021-02-04 15:29:54

Goal of the script

This script imports and merges all single TXT-files (strokes + sensors) produced with the Inotec Smarttester during the 'tool function experiment'. The experiment involved 24 samples (12 flint, 12 lydite) which have been used in four cycles (0-2000 strokes) respectively. The script will:

112. Read in the original TXT-files

113. Format and merge the data for each sample
114. Combine the data from the 24 samples into one
115. Write an XLSX-file and save an R object ready for further analysis in R

```
dir_in <- "E:/Sync/EXPERIMENTS/tool-function_experiment/DATA/Inotec/R/raw_data/data_txt"
dir_out <- "analysis/derived_data/"
```

Raw data must be located in "E:/Sync/EXPERIMENTS/tool-function_experiment/DATA/Inotec/R/raw_data/data_txt".
Formatted data will be saved in "analysis/derived_data/".

The knit directory for this script is the project directory.

Load packages

```
library(tidyverse)
Warning: package 'ggplot2' was built under R version 4.0.3
Warning: package 'readr' was built under R version 4.0.3
Warning: package 'dplyr' was built under R version 4.0.3
Warning: package 'forcats' was built under R version 4.0.3
library(R.utils)
library(openxlsx)
Warning: package 'openxlsx' was built under R version 4.0.3
library(tools)
```

List all files and get names of the files

```
# List all CSV files in dir_in
TXT_files <- list.files(dir_in, pattern = "\\.txt$", recursive = TRUE, full.names = TRUE)

# Extract sample names from paths
samples_names <- dirname(dirname(dirname(TXT_files))) %>% # Path of folder 3 levels higher
            basename() %>%                   # Name of folder 3 levels higher
            unique()                        # Unique names
```

Define cycles and sensors

```
# Define index of first stroke in each series
cycle_start <- c(1, 51, 251, 1001)
```

```r
# Define sensors
sensors <- data.frame(mess = paste0("Messung", 1:5),
                      meas = c("Force", "Friction", "Depth", "Position", "Velocity"),
                      unit = c("N", "N", "mm", "mm", "mm/s"))
```

Merge all files and format the data

```r
# Create named list, 1 element for each sample
sampl <- vector(mode = "list", length = length(samples_names))
names(sampl) <- samples_names

# For each sample
for (s in seq_along(samples_names)) {

  # Create named list, 1 element for each sensor ("Messung")
  sampl[[s]] <- vector(mode = "list", length = nrow(sensors))
  names(sampl[[s]]) <- sensors [["meas"]]

  # For each sensor ("Messung")
  for (m in seq_along(sampl[[s]])) {

    # Extract file names of all strokes for the given sensor
    # Paste sample name and slash to avoid partial matching
    s_m <- paste0(samples_names[[s]], "/") %>%
           # Extract sample "s" from all files
           grep(TXT_files, value = TRUE) %>%
           # Extract sensor "m" from sample "s"
           grep(sensors[["mess"]][m], ., value = TRUE)

    # Get cycle from path and re-order them
    cycles <- unique(basename(dirname(dirname(s_m))))[c(1, 4, 3, 2)]

    # Check if number of cycles is equal to number of indices of first cycle stroke
    if (length(cycles) != length(cycle_start))
      stop("There are more cycles than indices of first cycle stroke")

    # Create named list, 1 element for each stroke bin
    sampl[[s]][[m]] <- vector(mode = "list", length = length(cycles))
    names(sampl[[s]][[m]]) <- cycles

    # For each cycle
    for (cy in seq_along(sampl[[s]][[m]])) {

      # Extract file names of all strokes for each cycle
      s_m_cy <- grep(cycles[cy], s_m, value = TRUE)

      # Create named list, 1 element for each stroke
      sampl[[s]][[m]][[cy]] <- vector(mode = "list", length = length(s_m_cy))
      names(sampl[[s]][[m]][[cy]]) <- paste0("Stroke", seq_along(s_m_cy))

      # For each stroke
      for (st in seq_along(s_m_cy)) {

        # Read in TXT file
        sampl[[s]][[m]][[cy]][[st]] <- read.table(s_m_cy[st], skip = 4, sep = ";") %>%

          # Add columns Step based on V2 and Stroke based on "st"
          mutate(Step = V2/100000+1, Stroke = st + cycle_start[cy] -1) %>%
```

```r
        # Select columns stroke, step, V1
        select(Stroke, Step, V1)

      # Rename column V1 based on "m"
      names(sampl[[s]][[m]][[cy]][[st]])[3] <- sensors[m, "meas"]
    }

    # rbind all files per cycle
    sampl[[s]][[m]][[cy]] <- do.call(rbind, sampl[[s]][[m]][[cy]])
  }

  # rbind all cycles per sensor
  sampl[[s]][[m]] <- do.call(rbind, sampl[[s]][[m]])
 }

 # rbind all sensors per sample
 angle <- basename(dirname(dirname(dirname(dirname(s_m[1])))))
 task <- basename(dirname(dirname(dirname(dirname(dirname(s_m[1]))))))
 raw_mat <- ifelse(grepl("FLT", names(sampl)[s]), "Flint", "Lydite")
 sampl[[s]] <- full_join(sampl[[s]][[1]], sampl[[s]][[2]]) %>%
  full_join(sampl[[s]][[3]]) %>%
  full_join(sampl[[s]][[4]]) %>%
  full_join(sampl[[s]][[5]]) %>%
  mutate(Sample = names(sampl)[s], Angle = angle, Task = task,
        Raw_material = raw_mat) %>%
  select(Sample, Angle, Task, Raw_material, everything())
}

# rbind all samples
sampl <- do.call(rbind, sampl)

str(sampl)
'data.frame':   479933 obs. of  11 variables:
 $ Sample      : chr  "FLT8-7" "FLT8-7" "FLT8-7" "FLT8-7" ...
 $ Angle       : chr  "35°" "35°" "35°" "35°" ...
 $ Task        : chr  "carving" "carving" "carving" "carving" ...
 $ Raw_material: chr  "Flint" "Flint" "Flint" "Flint" ...
 $ Stroke      : num  1 1 1 1 1 1 1 1 1 1 ...
 $ Step        : num  1 2 3 4 5 6 7 8 9 10 ...
 $ Force       : num  -58.9 -59.2 -62.4 -59.6 -59.2 ...
 $ Friction    : num  -9.06 -8.84 -31.52 -28.64 -27.95 ...
 $ Depth       : num  5.57 5.59 5.72 5.75 5.58 ...
 $ Position    : num  65 66.4 97 155.4 211.3 ...
 $ Velocity    : num  -1.72e-04 6.87e+01 4.61e+02 5.94e+02 4.65e+02 ...
```

Save data

Format name of output file

```r
file_out <- "TFE_inotec"
```

Write to XLSX

```r
write.xlsx(list(data = sampl, units = sensors), file = paste0(dir_out, file_out, ".xlsx"))
```

Save R object

```r
saveObject(sampl, file = paste0(dir_out, file_out, ".Rbin"))
```

---

sessionInfo() and RStudio version

```
sessionInfo()
R version 4.0.2 (2020-06-22)
Platform: x86_64-w64-mingw32/x64 (64-bit)
Running under: Windows 10 x64 (build 19041)

Matrix products: default

locale:
[1] LC_COLLATE=German_Germany.1252  LC_CTYPE=German_Germany.1252
[3] LC_MONETARY=German_Germany.1252 LC_NUMERIC=C
[5] LC_TIME=German_Germany.1252

attached base packages:
[1] tools     stats     graphics  grDevices utils     datasets  methods
[8] base

other attached packages:
 [1] openxlsx_4.2.3    R.utils_2.10.1    R.oo_1.24.0       R.methodsS3_1.8.1
 [5] forcats_0.5.1     stringr_1.4.0     dplyr_1.0.3       purrr_0.3.4
 [9] readr_1.4.0       tidyr_1.1.2       tibble_3.0.6      ggplot2_3.3.3
[13] tidyverse_1.3.0

loaded via a namespace (and not attached):
 [1] tidyselect_1.1.0  xfun_0.20         haven_2.3.1       colorspace_2.0-0
 [5] vctrs_0.3.6       generics_0.1.0    htmltools_0.5.1.1 yaml_2.2.1
 [9] rlang_0.4.10      pillar_1.4.7      glue_1.4.2        withr_2.4.1
[13] DBI_1.1.1         dbplyr_2.0.0      modelr_0.1.8      readxl_1.3.1
[17] lifecycle_0.2.0   munsell_0.5.0     gtable_0.3.0      cellranger_1.1.0
[21] zip_2.1.1         rvest_0.3.6       evaluate_0.14     knitr_1.31
[25] broom_0.7.4       Rcpp_1.0.6        scales_1.1.1      backports_1.2.1
[29] jsonlite_1.7.2    fs_1.5.0          hms_1.0.0         digest_0.6.27
[33] stringi_1.5.3     grid_4.0.2        cli_2.3.0         magrittr_2.0.1
[37] crayon_1.4.0      pkgconfig_2.0.3   ellipsis_0.3.1    xml2_1.3.2
[41] reprex_1.0.0      lubridate_1.7.9.2 assertthat_0.2.1  rmarkdown_2.6
[45] httr_1.4.2        rstudioapi_0.13   R6_2.5.0          compiler_4.0.2
```

RStudio version 1.3.1073.

END OF SCRIPT

Plots_TFE-Inotec

Ivan Calandra & Lisa Schunk

2021-02-14 15:47:41

Goal of the script

This script plots a sensor data in order to visualizes the measurements recorded throughout the tool function experiment.
Variables of interest are: * Penetration depth

```
dir_in <- "analysis/derived_data/"
dir_out <- "analysis/plots"
```

Raw data must be located in ~/analysis/derived_data/.
Formatted data will be saved in ~/analysis/plots. The knit directory for this script is the project directory.

Load packages

```
library(R.utils)
library(ggplot2)
Warning: package 'ggplot2' was built under R version 4.0.3
library(tools)
library(tidyverse)
Warning: package 'tidyverse' was built under R version 4.0.3
Warning: package 'tibble' was built under R version 4.0.3
Warning: package 'readr' was built under R version 4.0.3
Warning: package 'dplyr' was built under R version 4.0.3
library(patchwork)
Warning: package 'patchwork' was built under R version 4.0.3
library(doBy)
Warning: package 'doBy' was built under R version 4.0.3
library(ggrepel)
Warning: package 'ggrepel' was built under R version 4.0.3
library(openxlsx)
Warning: package 'openxlsx' was built under R version 4.0.3
```

Get name, path and information of the file

```
data_file <- list.files(dir_in, pattern = "\\.Rbin$", full.names = TRUE)
md5_in <- md5sum(data_file)
info_in <- data.frame(file = basename(names(md5_in)), checksum = md5_in, row.names = NULL)
```

The checksum (MD5 hashes) of the imported file is:

```
             file                         checksum
1 TFE_inotec.Rbin 5b7aec93774d5711014375166947c3f2
```

Load data into R object

```
imp_data <- loadObject(data_file)
str(imp_data)
'data.frame':   479933 obs. of  11 variables:
 $ Sample       : chr  "FLT8-7" "FLT8-7" "FLT8-7" "FLT8-7" ...
```

```
 $ Angle       : chr  "35°" "35°" "35°" "35°" ...
 $ Task        : chr  "carving" "carving" "carving" "carving" ...
 $ Raw_material: chr  "Flint" "Flint" "Flint" "Flint" ...
 $ Stroke      : num  1 1 1 1 1 1 1 1 1 1 ...
 $ Step        : num  1 2 3 4 5 6 7 8 9 10 ...
 $ Force       : num  -58.9 -59.2 -62.4 -59.6 -59.2 ...
 $ Friction    : num  -9.06 -8.84 -31.52 -28.64 -27.95 ...
 $ Depth       : num  5.57 5.59 5.72 5.75 5.58 ...
 $ Position    : num  65 66.4 97 155.4 211.3 ...
 $ Velocity    : num  -1.72e-04 6.87e+01 4.61e+02 5.94e+02 4.65e+02 ...
```

The imported file is: “~/analysis/derived_data/TFE_inotec.Rbin”

Plot each of the selected numeric variable

Plots showing the strokes as lines

```r
# plots all 2000 strokes per sample divided by 40
# splits the data in the individual 24 samples
sp <- split(imp_data, imp_data[["Sample"]])


for (i in seq_along(sp)) {
  # creates a sequence of every ~ 50th strokes
  seq_st <- seq(1, length(unique(sp[[i]][["Stroke"]])), by = 40) %>%
          c(max(unique(sp[[i]][["Stroke"]])))
  dat_i_all <- sp[[i]] %>%
             filter(Stroke %in% seq_st)
  range_depth <- range(dat_i_all[["Depth"]])
  p1 <- ggplot(data = dat_i_all, aes(x = Step, y = Depth, colour = Stroke)) +
        geom_line(aes(group = Stroke), alpha = 0.3) +
        labs(x = "Step", y = "Depth (mm)") + ylab(NULL) +
        # reverses the legend starting with 0 going to 2000 strokes
        scale_colour_continuous(trans = "reverse") +
        coord_cartesian(ylim = range_depth) +
        # changes the 'Step-number' in the x-legend
        scale_x_continuous(breaks=c(1, 4, 7, 10)) +
          theme_classic()

# plots only the first 50 strokes per sample
  dat_i_50 <- sp[[i]] %>%
            # takes only the first 50 strokes per sample
            filter(Stroke %in% 1:50)
  p2 <- ggplot(data = dat_i_50) +
        geom_line(aes(x = Step, y = Depth, colour = Stroke, group = Stroke), alpha = 0.3) +
        labs(x = "Step", y = "Depth (mm)") +
        scale_colour_continuous(trans = "reverse") +
        coord_cartesian(ylim = range_depth) +
        scale_x_continuous(breaks=c(1, 4, 7, 10)) +
          theme_classic()
  # patchwork plot
  p <- p2 + p1 + plot_annotation(title = names(sp)[i])

  # save to PDF
  file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "_plot_",
                     names(sp)[i], ".pdf")
  ggsave(filename = file_out, plot = p, path = dir_out, device = "pdf")
}
```

Plots showing the absolut penetration depths

Plot of all samples

```
# calculates the absolute depths reached per sample
abs.depth <- function(x) {
  out <- abs(min(x) - max(x))
}

# Define grouping variable and compute the summary statistics
depth <- summaryBy(Depth ~ Sample+Angle+Task+Raw_material,
                   data=imp_data,
                   FUN=abs.depth)

str(depth)
'data.frame':   24 obs. of  5 variables:
 $ Sample          : chr  "FLT8-1" "FLT8-10" "FLT8-11" "FLT8-12" ...
 $ Angle           : chr  "45°" "45°" "45°" "45°" ...
 $ Task            : chr  "cutting" "carving" "carving" "carving" ...
 $ Raw_material    : chr  "Flint" "Flint" "Flint" "Flint" ...
 $ Depth.abs.depth: num  0.687 11.923 0.822 1.685 0.69 ...
# colour
depth[["Raw_material"]] <- factor(depth[["Raw_material"]])
#Royal1 = c("#899DA4", "#C93312", "#FAEFD1", "#DC863B")
custom.col7 <- data.frame(type = levels(depth$Raw_material),
                          col = c("#899DA4", "#DC863B"))
depth$col <- custom.col7[depth$Raw_material, "col"]



# plots all depth points in one facet plot
p3 <- ggplot(data = depth, aes(x = Angle, y = Depth.abs.depth, colour = Raw_material)) +
       geom_point() + labs(y = "Absolute depth (mm)") +
       facet_wrap(~Task, strip.position = "bottom") +
       # avoids overplotting of the labels (sample IDs)
       geom_text_repel(aes(label=Sample), size = 2, nudge_x = -0.4,
                       segment.size = 0.1, force = 2, seed = 123) +
       scale_y_continuous(trans = "reverse") +
       scale_x_discrete(position="top") +
       # removes the "_" between "Raw_material in the legend
         labs(colour = gsub("_", " ", "Raw_material")) +
       scale_colour_manual(values = custom.col7$col) +
         theme_classic()

# save to PDF
file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "_P3_depth_plot", ".pdf")
ggsave(filename = file_out, plot = p3, path = dir_out, device = "pdf",
       width = 180, units = "mm")
```

Plot of all samples except the three outliers

```
# defines the three outliers/bad samples
bad_samples <- c("FLT8-3", "FLT8-4", "FLT8-10")
# creates data frames without the outliers
imp_data_good <- imp_data[!imp_data$Sample %in% bad_samples, ]
# splits the data in the individual 21 samples
sp_good <- split(imp_data_good, imp_data_good[["Sample"]])



# calculates the absolute depths reached per sample
abs.depth <- function(x) {
  out <- abs(min(x) - max(x))
}
```

```r
# Define grouping variable and compute the summary statistics
depth_good <- summaryBy(Depth ~ Sample+Angle+Task+Raw_material,
                data=imp_data_good,
                FUN=abs.depth)

str(depth_good)
'data.frame':   21 obs. of  5 variables:
 $ Sample        : chr  "FLT8-1" "FLT8-11" "FLT8-12" "FLT8-2" ...
 $ Angle         : chr  "45°" "45°" "45°" "45°" ...
 $ Task          : chr  "cutting" "carving" "carving" "cutting" ...
 $ Raw_material   : chr  "Flint" "Flint" "Flint" "Flint" ...
 $ Depth.abs.depth: num  0.687 0.822 1.685 0.69 0.854 ...
# plots all depth points in one facet plot
p4 <- ggplot(data = depth_good, aes(x = Angle, y = Depth.abs.depth,
                          colour = Raw_material)) +
      geom_point() + labs(y = "Absolute depth (mm)") +
      facet_wrap(~Task, strip.position = "bottom") +
      geom_text_repel(aes(label=Sample), size = 2,
                  nudge_x = -0.4, segment.size = 0.1, force = 2, seed = 123) +
      scale_y_continuous(trans = "reverse") +
      scale_x_discrete(position="top") +
      # removes the "_" between "Raw_material in the legend
        labs(colour = gsub("_", " ", "Raw_material")) +
      scale_colour_manual(values = custom.col7$col) +
        theme_classic()

# save to PDF
file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "_P4_depth_plot", ".pdf")
ggsave(filename = file_out, plot = p4, path = dir_out, device = "pdf",
      width = 180, units = "mm")
```

The files will be saved as "~/analysis/plots.[ext]".

Show plot files information

```r
info_out <- list.files(path = dir_out, pattern = "\\.pdf$",
                  full.names = TRUE) %>%
          md5sum()
```

The checksum (MD5 hashes) of the exported files are:

```
analysis/plots/aVSn_inotec_aVSn_P3_depth_plot_.pdf
               "fed975d43682ae051006f2fb84feeda2"
analysis/plots/aVSn_inotec_aVSn_P4_depth_plot_.pdf
               "84ce8d4519045123a65a60dad805b818"
  analysis/plots/aVSn_inotec_aVSn_plot_FLT4-10.pdf
               "c26c6fc8a7dbf131da36d8337a01a7b2"
  analysis/plots/aVSn_inotec_aVSn_plot_FLT4-11.pdf
               "52cd77d943aa5b9992b70a17c6337c67"
  analysis/plots/aVSn_inotec_aVSn_plot_FLT4-12.pdf
               "1934411f0c5d1b90968a67ce499eee6e"
  analysis/plots/aVSn_inotec_aVSn_plot_FLT4-13.pdf
               "25705cfa847f82dbac64383ad06eac25"
  analysis/plots/aVSn_inotec_aVSn_plot_FLT4-14.pdf
               "781f39639c5ad2116c30c3e77a91107d"
  analysis/plots/aVSn_inotec_aVSn_plot_FLT4-15.pdf
               "f561a3d6594a8df73383a5465f6ab957"
   analysis/plots/aVSn_inotec_aVSn_plot_FLT4-4.pdf
               "c11e8519ee618a2987776d70a1069a87"
   analysis/plots/aVSn_inotec_aVSn_plot_FLT4-5.pdf
```

"01503239701b810bd415313a53dbf692"
analysis/plots/aVSn_inotec_aVSn_plot_FLT4-6.pdf
"5dff0b735b8de3d93e76dec15860b490"
analysis/plots/aVSn_inotec_aVSn_plot_FLT4-7.pdf
"8317b616adaf0bbf7828972be4d5e121"
analysis/plots/aVSn_inotec_aVSn_plot_FLT4-8.pdf
"01a8fa660e2a4157d5647e81286e79bc"
analysis/plots/aVSn_inotec_aVSn_plot_FLT4-9.pdf
"76964c5012d079241887483c1620ab09"
analysis/plots/aVSn_inotec_aVSn_plot_LYDIT4-1.pdf
"29d83a4167cecedff45bc48907d96391"
analysis/plots/aVSn_inotec_aVSn_plot_LYDIT4-10.pdf
"de0b41ce7ebc67c3f759a821a18162f7"
analysis/plots/aVSn_inotec_aVSn_plot_LYDIT4-11.pdf
"cc884b471c99079d7575a9b80c0a368e"
analysis/plots/aVSn_inotec_aVSn_plot_LYDIT4-12.pdf
"548110428ec329b4516328905c683b8e"
analysis/plots/aVSn_inotec_aVSn_plot_LYDIT4-2.pdf
"f16372f95c2badd50d7cf2080dfa475b"
analysis/plots/aVSn_inotec_aVSn_plot_LYDIT4-3.pdf
"13226ba1f7c8fa49eedba50feb5d6772"
analysis/plots/aVSn_inotec_aVSn_plot_LYDIT4-4.pdf
"f3ab81a0d9c63238337fada3af80903d"
analysis/plots/aVSn_inotec_aVSn_plot_LYDIT4-5.pdf
"289c559e80b6e2c8960a11b82dcb83c6"
analysis/plots/aVSn_inotec_aVSn_plot_LYDIT4-6.pdf
"069741d9a32cc8e4dfea881d06ada880"
analysis/plots/aVSn_inotec_aVSn_plot_LYDIT4-7.pdf
"6e6ddd107b3bea6cadf41fe8b21c825b"
analysis/plots/aVSn_inotec_aVSn_plot_LYDIT4-8.pdf
"7b688b7ec65abb7de76daa3f3b80fb4c"
analysis/plots/aVSn_inotec_aVSn_plot_LYDIT4-9.pdf
"20f373f0b5371d2ad5b911cba204e64c"
analysis/plots/aVSn_inotec_P3_depth_plot.pdf
"3da906dae4635c7209e14e67f9e833d7"
analysis/plots/aVSn_inotec_P4_depth_plot.pdf
"3da906dae4635c7209e14e67f9e833d7"
analysis/plots/TFE_inotec_P3_depth_plot.pdf
"0814b442a4177230be87ae4ca7f3a279"
analysis/plots/TFE_inotec_P4_depth_plot.pdf
"925a84d760ece763e501a74bc58d1a5a"
analysis/plots/TFE_inotec_plot_FLT8-1.pdf
"2e11ffd5bb061002c579d659f5900f37"
analysis/plots/TFE_inotec_plot_FLT8-10.pdf
"844c49e67400c56b52ede77d08a8d960"
analysis/plots/TFE_inotec_plot_FLT8-11.pdf
"f3cb6430cedc040e4b2504d7be0ff736"
analysis/plots/TFE_inotec_plot_FLT8-12.pdf
"5b8d2632ecce009afa338dec3a1b3038"
analysis/plots/TFE_inotec_plot_FLT8-2.pdf
"a682d96c68117f70075c88c622004a7f"
analysis/plots/TFE_inotec_plot_FLT8-3.pdf
"c9aeb8f9f015f960c5c3677c41065bd9"
analysis/plots/TFE_inotec_plot_FLT8-4.pdf
"e5f31cb4c22dedadee08b4b6d58a71c7"
analysis/plots/TFE_inotec_plot_FLT8-5.pdf
"53222cf7a5a2d204c2e523aa4d9ac796"
analysis/plots/TFE_inotec_plot_FLT8-6.pdf
"43773551a81710efb3c6ed8191485661"
analysis/plots/TFE_inotec_plot_FLT8-7.pdf
"2e88961092c5ce0a9c07764b0834b01b"

```
        analysis/plots/TFE_inotec_plot_FLT8-8.pdf 
              "5fd05d4c131c1f0ee080f700e6c86692" 
        analysis/plots/TFE_inotec_plot_FLT8-9.pdf 
              "1b9cf37ea13ced927cc96e8b80ffc31c" 
      analysis/plots/TFE_inotec_plot_LYDIT5-10.pdf 
              "a642ad9b558f60597592c0c26080b83d" 
      analysis/plots/TFE_inotec_plot_LYDIT5-11.pdf 
              "116ee13ff0f44e9e657b4c4260e565da" 
      analysis/plots/TFE_inotec_plot_LYDIT5-12.pdf 
              "a4dc9ac9d8edcfe407bd07121c49d511" 
      analysis/plots/TFE_inotec_plot_LYDIT5-13.pdf 
              "935c35e03c71b5d770e96bc1c9e539e4" 
       analysis/plots/TFE_inotec_plot_LYDIT5-2.pdf 
              "57c084396c3e1cebb6ea52d2fa536ad0" 
       analysis/plots/TFE_inotec_plot_LYDIT5-3.pdf 
              "005f048a73e4568737daa13c542308a0" 
       analysis/plots/TFE_inotec_plot_LYDIT5-4.pdf 
              "628c34d00fe5087b516d9da6057ae9b3" 
       analysis/plots/TFE_inotec_plot_LYDIT5-5.pdf 
              "ed613efc636032e446378112c3735d26" 
       analysis/plots/TFE_inotec_plot_LYDIT5-6.pdf 
              "bff0fc0414e095379ef55ab59d1ee59c" 
       analysis/plots/TFE_inotec_plot_LYDIT5-7.pdf 
              "793860886f9ed409efa20a81599ddb8f" 
       analysis/plots/TFE_inotec_plot_LYDIT5-8.pdf 
              "4eb2a9d6ac929f232ad3b817eedec240" 
       analysis/plots/TFE_inotec_plot_LYDIT5-9.pdf 
              "8c8b7468fd9db5d4db790728ff166f66" 
```

---

sessionInfo() and RStudio version

```
sessionInfo()
R version 4.0.2 (2020-06-22)
Platform: x86_64-w64-mingw32/x64 (64-bit)
Running under: Windows 10 x64 (build 19041)

Matrix products: default

locale:
[1] LC_COLLATE=German_Germany.1252  LC_CTYPE=German_Germany.1252   
[3] LC_MONETARY=German_Germany.1252 LC_NUMERIC=C                   
[5] LC_TIME=German_Germany.1252    

attached base packages:
[1] tools     stats     graphics  grDevices utils     datasets  methods  
[8] base     

other attached packages:
 [1] openxlsx_4.2.3    ggrepel_0.9.1     doBy_4.6.8        patchwork_1.1.1  
 [5] forcats_0.5.1     stringr_1.4.0     dplyr_1.0.3       purrr_0.3.4      
 [9] readr_1.4.0       tidyr_1.1.2       tibble_3.0.5      tidyverse_1.3.0  
[13] ggplot2_3.3.3     R.utils_2.10.1    R.oo_1.24.0       R.methodsS3_1.8.1

loaded via a namespace (and not attached):
 [1] Rcpp_1.0.6        lubridate_1.7.9.2 lattice_0.20-41   assertthat_0.2.1 
 [5] digest_0.6.27     R6_2.5.0          cellranger_1.1.0  backports_1.2.0  
 [9] reprex_1.0.0      evaluate_0.14     httr_1.4.2        pillar_1.4.7     
[13] rlang_0.4.10      readxl_1.3.1      rstudioapi_0.13   Matrix_1.2-18    
[17] rmarkdown_2.6     labeling_0.4.2    munsell_0.5.0     broom_0.7.4      
```

```
[21] compiler_4.0.2    Deriv_4.1.2       modelr_0.1.8      xfun_0.20
[25] pkgconfig_2.0.3   htmltools_0.5.1.1 tidyselect_1.1.0  crayon_1.4.0
[29] dbplyr_2.0.0      withr_2.4.1       MASS_7.3-53       grid_4.0.2
[33] jsonlite_1.7.2    gtable_0.3.0      lifecycle_0.2.0   DBI_1.1.1
[37] magrittr_2.0.1    scales_1.1.1      zip_2.1.1         cli_2.3.0
[41] stringi_1.5.3     farver_2.0.3      fs_1.5.0          xml2_1.3.2
[45] ellipsis_0.3.1    generics_0.1.0    vctrs_0.3.6       glue_1.4.2
[49] hms_1.0.0         yaml_2.2.1        colorspace_2.0-0  rvest_0.3.6
[53] knitr_1.31        haven_2.3.1
```

RStudio version 1.3.1073.

END OF SCRIPT

Import CSV from ConfoMap ISO25178 - tool function experiment

Lisa Schunk

2021-02-04 14:45:52

Goal of the script

This script formats the output of the resulting CSV-file from applying a template computing ISO 25178 parameters in ConfoMap. The script will:

116. Read in the original CSV-file
117. Format the data

118. Write an XLSX-file and save an R object ready for further analysis in R

```
dir_in <- "analysis/raw_data"
dir_out <- "analysis/derived_data/"
```

Raw data must be located in ~/analysis/raw_data.
Formatted data will be saved in ~/analysis/derived_data/.

The knit directory for this script is the project directory.

Load packages

```
library(openxlsx)
Warning: package 'openxlsx' was built under R version 4.0.3
library(tools)
library(R.utils)
library(chron)
```

Get names, path and information of the file

```
data_file <- list.files(dir_in, pattern = "\\.csv$", full.names = TRUE)
md5_in <- md5sum(data_file)
info_in <- data.frame(file = basename(names(md5_in)), checksum = md5_in, row.names = NULL)
```

The checksum (MD5 hashes) of the imported file are:

```
         file                         checksum
1 TFE_pro.csv aca5a03e94d1efdc6197b198b5c68147
```

Read in original CSV-file

```
imp_data <- read.csv(data_file, header = FALSE, stringsAsFactors = FALSE,
                     na.strings = "*****")

str(imp_data)
'data.frame':   27 obs. of  100 variables:
 $ V1  : chr  "#" "#" "#" "27.08.2020" ...
 $ V2  : chr  "#" "#" "#" "15:01:32" ...
 $ V3  : chr  "#" "#" "#" "C:\\Users\\schunk\\Documents\\USE-WEAR\\experiment\\tool_function-
```

```
experiment\\ConfoMap\\TFE_pro --- TFE_50x_res"| __truncated__ ...
 $ V4  : chr  "OPERATOR:1" "X-axis rotation angle" "°" "-0.473512322" ...
 $ V5  : chr  "OPERATOR:1" "Y-axis rotation angle" "°" "1.731683477" ...
 $ V6  : chr  "OPERATOR:2" "a0" "nm" "-370.3850221" ...
 $ V7  : chr  "OPERATOR:2" "ax" "nm" "12.47840143" ...
 $ V8  : chr  "OPERATOR:2" "ax2" "nm" "-0.01786267" ...
 $ V9  : chr  "OPERATOR:2" "ax3" "nm" "-3.63E-06" ...
 $ V10 : chr  "OPERATOR:2" "ay" "nm" "0.843379272" ...
 $ V11 : chr  "OPERATOR:2" "axy" "nm" "0.010205056" ...
 $ V12 : chr  "OPERATOR:2" "ax2y" "nm" "2.72E-05" ...
 $ V13 : chr  "OPERATOR:2" "ay2" "nm" "-0.013967608" ...
 $ V14 : chr  "OPERATOR:2" "axy2" "nm" "-2.51E-05" ...
 $ V15 : chr  "OPERATOR:2" "ay3" "nm" "1.15E-05" ...
 $ V16 : chr  "6" "Name" "<no unit>" "TFE_50x_res --- FLT8-10 - FLT8-10_2000_C1-01-a_50x095_LSM_Topo" ...
 $ V17 : chr  "6" "Created on" "<no unit>" "8/27/2020 11:10:06 AM" ...
 $ V18 : chr  "6" "Studiable type" "<no unit>" "Surface" ...
 $ V19 : chr  "6" "Axis name - X" "<no unit>" "X" ...
 $ V20 : chr  "6" "Axis length - X" "µm" "255.4748056" ...
 $ V21 : chr  "6" "Axis size - X" "points" "1198" ...
 $ V22 : chr  "6" "Axis spacing - X" "µm" "0.213429245" ...
 $ V23 : chr  "6" "Axis name - Y" "<no unit>" "Y" ...
 $ V24 : chr  "6" "Axis length - Y" "µm" "255.4748056" ...
 $ V25 : chr  "6" "Axis size - Y" "points" "1198" ...
 $ V26 : chr  "6" "Axis spacing - Y" "µm" "0.213429245" ...
 $ V27 : chr  "6" "Axis name - Z" "<no unit>" "Z" ...
 $ V28 : chr  "6" "Layer type - Z" "<no unit>" "Topography" ...
 $ V29 : chr  "6" "Axis length - Z" "nm" "34010.19716" ...
 $ V30 : chr  "6" "Axis size - Z" "digits" "73180" ...
 $ V31 : chr  "6" "Axis spacing - Z" "nm" "0.46474716" ...
 $ V32 : chr  "6" "NM-points ratio - Z" "%" "0" ...
 $ V33 : chr  "8" "Name" "<no unit>" "TFE_50x_res --- FLT8-10 - FLT8-10-2000s-C1-01-a_50x095_LSM_Topo > Leveled
(LS-plane)" ...
 $ V34 : chr  "8" "Created on" "<no unit>" "8/27/2020 11:10:06 AM" ...
 $ V35 : chr  "8" "Studiable type" "<no unit>" "Surface" ...
 $ V36 : chr  "8" "Axis name - X" "<no unit>" "X" ...
 $ V37 : chr  "8" "Axis length - X" "µm" "255.4748056" ...
 $ V38 : chr  "8" "Axis size - X" "points" "1198" ...
 $ V39 : chr  "8" "Axis spacing - X" "µm" "0.213429245" ...
 $ V40 : chr  "8" "Axis name - Y" "<no unit>" "Y" ...
 $ V41 : chr  "8" "Axis length - Y" "µm" "255.4748056" ...
 $ V42 : chr  "8" "Axis size - Y" "points" "1198" ...
 $ V43 : chr  "8" "Axis spacing - Y" "µm" "0.213429245" ...
 $ V44 : chr  "8" "Axis name - Z" "<no unit>" "Z" ...
 $ V45 : chr  "8" "Layer type - Z" "<no unit>" "Topography" ...
 $ V46 : chr  "8" "Axis length - Z" "nm" "34296.48141" ...
 $ V47 : chr  "8" "Axis size - Z" "digits" "73796" ...
 $ V48 : chr  "8" "Axis spacing - Z" "nm" "0.46474716" ...
 $ V49 : chr  "8" "NM-points ratio - Z" "%" "0" ...
 $ V50 : chr  "15" "Name" "<no unit>" "TFE_50x_res --- FLT8-10 - FLT8-10-2000s-C1-01-a_50x095_LSM_Topo >
Leveled (LS-plane) > Form removed (LS-poly 3)"| __truncated__ ...
 $ V51 : chr  "15" "Created on" "<no unit>" "8/27/2020 11:10:06 AM" ...
 $ V52 : chr  "15" "Studiable type" "<no unit>" "Surface" ...
 $ V53 : chr  "15" "Axis name - X" "<no unit>" "X" ...
 $ V54 : chr  "15" "Axis length - X" "µm" "255.4748056" ...
 $ V55 : chr  "15" "Axis size - X" "points" "1198" ...
 $ V56 : chr  "15" "Axis spacing - X" "µm" "0.213429245" ...
 $ V57 : chr  "15" "Axis name - Y" "<no unit>" "Y" ...
 $ V58 : chr  "15" "Axis length - Y" "µm" "255.4748056" ...
 $ V59 : chr  "15" "Axis size - Y" "points" "1198" ...
 $ V60 : chr  "15" "Axis spacing - Y" "µm" "0.213429245" ...
 $ V61 : chr  "15" "Axis name - Z" "<no unit>" "Z" ...
```

```
 $ V62 : chr  "15" "Layer type - Z" "<no unit>" "Topography" ...
 $ V63 : chr  "15" "Axis length - Z" "nm" "12956.17485" ...
 $ V64 : chr  "15" "Axis size - Z" "digits" "278779" ...
 $ V65 : chr  "15" "Axis spacing - Z" "nm" "0.046474716" ...
 $ V66 : chr  "15" "NM-points ratio - Z" "%" "0" ...
 $ V67 : chr  "17" "Sq" "nm" "1639.824789" ...
 $ V68 : chr  "17" "Ssk" "<no unit>" "-0.625520875" ...
 $ V69 : chr  "17" "Sku" "<no unit>" "7.122443946" ...
 $ V70 : chr  "17" "Sp" "nm" "5602.619962" ...
 $ V71 : chr  "17" "Sv" "nm" "7353.554886" ...
 $ V72 : chr  "17" "Sz" "nm" "12956.17485" ...
 $ V73 : chr  "17" "Sa" "nm" "1080.425967" ...
 $ V74 : chr  "17" "Smr (c = 1000 nm below highest peak)" "%" "0.88718972" ...
 $ V75 : chr  "17" "Smc (p = 10.00%)" "nm" "1669.034734" ...
 $ V76 : chr  "17" "Sxp (p = 50.00%  q = 97.50%)" "nm" "4453.800909" ...
 $ V77 : chr  "17" "Sal (s = 0.2000)" "µm" "19.27134811" ...
 $ V78 : chr  "17" "Str (s = 0.2000)" "<no unit>" "0.259543727" ...
 $ V79 : chr  "17" "Std (Reference angle = 0.000°)" "°" "159.2409342" ...
 $ V80 : chr  "17" "Sdq" "<no unit>" "0.269035059" ...
 $ V81 : chr  "17" "Sdr" "%" "3.006301428" ...
 $ V82 : chr  "17" "Vm (p = 10.00%)" "µm³/µm²" "0.135390838" ...
 $ V83 : chr  "17" "Vv (p = 10.00%)" "µm³/µm²" "1.804402664" ...
 $ V84 : chr  "17" "Vmp (p = 10.00%)" "µm³/µm²" "0.135390838" ...
 $ V85 : chr  "17" "Vmc (p = 10.00%  q = 80.00%)" "µm³/µm²" "0.927873972" ...
 $ V86 : chr  "17" "Vvc (p = 10.00%  q = 80.00%)" "µm³/µm²" "1.553178741" ...
 $ V87 : chr  "17" "Vvv (p = 80.00%)" "µm³/µm²" "0.251223923" ...
 $ V88 : chr  "18" "Maximum depth of furrows" "nm" "7250.562268" ...
 $ V89 : chr  "18" "Mean depth of furrows" "nm" "1161.089383" ...
 $ V90 : chr  "18" "Mean density of furrows" "cm/cm2" "2724.29728" ...
 $ V91 : chr  "19" "First direction" "°" "89.98041753" ...
 $ V92 : chr  "19" "Second direction" "°" "135.0199217" ...
 $ V93 : chr  "19" "Third direction" "°" "0.001700073" ...
 $ V94 : chr  "20" "Isotropy" "%" "18.27056476" ...
 $ V95 : chr  "21" "Length-scale anisotropy (Sfrax) (epLsar)" "<no unit>" "0.002336563" ...
 $ V96 : chr  "21" "Length-scale anisotropy (NewEplsar)" "<no unit>" "0.018492557" ...
 $ V97 : chr  "22" "Fractal complexity (Asfc)" "<no unit>" "4.309128563" ...
 $ V98 : chr  "22" "Scale of max complexity (Smfc)" "µm²" "4.931042371" ...
 $ V99 : chr  "22" "HAsfc9 (HAsfc9)" "<no unit>" "0.662829456" ...
  [list output truncated]
```

Format data

Keep only interesting columns and rows

```
# keeps only the columns and rows of interest for the analysis
data_keep_col <- c(1:2, 16:17, 20:22, 24:26, 29:32, 67:100)
data_keep_rows <- which(imp_data[[1]] != "#")
data_keep <- imp_data[data_keep_rows, data_keep_col]
```

Add headers

```
head_data_keep <- unlist(imp_data[2, data_keep_col])
colnames(data_keep) <- gsub("\\.+", "\\.", make.names(head_data_keep))
colnames(data_keep) <- gsub("\\.$", "", colnames(data_keep))
```

Identify results using frame numbers

```
# combines the results from the different analysis based on the column numbers
# (ID from MountainsMAp)
frames <- as.numeric(unlist(imp_data[1, data_keep_col]))
Warning: NAs introduced by coercion
```

```
ID <- which(frames == 6)[-(1:2)]
ISO <- which(frames == 17)
furrow <- which(frames == 18)
diriso <- which(frames %in% 19:20)
SSFA <- which(frames %in% 21:22)
```

Shorten the names for parameters

```
# keeps only the important information of the headers
colnames(data_keep)[ISO] <- sapply(strsplit(names(data_keep)[ISO], "."), fixed = TRUE),
                         `[[`, 1)
colnames(data_keep)[SSFA] <- gsub("^([A-Za-z0-9]+\\.)+", "", colnames(data_keep)[SSFA])
```

Save units

```
# takes the units which were part of the headers and separates them; creates a data frame
var_num <- c(ID, ISO, furrow, diriso, SSFA)
# extracts 'unit' line for considered columns
units_var <- unlist(imp_data[3, data_keep_col])[var_num]
# gets names associated to the units
names(units_var) <- head_data_keep[var_num]
# puts all of it into a data.frame
units_var_table <- data.frame(variable = names(units_var), unit = units_var)
```

Convert to numeric

```
for (i in var_num) data_keep[[i]] <- as.numeric(data_keep[[i]])
```

Split the column 'Name' into several columns

```
# these lines extract the artefact ID out of the path name
stud_name <- gsub("^([A-Za-z0-9_]+( --- ))+", "", data_keep[["Name"]])
stud_name <- gsub("([A-Za-z0-9_-]*( - ))+", "", stud_name)
split_name <- do.call(rbind, strsplit(stud_name, "_"))[, 1:4]
split_loc <- do.call(rbind, strsplit(split_name[, 3], "-"))

# splits the ID in the separat information
data_final <- data.frame(split_name[, -3], split_loc, data_keep[-3],
                        stringsAsFactors = FALSE)
colnames(data_final)[1:9] <- c("Sample", "Cycle","Objective", "Location", "Area", "Spot",
                              "Analysis.date", "Analysis.time",
                              "Acquisition.date.time")
```

Format date and time columns

```
data_final[["Analysis.date"]] <- as.Date(data_final[["Analysis.date"]], format = "%d.%m.%Y")
data_final[["Analysis.time"]] <- times(data_final[["Analysis.time"]])
```

The column `data_final[["Acquisition.date.time"]]` includes several formats and is therefore left as `character` without convertion to `POSIXct`.

Add columns about site, contact material, the task and the edge angle

```
# extracts the raw material based on the ID
data_final[grep("FLT8-", data_final[["Sample"]]), "Raw.material"] <- "flint"
data_final[grep("LYDIT5-", data_final[["Sample"]]), "Raw.material"] <- "lydite"
data_final[["Raw.material"]] <- factor(data_final[["Raw.material"]])

# adds column about the contact material
data_final[grep("LYDIT5-", data_final[["Sample"]]), "Contact.material"] <- "bone plate"
data_final[grep("FLT8-", data_final[["Sample"]]), "Contact.material"] <- "bone plate"
data_final[["Contact.material"]] <- factor(data_final[["Contact.material"]])

# adds column about the task/movement
data_final[grep("FLT8-2", data_final[["Sample"]]), "Task"] <- "cutting"
```

```
data_final[grep("LYDIT5-2", data_final[["Sample"]]), "Task"] <- "cutting"
data_final[grep("FLT8-5", data_final[["Sample"]]), "Task"] <- "cutting"
data_final[grep("LYDIT5-7", data_final[["Sample"]]), "Task"] <- "cutting"

data_final[grep("FLT8-10", data_final[["Sample"]]), "Task"] <- "carving"
data_final[grep("LYDIT5-8", data_final[["Sample"]]), "Task"] <- "carving"
data_final[grep("FLT8-9", data_final[["Sample"]]), "Task"] <- "carving"
data_final[grep("LYDIT5-12", data_final[["Sample"]]), "Task"] <- "carving"
data_final[["Task"]] <- factor(data_final[["Task"]])

# adds column about the edge angle
data_final[grep("FLT8-2", data_final[["Sample"]]), "Edge.angle"] <- "45°"
data_final[grep("LYDIT5-2", data_final[["Sample"]]), "Edge.angle"] <- "45°"
data_final[grep("FLT8-5", data_final[["Sample"]]), "Edge.angle"] <- "35°"
data_final[grep("LYDIT5-7", data_final[["Sample"]]), "Edge.angle"] <- "35°"

data_final[grep("FLT8-10", data_final[["Sample"]]), "Edge.angle"] <- "45°"
data_final[grep("LYDIT5-8", data_final[["Sample"]]), "Edge.angle"] <- "45°"
data_final[grep("FLT8-9", data_final[["Sample"]]), "Edge.angle"] <- "35°"
data_final[grep("LYDIT5-12", data_final[["Sample"]]), "Edge.angle"] <- "35°"
data_final[["Edge.angle"]] <- factor(data_final[["Edge.angle"]])
```

Ignore some columns and reorder columns

```
data_final <- data_final[c(1:2, 4:6, 3, 54:57, 7:9, 10:53)]
```

Add units as comment()

```
comment(data_final) <- units_var
```

Type comment(data_final) to check the units of the columns.

Check the result

```
str(data_final)
'data.frame':   24 obs. of  57 variables:
 $ Sample                : chr  "FLT8-10" "FLT8-10" "FLT8-10" "FLT8-2" ...
 $ Cycle                 : chr  "2000" "2000" "2000" "2000" ...
 $ Location              : chr  "C1" "C1" "C1" "D1" ...
 $ Area                  : chr  "01" "01" "01" "01" ...
 $ Spot                  : chr  "a" "b" "c" "a" ...
 $ Objective             : chr  "50x095" "50x095" "50x095" "50x095" ...
 $ Raw.material          : Factor w/ 2 levels "flint","lydite": 1 1 1 1 1 1 1 1 1 1 ...
 $ Contact.material      : Factor w/ 1 level "bone plate": 1 1 1 1 1 1 1 1 1 1 ...
 $ Task                  : Factor w/ 2 levels "carving","cutting": 1 1 1 2 2 2 2 2 2 1 ...
 $ Edge.angle            : Factor w/ 2 levels "35°","45°": 2 2 2 2 2 2 1 1 1 1 ...
 $ Analysis.date         : Date, format: "2020-08-27" "2020-08-27" ...
 $ Analysis.time         : 'times' num  15:01:32 15:02:11 15:02:48 15:03:28 15:04:06 ...
  ..- attr(*, "format")= chr "h:m:s"
 $ Acquisition.date.time : chr  "8/27/2020 11:10:06 AM" "8/27/2020 11:41:47 AM" "8/27/2020 11:54:14 AM" "8/26/2020 4:10:04 PM" ...
 $ Axis.length.X         : num  255 255 255 255 255 ...
 $ Axis.size.X           : num  1198 1198 1198 1198 1198 ...
 $ Axis.spacing.X        : num  0.213 0.213 0.213 0.213 0.213 ...
 $ Axis.length.Y         : num  255 255 255 255 255 ...
 $ Axis.size.Y           : num  1198 1198 1198 1198 1198 ...
 $ Axis.spacing.Y        : num  0.213 0.213 0.213 0.213 0.213 ...
 $ Axis.length.Z         : num  34010 95224 7771 60579 60641 ...
 $ Axis.size.Z           : num  73180 61441 61664 52314 57436 ...
 $ Axis.spacing.Z        : num  0.465 1.55 0.126 1.158 1.056 ...
 $ NM.points.ratio.Z     : num  0 0 0 0 0 0 0 0 0 0 ...
 $ Sq                    : num  1640 7217 315 2525 1718 ...
 $ Ssk                   : num  -0.626 0.517 -1.202 -0.51 -1.432 ...
```

```
 $ Sku                      : num  7.12 4.34 6.34 6.94 12.01 ...
 $ Sp                       : num  5603 24832 716 8900 5842 ...
 $ Sv                       : num  7354 24749 1929 12958 11581 ...
 $ Sz                       : num  12956 49581 2645 21858 17423 ...
 $ Sa                       : num  1080 5359 239 1814 1117 ...
 $ Smr                      : num  0.887 0.151 84.156 0.519 0.768 ...
 $ Smc                      : num  1669 8453 350 2620 1633 ...
 $ Sxp                      : num  4454 13827 770 5202 3974 ...
 $ Sal                      : num  19.3 18.3 11.3 20.1 17.7 ...
 $ Str                      : num  0.26 NA 0.286 NA 0.154 ...
 $ Std                      : num  159 169 156 148 148 ...
 $ Sdq                      : num  0.269 1.165 0.166 0.336 0.294 ...
 $ Sdr                      : num  3.01 19.2 1.35 4.62 3.61 ...
 $ Vm                       : num  0.1354 0.6714 0.0093 0.1819 0.1149 ...
 $ Vv                       : num  1.804 9.125 0.359 2.802 1.748 ...
 $ Vmp                      : num  0.1354 0.6714 0.0093 0.1819 0.1149 ...
 $ Vmc                      : num  0.928 5.19 0.266 1.856 1.034 ...
 $ Vvc                      : num  1.553 8.34 0.309 2.488 1.485 ...
 $ Vvv                      : num  0.2512 0.7845 0.0502 0.314 0.2637 ...
 $ Maximum.depth.of.furrows: num  7251 27509 2061 7182 6417 ...
 $ Mean.depth.of.furrows   : num  1161 8568 433 2115 1408 ...
 $ Mean.density.of.furrows : num  2724 2613 3036 2486 2519 ...
 $ First.direction         : num  90 169 90 135 135 ...
 $ Second.direction        : num  135 174 154 154 154 ...
 $ Third.direction         : num  0.0017 179.9953 135.0327 0.0028 161.4949 ...
 $ Isotropy                : num  18.3 NA 38.2 NA 35.8 ...
 $ epLsar                  : num  0.00234 0.00814 0.00109 0.00501 0.00521 ...
 $ NewEplsar               : num  0.0185 0.021 0.0178 0.0199 0.02 ...
 $ Asfc                    : num  4.31 37.84 2.9 5.11 4.67 ...
 $ Smfc                    : num  4.93 759.24 3.3 32.33 6.9 ...
 $ HAsfc9                  : num  0.6628 6.9889 0.0727 0.5633 0.4985 ...
 $ HAsfc81                 : num  0.708 6.728 0.198 1.53 1.352 ...
 - attr(*, "comment")= Named chr [1:44] "µm" "points" "µm" "µm" ...
  ..- attr(*, "names")= chr [1:44] "Axis length - X" "Axis size - X" "Axis spacing - X" "Axis length - Y" ...
head(data_final)
   Sample Cycle Location Area Spot Objective Raw.material Contact.material
4 FLT8-10  2000       C1   01    a    50x095        flint       bone plate
5 FLT8-10  2000       C1   01    b    50x095        flint       bone plate
6 FLT8-10  2000       C1   01    c    50x095        flint       bone plate
7  FLT8-2  2000       D1   01    a    50x095        flint       bone plate
8  FLT8-2  2000       D1   01    b    50x095        flint       bone plate
9  FLT8-2  2000       D1   01    c    50x095        flint       bone plate
     Task Edge.angle Analysis.date Analysis.time Acquisition.date.time
4 carving        45°    2020-08-27      15:01:32 8/27/2020 11:10:06 AM
5 carving        45°    2020-08-27      15:02:11 8/27/2020 11:41:47 AM
6 carving        45°    2020-08-27      15:02:48 8/27/2020 11:54:14 AM
7 cutting        45°    2020-08-27      15:03:28  8/26/2020 4:10:04 PM
8 cutting        45°    2020-08-27      15:04:06  8/26/2020 3:41:55 PM
9 cutting        45°    2020-08-27      15:04:42  8/26/2020 3:12:27 PM
  Axis.length.X Axis.size.X Axis.spacing.X Axis.length.Y Axis.size.Y
4      255.4748        1198      0.2134292      255.4748        1198
5      255.4748        1198      0.2134292      255.4748        1198
6      255.4748        1198      0.2134292      255.4748        1198
7      255.4748        1198      0.2134292      255.4748        1198
8      255.4748        1198      0.2134292      255.4748        1198
9      255.4748        1198      0.2134292      255.4748        1198
  Axis.spacing.Y Axis.length.Z Axis.size.Z Axis.spacing.Z NM.points.ratio.Z
4      0.2134292     34010.197       73180      0.4647472                 0
5      0.2134292     95223.581       61441      1.5498377                 0
6      0.2134292      7771.318       61664      0.1260268                 0
7      0.2134292     60578.579       52314      1.1579803                 0
```

```
8      0.2134292     60640.746       57436      1.0557968                0
9      0.2134292     47752.177       64939      0.7353390                0
         Sq        Ssk       Sku         Sp        Sv        Sz        Sa
4 1639.8248 -0.6255209  7.122444  5602.6200  7353.555 12956.175 1080.4260
5 7217.0443  0.5167268  4.344765 24832.4303 24748.739 49581.169 5359.1126
6  315.3104 -1.2015183  6.336598   715.8449  1928.929  2644.774  238.6203
7 2524.8750 -0.5100466  6.937178  8900.2362 12958.262 21858.498 1813.9692
8 1718.2963 -1.4319687 12.005263  5841.7238 11581.352 17423.076 1117.1372
9 2545.8971 -0.7719253  8.618212  8665.1609 14245.575 22910.736 1769.3464
         Smr       Smc        Sxp       Sal       Str      Std       Sdq
4  0.8871897 1669.0347  4453.8009 19.27135 0.2595437 159.2409 0.2690351
5  0.1508375 8453.3226 13827.0922 18.33296        NA 169.0020 1.1647737
6 84.1558025  349.5086   770.2046 11.34748 0.2859776 156.2535 0.1656981
7  0.5191462 2619.7487  5201.6690 20.11496        NA 148.4946 0.3357202
8  0.7680698 1633.4928  3973.5568 17.69425 0.1541349 148.4927 0.2936511
9  0.4101862 2736.5890  4848.5961 23.58091 0.5143067 140.5092 0.3499047
        Sdr          Vm         Vv         Vmp        Vmc       Vvc        Vvv
4  3.006301 0.135390838 1.8044027 0.135390838 0.9278740 1.553179 0.25122392
5 19.198216 0.671390167 9.1247611 0.671390167 5.1904172 8.340286 0.78447482
6  1.348053 0.009299266 0.3588037 0.009299266 0.2655201 0.308595 0.05020862
7  4.622614 0.181895348 2.8016366 0.181895348 1.8557557 2.487597 0.31403995
8  3.607732 0.114859889 1.7483200 0.114859889 1.0337459 1.484646 0.26367368
9  4.759987 0.184034352 2.9206306 0.184034352 1.6632884 2.589177 0.33145377
  Maximum.depth.of.furrows Mean.depth.of.furrows Mean.density.of.furrows
4                 7250.562             1161.0894                2724.297
5                27509.465             8568.3982                2612.809
6                 2061.349              433.1047                3035.797
7                 7181.678             2114.8766                2486.011
8                 6416.840             1408.2987                2519.403
9                 7852.023             1610.6934                2486.264
  First.direction Second.direction Third.direction Isotropy       epLsar
4        89.98042         135.0199    1.700073e-03 18.27056 0.002336563
5       168.71931         173.7408    1.799953e+02       NA 0.008143085
6        89.99392         153.5202    1.350327e+02 38.23035 0.001092762
7       134.98947         153.5122    2.795585e-03       NA 0.005005935
8       134.99394         153.5137    1.614949e+02 35.83259 0.005207355
9       179.99879         134.9911    1.535509e+02 22.87662 0.001825272
   NewEplsar      Asfc       Smfc     HAsfc9   HAsfc81
4 0.01849256  4.309129   4.931042 0.66282946 0.7077260
5 0.02100014 37.843449 759.238285 6.98892403 6.7282198
6 0.01777594  2.897573   3.295669 0.07267422 0.1976211
7 0.01986757  5.112870  32.328292 0.56331153 1.5301426
8 0.01996242  4.673498   6.898712 0.49849387 1.3522344
9 0.01807974  6.785818  11.805786 0.72980153 0.9899596
```

Save data

Format name of output file

```
file_out <- "TFE_use-wear"
```

The files will be saved as "~/TFE_use-wear.[ext]".

Write to XLSX

```
write.xlsx(list(data = data_final, units = units_var_table),
           file = paste0(dir_out, file_out, ".xlsx"))
```

Save R object

```
saveObject(data_final, file = paste0(dir_out, file_out, ".Rbin"))
```

sessionInfo() and RStudio version

```
sessionInfo()
R version 4.0.2 (2020-06-22)
Platform: x86_64-w64-mingw32/x64 (64-bit)
Running under: Windows 10 x64 (build 19041)

Matrix products: default

locale:
[1] LC_COLLATE=German_Germany.1252  LC_CTYPE=German_Germany.1252
[3] LC_MONETARY=German_Germany.1252 LC_NUMERIC=C
[5] LC_TIME=German_Germany.1252

attached base packages:
[1] tools     stats     graphics  grDevices utils     datasets  methods
[8] base

other attached packages:
[1] chron_2.3-56      R.utils_2.10.1    R.oo_1.24.0       R.methodsS3_1.8.1
[5] openxlsx_4.2.3

loaded via a namespace (and not attached):
 [1] Rcpp_1.0.6        digest_0.6.27     magrittr_2.0.1    evaluate_0.14
 [5] zip_2.1.1         rlang_0.4.10      stringi_1.5.3     rmarkdown_2.6
 [9] stringr_1.4.0     xfun_0.20         yaml_2.2.1        compiler_4.0.2
[13] htmltools_0.5.1.1 knitr_1.31
```

RStudio version 1.3.1073.

END OF SCRIPT

Summary statistics - tool function experiment

Lisa Schunk
2021-02-04 14:51:19

Goal of the script

This script computes standard descriptive statistics for each group.
The groups are based on:

119. Raw material
120. Spots (replicas)
121. Task + edge angle

It computes the following statistics:

122. n (sample size = length): number of measurements
123. smallest value (min)
124. largest value (max)
125. mean
126. median
127. standard deviation (sd)

```
dir_in <- "analysis/derived_data/"
dir_out <- "analysis/summary_stats/"
```

Raw data must be located in ~/analysis/derived_data/.
Formatted data will be saved in ~/analysis/summary_stats/. The knit directory for this script is the project directory.

Load packages

```
library(openxlsx)
Warning: package 'openxlsx' was built under R version 4.0.3
library(R.utils)
library(tools)
library(doBy)
Warning: package 'doBy' was built under R version 4.0.3
```

Get names, path and information of the file

```
data_file <- list.files(dir_in, pattern = "\\.xlsx$", full.names = TRUE)
md5_in <- md5sum(data_file)
info_in <- data.frame(file = basename(names(md5_in)), checksum = md5_in, row.names = NULL)
```

The checksum (MD5 hashes) of the imported file is

```
               file                         checksum
1 TFE_use-wear.xlsx 894a29ed63d7a8b55ea6ff4b15e59623
```

Load data into R object

```
imp_data <- loadObject(paste0(dir_in, "TFE_use-wear.Rbin"))
```

The imported file is: "~/analysis/derived_data/TFE_use-wear.xlsx"

---

4. Define numeric variables

```
num.var <- 24:length(imp_data)
```

The following variables will be used:

```
[24] Sq
[25] Ssk
[26] Sku
[27] Sp
[28] Sv
[29] Sz
[30] Sa
[31] Smr
[32] Smc
[33] Sxp
[34] Sal
[35] Str
[36] Std
[37] Sdq
[38] Sdr
[39] Vm
[40] Vv
[41] Vmp
[42] Vmc
[43] Vvc
[44] Vvv
[45] Maximum.depth.of.furrows
[46] Mean.depth.of.furrows
[47] Mean.density.of.furrows
[48] First.direction
[49] Second.direction
[50] Third.direction
[51] Isotropy
[52] epLsar
[53] NewEplsar
[54] Asfc
[55] Smfc
[56] HAsfc9
[57] HAsfc81
```

Compute summary statistics

Create function to compute the statistics at once

```
nminmaxmeanmedsd <- function(x){
  y <- x[!is.na(x)]
  n_test <- length(y)
  min_test <- min(y)
  max_test <- max(y)
  mean_test <- mean(y)
  med_test <- median(y)
  sd_test <- sd(y)
```

```
    out <- c(n_test, min_test, max_test, mean_test, med_test, sd_test)
    names(out) <- c("n", "min", "max", "mean", "median", "sd")
    return(out)
}
```

Compute the summary statistics in groups

Spots

```
spot <- summaryBy(.~ Sample + Location + Area,
                  data = imp_data[c("Sample","Location","Area" ,names(imp_data)[num.var])],
                  FUN = nminmaxmeanmedsd)
str(spot)
'data.frame':   8 obs. of  207 variables:
 $ Sample                 : chr  "FLT8-10" "FLT8-2" "FLT8-5" "FLT8-9" ...
 $ Location               : chr  "C1" "D1" "C1" "B1" ...
 $ Area                   : chr  "01" "01" "01" "01" ...
 $ Sq.n                   : num  3 3 3 3 3 3 3 3
 $ Sq.min                 : num  315 1718 196 153 231 ...
 $ Sq.max                 : num  7217 2546 226 13075 433 ...
 $ Sq.mean                : num  3057 2263 215 4465 323 ...
 $ Sq.median              : num  1640 2525 223 167 306 ...
 $ Sq.sd                  : num  3662.7 471.9 16.6 7456.4 102.1 ...
 $ Ssk.n                  : num  3 3 3 3 3 3 3 3
 $ Ssk.min                : num  -1.202 -1.432 -3.721 -0.315 -3.03 ...
 $ Ssk.max                : num  0.517 -0.51 -0.791 3.156 2.896 ...
 $ Ssk.mean               : num  -0.437 -0.905 -2.155 1.664 -0.595 ...
 $ Ssk.median             : num  -0.626 -0.772 -1.953 2.152 -1.65 ...
 $ Ssk.sd                 : num  0.875 0.475 1.475 1.786 3.1 ...
 $ Sku.n                  : num  3 3 3 3 3 3 3 3
 $ Sku.min                : num  4.34 6.94 4.74 4.58 18.08 ...
 $ Sku.max                : num  7.12 12.01 27.61 31.11 32.75 ...
 $ Sku.mean               : num  5.93 9.19 14.2 18.52 23.4 ...
 $ Sku.median             : num  6.34 8.62 10.24 19.86 19.36 ...
 $ Sku.sd                 : num  1.43 2.58 11.94 13.31 8.13 ...
 $ Sp.n                   : num  3 3 3 3 3 3 3 3
 $ Sp.min                 : num  716 5842 525 1458 1712 ...
 $ Sp.max                 : num  24832 8900 620 26706 3221 ...
 $ Sp.mean                : num  10384 7802 572 9910 2217 ...
 $ Sp.median              : num  5603 8665 570 1565 1717 ...
 $ Sp.sd                  : num  12749.4 1702 47.6 14546.2 870 ...
 $ Sv.n                   : num  3 3 3 3 3 3 3 3
 $ Sv.min                 : num  1929 11581 1068 768 1264 ...
 $ Sv.max                 : num  24749 14246 2162 99093 3612 ...
 $ Sv.mean                : num  11344 12928 1552 33611 2400 ...
 $ Sv.median              : num  7354 12958 1426 971 2322 ...
 $ Sv.sd                  : num  11922 1332 557 56710 1176 ...
 $ Sz.n                   : num  3 3 3 3 3 3 3 3
 $ Sz.min                 : num  2645 17423 1688 2333 4034 ...
 $ Sz.max                 : num  49581 22911 2686 125800 5329 ...
 $ Sz.mean                : num  21727 20731 2124 43521 4616 ...
 $ Sz.median              : num  12956 21858 1996 2429 4486 ...
 $ Sz.sd                  : num  24667 2912 511 71256 657 ...
 $ Sa.n                   : num  3 3 3 3 3 3 3 3
 $ Sa.min                 : num  238.6 1117.1 138.7 85.2 157 ...
 $ Sa.max                 : num  5359 1814 166 10906 266 ...
 $ Sa.mean                : num  2226 1567 148 3695 203 ...
 $ Sa.median              : num  1080.4 1769.3 139.3 93.9 184.6 ...
 $ Sa.sd                  : num  2745.8 390.1 15.4 6244.7 56.6 ...
 $ Smr.n                  : num  3 3 3 3 3 3 3 3
 $ Smr.min                : num  0.151 0.41 94.062 0.296 0.345 ...
 $ Smr.max                : num  84.156 0.768 97.359 1.943 0.77 ...
```

```
 $ Smr.mean                          : num  28.398 0.566 96.055 1.109 0.493 ...
 $ Smr.median                        : num  0.887 0.519 96.743 1.088 0.365 ...
 $ Smr.sd                            : num  48.289 0.183 1.753 0.824 0.24 ...
 $ Smc.n                             : num  3 3 3 3 3 3 3 3
 $ Smc.min                           : num  349.5 1633.5 191.7 95.7 199 ...
 $ Smc.max                           : num  8453 2737 248 18265 335 ...
 $ Smc.mean                          : num  3491 2330 211 6154 252 ...
 $ Smc.median                        : num  1669 2619.7 194.4 99.7 223.2 ...
 $ Smc.sd                            : num  4348.2 606 31.9 10489 72.5 ...
 $ Sxp.n                             : num  3 3 3 3 3 3 3 3
 $ Sxp.min                           : num  770 3974 526 280 561 ...
 $ Sxp.max                           : num  13827 5202 576 18794 1190 ...
 $ Sxp.mean                          : num  6350 4675 544 6460 796 ...
 $ Sxp.median                        : num  4454 4849 530 305 637 ...
 $ Sxp.sd                            : num  6732 632 28 10682 343 ...
 $ Sal.n                             : num  3 3 3 3 3 3 3 3
 $ Sal.min                           : num  11.35 17.69 9.98 9.34 6.8 ...
 $ Sal.max                           : num  19.27 23.58 17.34 46.79 9.97 ...
 $ Sal.mean                          : num  16.32 20.46 13.43 22.24 8.58 ...
 $ Sal.median                        : num  18.33 20.11 12.98 10.58 8.96 ...
 $ Sal.sd                            : num  4.33 2.96 3.7 21.27 1.62 ...
 $ Str.n                             : num  2 2 3 2 3 3 3 3
 $ Str.min                           : num  0.26 0.154 0.222 0.689 0.139 ...
 $ Str.max                           : num  0.286 0.514 0.844 0.714 0.544 ...
 $ Str.mean                          : num  0.273 0.334 0.446 0.701 0.386 ...
 $ Str.median                        : num  0.273 0.334 0.272 0.701 0.476 ...
 $ Str.sd                            : num  0.0187 0.2547 0.3456 0.0183 0.2168 ...
 $ Std.n                             : num  3 3 3 3 3 3 3 3
 $ Std.min                           : num  156.3 140.5 151.7 25 79.3 ...
 $ Std.max                           : num  169 148.5 151.8 176.5 99.7 ...
 $ Std.mean                          : num  161.5 145.8 151.7 88.4 87 ...
 $ Std.median                        : num  159.2 148.5 151.7 63.8 82 ...
 $ Std.sd                            : num  6.66741 4.60984 0.00718 78.70957 11.12649 ...
 $ Sdq.n                             : num  3 3 3 3 3 3 3 3
 $ Sdq.min                           : num  0.1657 0.2937 0.0927 0.1005 0.1363 ...
 $ Sdq.max                           : num  1.165 0.35 0.102 1.551 0.198 ...
 $ Sdq.mean                          : num  0.5332 0.3264 0.0979 0.5869 0.1611 ...
 $ Sdq.median                        : num  0.269 0.3357 0.0994 0.109 0.1493 ...
 $ Sdq.sd                            : num  0.54942 0.02926 0.00469 0.83509 0.03229 ...
 $ Sdr.n                             : num  3 3 3 3 3 3 3 3
 $ Sdr.min                           : num  1.348 3.608 0.421 0.495 0.906 ...
 $ Sdr.max                           : num  19.198 4.76 0.511 27.267 1.829 ...
 $ Sdr.mean                          : num  7.851 4.33 0.474 9.446 1.264 ...
 $ Sdr.median                        : num  3.006 4.623 0.489 0.578 1.057 ...
 $ Sdr.sd                            : num  9.862 0.6294 0.0472 15.4327 0.4948 ...
 $ Vm.n                              : num  3 3 3 3 3 3 3 3
 $ Vm.min                            : num  0.0093 0.11486 0.00505 0.01399 0.00937 ...
 $ Vm.max                            : num  0.67139 0.18403 0.00995 0.29933 0.02147 ...
 $ Vm.mean                           : num  0.27203 0.16026 0.00697 0.11089 0.01434 ...
 $ Vm.median                         : num  0.1354 0.1819 0.0059 0.0193 0.0122 ...
 $ Vm.sd                             : num  0.35156 0.03933 0.00262 0.16322 0.00634 ...
  [list output truncated]
```

Task and edge angel

```
task <- summaryBy(.~ Sample + Task + Edge.angle,
                  data = imp_data[c("Sample", "Task", "Edge.angle",
                  names(imp_data)[num.var])], FUN = nminmaxmeanmedsd)
str(task)
'data.frame':   8 obs. of  207 variables:
 $ Sample                            : chr  "FLT8-10" "FLT8-2" "FLT8-5" "FLT8-9" ...
 $ Task                              : Factor w/ 2 levels "carving","cutting": 1 2 2 1 1 2 2 1
```

```
$ Edge.angle : Factor w/ 2 levels "35°","45°": 2 2 1 1 1 2 1 2
$ Sq.n : num 3 3 3 3 3 3 3 3
$ Sq.min : num 315 1718 196 153 231 ...
$ Sq.max : num 7217 2546 226 13075 433 ...
$ Sq.mean : num 3057 2263 215 4465 323 ...
$ Sq.median : num 1640 2525 223 167 306 ...
$ Sq.sd : num 3662.7 471.9 16.6 7456.4 102.1 ...
$ Ssk.n : num 3 3 3 3 3 3 3 3
$ Ssk.min : num -1.202 -1.432 -3.721 -0.315 -3.03 ...
$ Ssk.max : num 0.517 -0.51 -0.791 3.156 2.896 ...
$ Ssk.mean : num -0.437 -0.905 -2.155 1.664 -0.595 ...
$ Ssk.median : num -0.626 -0.772 -1.953 2.152 -1.65 ...
$ Ssk.sd : num 0.875 0.475 1.475 1.786 3.1 ...
$ Sku.n : num 3 3 3 3 3 3 3 3
$ Sku.min : num 4.34 6.94 4.74 4.58 18.08 ...
$ Sku.max : num 7.12 12.01 27.61 31.11 32.75 ...
$ Sku.mean : num 5.93 9.19 14.2 18.52 23.4 ...
$ Sku.median : num 6.34 8.62 10.24 19.86 19.36 ...
$ Sku.sd : num 1.43 2.58 11.94 13.31 8.13 ...
$ Sp.n : num 3 3 3 3 3 3 3 3
$ Sp.min : num 716 5842 525 1458 1712 ...
$ Sp.max : num 24832 8900 620 26706 3221 ...
$ Sp.mean : num 10384 7802 572 9910 2217 ...
$ Sp.median : num 5603 8665 570 1565 1717 ...
$ Sp.sd : num 12749.4 1702 47.6 14546.2 870 ...
$ Sv.n : num 3 3 3 3 3 3 3 3
$ Sv.min : num 1929 11581 1068 768 1264 ...
$ Sv.max : num 24749 14246 2162 99093 3612 ...
$ Sv.mean : num 11344 12928 1552 33611 2400 ...
$ Sv.median : num 7354 12958 1426 971 2322 ...
$ Sv.sd : num 11922 1332 557 56710 1176 ...
$ Sz.n : num 3 3 3 3 3 3 3 3
$ Sz.min : num 2645 17423 1688 2333 4034 ...
$ Sz.max : num 49581 22911 2686 125800 5329 ...
$ Sz.mean : num 21727 20731 2124 43521 4616 ...
$ Sz.median : num 12956 21858 1996 2429 4486 ...
$ Sz.sd : num 24667 2912 511 71256 657 ...
$ Sa.n : num 3 3 3 3 3 3 3 3
$ Sa.min : num 238.6 1117.1 138.7 85.2 157 ...
$ Sa.max : num 5359 1814 166 10906 266 ...
$ Sa.mean : num 2226 1567 148 3695 203 ...
$ Sa.median : num 1080.4 1769.3 139.3 93.9 184.6 ...
$ Sa.sd : num 2745.8 390.1 15.4 6244.7 56.6 ...
$ Smr.n : num 3 3 3 3 3 3 3 3
$ Smr.min : num 0.151 0.41 94.062 0.296 0.345 ...
$ Smr.max : num 84.156 0.768 97.359 1.943 0.77 ...
$ Smr.mean : num 28.398 0.566 96.055 1.109 0.493 ...
$ Smr.median : num 0.887 0.519 96.743 1.088 0.365 ...
$ Smr.sd : num 48.289 0.183 1.753 0.824 0.24 ...
$ Smc.n : num 3 3 3 3 3 3 3 3
$ Smc.min : num 349.5 1633.5 191.7 95.7 199 ...
$ Smc.max : num 8453 2737 248 18265 335 ...
$ Smc.mean : num 3491 2330 211 6154 252 ...
$ Smc.median : num 1669 2619.7 194.4 99.7 223.2 ...
$ Smc.sd : num 4348.2 606 31.9 10489 72.5 ...
$ Sxp.n : num 3 3 3 3 3 3 3 3
$ Sxp.min : num 770 3974 526 280 561 ...
$ Sxp.max : num 13827 5202 576 18794 1190 ...
$ Sxp.mean : num 6350 4675 544 6460 796 ...
$ Sxp.median : num 4454 4849 530 305 637 ...
$ Sxp.sd : num 6732 632 28 10682 343 ...
```

```
 $ Sal.n                     : num  3 3 3 3 3 3 3 3
 $ Sal.min                   : num  11.35 17.69 9.98 9.34 6.8 ...
 $ Sal.max                   : num  19.27 23.58 17.34 46.79 9.97 ...
 $ Sal.mean                  : num  16.32 20.46 13.43 22.24 8.58 ...
 $ Sal.median                : num  18.33 20.11 12.98 10.58 8.96 ...
 $ Sal.sd                    : num  4.33 2.96 3.7 21.27 1.62 ...
 $ Str.n                     : num  2 2 3 2 3 3 3 3
 $ Str.min                   : num  0.26 0.154 0.222 0.689 0.139 ...
 $ Str.max                   : num  0.286 0.514 0.844 0.714 0.544 ...
 $ Str.mean                  : num  0.273 0.334 0.446 0.701 0.386 ...
 $ Str.median                : num  0.273 0.334 0.272 0.701 0.476 ...
 $ Str.sd                    : num  0.0187 0.2547 0.3456 0.0183 0.2168 ...
 $ Std.n                     : num  3 3 3 3 3 3 3 3
 $ Std.min                   : num  156.3 140.5 151.7 25 79.3 ...
 $ Std.max                   : num  169 148.5 151.8 176.5 99.7 ...
 $ Std.mean                  : num  161.5 145.8 151.7 88.4 87 ...
 $ Std.median                : num  159.2 148.5 151.7 63.8 82 ...
 $ Std.sd                    : num  6.66741 4.60984 0.00718 78.70957 11.12649 ...
 $ Sdq.n                     : num  3 3 3 3 3 3 3 3
 $ Sdq.min                   : num  0.1657 0.2937 0.0927 0.1005 0.1363 ...
 $ Sdq.max                   : num  1.165 0.35 0.102 1.551 0.198 ...
 $ Sdq.mean                  : num  0.5332 0.3264 0.0979 0.5869 0.1611 ...
 $ Sdq.median                : num  0.269 0.3357 0.0994 0.109 0.1493 ...
 $ Sdq.sd                    : num  0.54942 0.02926 0.00469 0.83509 0.03229 ...
 $ Sdr.n                     : num  3 3 3 3 3 3 3 3
 $ Sdr.min                   : num  1.348 3.608 0.421 0.495 0.906 ...
 $ Sdr.max                   : num  19.198 4.76 0.511 27.267 1.829 ...
 $ Sdr.mean                  : num  7.851 4.33 0.474 9.446 1.264 ...
 $ Sdr.median                : num  3.006 4.623 0.489 0.578 1.057 ...
 $ Sdr.sd                    : num  9.862 0.6294 0.0472 15.4327 0.4948 ...
 $ Vm.n                      : num  3 3 3 3 3 3 3 3
 $ Vm.min                    : num  0.0093 0.11486 0.00505 0.01399 0.00937 ...
 $ Vm.max                    : num  0.67139 0.18403 0.00995 0.29933 0.02147 ...
 $ Vm.mean                   : num  0.27203 0.16026 0.00697 0.11089 0.01434 ...
 $ Vm.median                 : num  0.1354 0.1819 0.0059 0.0193 0.0122 ...
 $ Vm.sd                     : num  0.35156 0.03933 0.00262 0.16322 0.00634 ...
  [list output truncated]
```

Raw material

```
raw_material <- summaryBy(.~ Raw.material + Task + Edge.angle,
                   data=imp_data[c("Raw.material","Task","Edge.angle",
                   names(imp_data)[num.var])], FUN = nminmaxmeanmedsd)
str(raw_material)
'data.frame':   8 obs. of  207 variables:
 $ Raw.material              : Factor w/ 2 levels "flint","lydite": 1 1 1 1 2 2 2 2
 $ Task                      : Factor w/ 2 levels "carving","cutting": 1 1 2 2 1 1 2 2
 $ Edge.angle                : Factor w/ 2 levels "35°","45°": 1 2 1 2 1 2 1 2
 $ Sq.n                      : num  3 3 3 3 3 3 3 3
 $ Sq.min                    : num  153 315 196 1718 231 ...
 $ Sq.max                    : num  13075 7217 226 2546 433 ...
 $ Sq.mean                   : num  4465 3057 215 2263 323 ...
 $ Sq.median                 : num  167 1640 223 2525 306 ...
 $ Sq.sd                     : num  7456.4 3662.7 16.6 471.9 102.1 ...
 $ Ssk.n                     : num  3 3 3 3 3 3 3 3
 $ Ssk.min                   : num  -0.315 -1.202 -3.721 -1.432 -3.03 ...
 $ Ssk.max                   : num  3.156 0.517 -0.791 -0.51 2.896 ...
 $ Ssk.mean                  : num  1.664 -0.437 -2.155 -0.905 -0.595 ...
 $ Ssk.median                : num  2.152 -0.626 -1.953 -0.772 -1.65 ...
 $ Ssk.sd                    : num  1.786 0.875 1.475 0.475 3.1 ...
 $ Sku.n                     : num  3 3 3 3 3 3 3 3
 $ Sku.min                   : num  4.58 4.34 4.74 6.94 18.08 ...
```

```
$ Sku.max                : num  31.11 7.12 27.61 12.01 32.75 ...
$ Sku.mean               : num  18.52 5.93 14.2 9.19 23.4 ...
$ Sku.median             : num  19.86 6.34 10.24 8.62 19.36 ...
$ Sku.sd                 : num  13.31 1.43 11.94 2.58 8.13 ...
$ Sp.n                   : num  3 3 3 3 3 3 3 3
$ Sp.min                 : num  1458 716 525 5842 1712 ...
$ Sp.max                 : num  26706 24832 620 8900 3221 ...
$ Sp.mean                : num  9910 10384 572 7802 2217 ...
$ Sp.median              : num  1565 5603 570 8665 1717 ...
$ Sp.sd                  : num  14546.2 12749.4 47.6 1702 870 ...
$ Sv.n                   : num  3 3 3 3 3 3 3 3
$ Sv.min                 : num  768 1929 1068 11581 1264 ...
$ Sv.max                 : num  99093 24749 2162 14246 3612 ...
$ Sv.mean                : num  33611 11344 1552 12928 2400 ...
$ Sv.median              : num  971 7354 1426 12958 2322 ...
$ Sv.sd                  : num  56710 11922 557 1332 1176 ...
$ Sz.n                   : num  3 3 3 3 3 3 3 3
$ Sz.min                 : num  2333 2645 1688 17423 4034 ...
$ Sz.max                 : num  125800 49581 2686 22911 5329 ...
$ Sz.mean                : num  43521 21727 2124 20731 4616 ...
$ Sz.median              : num  2429 12956 1996 21858 4486 ...
$ Sz.sd                  : num  71256 24667 511 2912 657 ...
$ Sa.n                   : num  3 3 3 3 3 3 3 3
$ Sa.min                 : num  85.2 238.6 138.7 1117.1 157 ...
$ Sa.max                 : num  10906 5359 166 1814 266 ...
$ Sa.mean                : num  3695 2226 148 1567 203 ...
$ Sa.median              : num  93.9 1080.4 139.3 1769.3 184.6 ...
$ Sa.sd                  : num  6244.7 2745.8 15.4 390.1 56.6 ...
$ Smr.n                  : num  3 3 3 3 3 3 3 3
$ Smr.min                : num  0.296 0.151 94.062 0.41 0.345 ...
$ Smr.max                : num  1.943 84.156 97.359 0.768 0.77 ...
$ Smr.mean               : num  1.109 28.398 96.055 0.566 0.493 ...
$ Smr.median             : num  1.088 0.887 96.743 0.519 0.365 ...
$ Smr.sd                 : num  0.824 48.289 1.753 0.183 0.24 ...
$ Smc.n                  : num  3 3 3 3 3 3 3 3
$ Smc.min                : num  95.7 349.5 191.7 1633.5 199 ...
$ Smc.max                : num  18265 8453 248 2737 335 ...
$ Smc.mean               : num  6154 3491 211 2330 252 ...
$ Smc.median             : num  99.7 1669 194.4 2619.7 223.2 ...
$ Smc.sd                 : num  10489 4348.2 31.9 606 72.5 ...
$ Sxp.n                  : num  3 3 3 3 3 3 3 3
$ Sxp.min                : num  280 770 526 3974 561 ...
$ Sxp.max                : num  18794 13827 576 5202 1190 ...
$ Sxp.mean               : num  6460 6350 544 4675 796 ...
$ Sxp.median             : num  305 4454 530 4849 637 ...
$ Sxp.sd                 : num  10682 6732 28 632 343 ...
$ Sal.n                  : num  3 3 3 3 3 3 3 3
$ Sal.min                : num  9.34 11.35 9.98 17.69 6.8 ...
$ Sal.max                : num  46.79 19.27 17.34 23.58 9.97 ...
$ Sal.mean               : num  22.24 16.32 13.43 20.46 8.58 ...
$ Sal.median             : num  10.58 18.33 12.98 20.11 8.96 ...
$ Sal.sd                 : num  21.27 4.33 3.7 2.96 1.62 ...
$ Str.n                  : num  2 2 3 2 3 3 3 3
$ Str.min                : num  0.689 0.26 0.222 0.154 0.139 ...
$ Str.max                : num  0.714 0.286 0.844 0.514 0.544 ...
$ Str.mean               : num  0.701 0.273 0.446 0.334 0.386 ...
$ Str.median             : num  0.701 0.273 0.272 0.334 0.476 ...
$ Str.sd                 : num  0.0183 0.0187 0.3456 0.2547 0.2168 ...
$ Std.n                  : num  3 3 3 3 3 3 3 3
$ Std.min                : num  25 156.3 151.7 140.5 79.3 ...
$ Std.max                : num  176.5 169 151.8 148.5 99.7 ...
```

```
 $ Std.mean          : num  88.4 161.5 151.7 145.8 87 ...
 $ Std.median        : num  63.8 159.2 151.7 148.5 82 ...
 $ Std.sd            : num  78.70957 6.66741 0.00718 4.60984 11.12649 ...
 $ Sdq.n             : num  3 3 3 3 3 3 3 3 3
 $ Sdq.min           : num  0.1005 0.1657 0.0927 0.2937 0.1363 ...
 $ Sdq.max           : num  1.551 1.165 0.102 0.35 0.198 ...
 $ Sdq.mean          : num  0.5869 0.5332 0.0979 0.3264 0.1611 ...
 $ Sdq.median        : num  0.109 0.269 0.0994 0.3357 0.1493 ...
 $ Sdq.sd            : num  0.83509 0.54942 0.00469 0.02926 0.03229 ...
 $ Sdr.n             : num  3 3 3 3 3 3 3 3 3
 $ Sdr.min           : num  0.495 1.348 0.421 3.608 0.906 ...
 $ Sdr.max           : num  27.267 19.198 0.511 4.76 1.829 ...
 $ Sdr.mean          : num  9.446 7.851 0.474 4.33 1.264 ...
 $ Sdr.median        : num  0.578 3.006 0.489 4.623 1.057 ...
 $ Sdr.sd            : num  15.4327 9.862 0.0472 0.6294 0.4948 ...
 $ Vm.n              : num  3 3 3 3 3 3 3 3 3
 $ Vm.min            : num  0.01399 0.0093 0.00505 0.11486 0.00937 ...
 $ Vm.max            : num  0.29933 0.67139 0.00995 0.18403 0.02147 ...
 $ Vm.mean           : num  0.11089 0.27203 0.00697 0.16026 0.01434 ...
 $ Vm.median         : num  0.0193 0.1354 0.0059 0.1819 0.0122 ...
 $ Vm.sd             : num  0.16322 0.35156 0.00262 0.03933 0.00634 ...
  [list output truncated]
```

Save data

Format name of output file

```r
file_out <- "TFE_stats"
```

The file will be saved as "~/analysis/summary_stats/.[ext]".

Write to XLSX

```r
write.xlsx(list(spot = spot, task = task, raw_material = raw_material),
           file = paste0(dir_out, file_out, ".xlsx"))
```

Save R object

```r
saveObject(list(spot = spot, task = task, raw_material = raw_material),
       file = paste0(dir_out, file_out, ".Rbin"))
```

---

sessionInfo() and RStudio version

```
sessionInfo()
R version 4.0.2 (2020-06-22)
Platform: x86_64-w64-mingw32/x64 (64-bit)
Running under: Windows 10 x64 (build 19041)

Matrix products: default

locale:
[1] LC_COLLATE=German_Germany.1252  LC_CTYPE=German_Germany.1252
[3] LC_MONETARY=German_Germany.1252 LC_NUMERIC=C
[5] LC_TIME=German_Germany.1252

attached base packages:
[1] tools     stats     graphics  grDevices utils     datasets  methods
[8] base
```

```
other attached packages:
[1] doBy_4.6.8        R.utils_2.10.1    R.oo_1.24.0       R.methodsS3_1.8.1
[5] openxlsx_4.2.3

loaded via a namespace (and not attached):
 [1] zip_2.1.1         Rcpp_1.0.6        compiler_4.0.2    pillar_1.4.7
 [5] digest_0.6.27     lattice_0.20-41   evaluate_0.14     lifecycle_0.2.0
 [9] tibble_3.0.6      gtable_0.3.0      pkgconfig_2.0.3   rlang_0.4.10
[13] Matrix_1.2-18     DBI_1.1.1         yaml_2.2.1        xfun_0.20
[17] dplyr_1.0.3       stringr_1.4.0     knitr_1.31        generics_0.1.0
[21] vctrs_0.3.6       grid_4.0.2        tidyselect_1.1.0  glue_1.4.2
[25] R6_2.5.0          rmarkdown_2.6     tidyr_1.1.2       purrr_0.3.4
[29] ggplot2_3.3.3     magrittr_2.0.1    backports_1.2.1   scales_1.1.1
[33] ellipsis_0.3.1    htmltools_0.5.1.1 MASS_7.3-51.6     assertthat_0.2.1
[37] colorspace_2.0-0  Deriv_4.1.2       stringi_1.5.3     munsell_0.5.0
[41] broom_0.7.4       crayon_1.4.0
```

RStudio version 1.3.1073.

END OF SCRIPT

Plots - tool function experiment

Lisa Schunk

2021-02-14 14:53:40

Goal of the script

This script plots all variables to see which ones should be used for further analysis.
Scatterplot of each variable will be plotted.

```
dir_in <- "analysis/derived_data/"
dir_out <- "analysis/plots"
```

Raw data must be located in ~/analysis/derived_data/.
Formatted data will be saved in ~/analysis/plots.

The knit directory for this script is the project directory.

Load packages

```
library(R.utils)
library(ggplot2)
Warning: package 'ggplot2' was built under R version 4.0.3
library(tools)
library(tidyverse)
Warning: package 'tidyverse' was built under R version 4.0.3
Warning: package 'tibble' was built under R version 4.0.3
Warning: package 'readr' was built under R version 4.0.3
Warning: package 'dplyr' was built under R version 4.0.3
library(ggfortify)
Warning: package 'ggfortify' was built under R version 4.0.3
```

Get name, path and information of the file

```
data_file <- list.files(dir_in, pattern = "\\.Rbin$", full.names = TRUE)
md5_in <- md5sum(data_file)
info_in <- data.frame(file = basename(names(md5_in)), checksum = md5_in, row.names = NULL)
```

The checksum (MD5 hashes) of the imported file is:

```
                file                         checksum
1 TFE_use-wear.Rbin 433a3db62e03eee5450b37da5616b1a7
```

Load data into R object

```
imp_data <- loadObject(data_file)
```

The imported file is: "~/analysis/derived_data/TFE_use-wear.Rbin"

Prepare variables

Define numeric variables

```
num.var <- 24:length(imp_data)
```

The following variables will be used:

```
[24] Sq
[25] Ssk
[26] Sku
[27] Sp
[28] Sv
[29] Sz
[30] Sa
[31] Smr
[32] Smc
[33] Sxp
[34] Sal
[35] Str
[36] Std
[37] Sdq
[38] Sdr
[39] Vm
[40] Vv
[41] Vmp
[42] Vmc
[43] Vvc
[44] Vvv
[45] Maximum.depth.of.furrows
[46] Mean.depth.of.furrows
[47] Mean.density.of.furrows
[48] First.direction
[49] Second.direction
[50] Third.direction
[51] Isotropy
[52] epLsar
[53] NewEplsar
[54] Asfc
[55] Smfc
[56] HAsfc9
[57] HAsfc81
```

Plot each of the selected numeric variable

(facet plot = 1 plot for flint, 1 plot for lydite)

```
# BottleRocket2
custom.col5 <- data.frame(type = levels(imp_data$Edge.angle), col = c("#046C9A", "#FAD510"))
imp_data$col <- custom.col5[imp_data$Edge.angle, "col"]


for (i in num.var){
 #plot
 range_var <- range(imp_data[[i]]) # gets the min/max range of the data set

   p <- ggplot(data=imp_data, aes_string(x = "Task", y=names(imp_data)[i],
                                 colour = "Edge.angle")) +
        # avoids overplotting
        geom_jitter(size = 3,  position = position_jitter(width = 0.4, seed = 1)) +
```

```
        coord_cartesian(ylim = range_var) +
        theme_classic() +
        scale_colour_manual(values = custom.col5$col) +
        # removes the "." between "Edge.angle" in the legend
        labs(colour = gsub("\\.", " ", "Edge.angle")) +
        # removes the "." between the variable names
        labs(y = gsub("\\.", " ", names(imp_data)[i])) +
      # combines the flint and the lydite plot into one
        facet_wrap(~Raw.material)

    #save to PDF
    file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "_plot_",
                       names(imp_data)[i], ".pdf")
    ggsave(filename = file_out, plot = p, path = dir_out, device = "pdf")
}
Warning: Removed 3 rows containing missing values (geom_point).

Warning: Removed 3 rows containing missing values (geom_point).
```

Principal component analysis (without outliers)

```
# excludes the outliers
# adds the indices as row numbers
imp_data <- imp_data %>% mutate(id = row_number())
imp_data2 <- imp_data[-c(2, 10), ]

# removes the rows with missing values
data_pca <- na.omit(imp_data2)
imp_data.pca <- prcomp(data_pca[, c(24:25, 42, 47, 51, 54, 56)], scale. = TRUE)

# FantasticFox1
custom.col4 <- data.frame(type = levels(data_pca$Task), col = c("#E58601", "#B40F20"))
data_pca$col <- custom.col4[data_pca$Task, "col"]



# plots the task - PCA with convex hull
# Using ggfortify
a<- autoplot(imp_data.pca, data = data_pca, colour = "Task", size = 2,
             loadings = TRUE, loadings.colour = "black", loadings.label = TRUE,
             loadings.label.colour = "black",
             loadings.label.size  = 4, loadings.label.hjust = 1, loadings.label.vjust = 1,
             frame = TRUE, frame.type = "convex", frame.colour = "Task", frame.alpha = 0) +
             theme_classic() +
             scale_colour_manual(values = custom.col4$col)

# saves the plot
file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "TFE_PCA_Task", ".pdf")
ggsave(filename = file_out, plot = a, path = dir_out, device = "pdf")




# BottleRocket2
custom.col5 <- data.frame(type = levels(data_pca$Edge.angle), col = c("#046C9A", "#FAD510"))
data_pca$col <- custom.col5[data_pca$Edge.angle, "col"]



# plots the edge angle  - PCA with convex hull
b<- autoplot(imp_data.pca, data = data_pca, colour = "Edge.angle", size = 2,
             loadings = TRUE, loadings.colour = "black", loadings.label = TRUE,
             loadings.label.colour = "black",
             loadings.label.size  = 4, loadings.label.hjust = 1, loadings.label.vjust = 1,
```

```r
          frame = TRUE, frame.type = "convex", frame.colour = "Edge.angle",
          frame.alpha = 0) +
          theme_classic() +
          scale_colour_manual(values = custom.col5$col)

# saves the plot
file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "TFE_PCA_angle", ".pdf")
ggsave(filename = file_out, plot = b, path = dir_out, device = "pdf")



# Royal1
custom.col7 <- data.frame(type = levels(data_pca$Raw.material), col = c("#899DA4", "#DC863B"))
data_pca$col <- custom.col7[data_pca$Raw.material, "col"]


# plots the raw material  - PCA with convex hull
c<- autoplot(imp_data.pca, data = data_pca, colour = "Raw.material", size = 2,
          loadings = TRUE, loadings.colour = "black", loadings.label = TRUE,
          loadings.label.colour = "black",
          loadings.label.size  = 4, loadings.label.hjust = 1, loadings.label.vjust = 1,
          frame = TRUE, frame.type = "convex", frame.colour = "Raw.material",
          frame.alpha = 0) +
          theme_classic() +
          scale_colour_manual(values = custom.col7$col)

# saves the plot
file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "TFE_PCA_raw.material", ".pdf")
ggsave(filename = file_out, plot = c, path = dir_out, device = "pdf")
```

The files will be saved as "~/analysis/plots.[ext]".

---

sessionInfo() and RStudio version

```r
sessionInfo()
R version 4.0.2 (2020-06-22)
Platform: x86_64-w64-mingw32/x64 (64-bit)
Running under: Windows 10 x64 (build 19041)

Matrix products: default

locale:
[1] LC_COLLATE=German_Germany.1252  LC_CTYPE=German_Germany.1252
[3] LC_MONETARY=German_Germany.1252 LC_NUMERIC=C
[5] LC_TIME=German_Germany.1252

attached base packages:
[1] tools     stats     graphics  grDevices utils     datasets  methods
[8] base

other attached packages:
 [1] ggfortify_0.4.11  forcats_0.5.1     stringr_1.4.0     dplyr_1.0.3
 [5] purrr_0.3.4       readr_1.4.0       tidyr_1.1.2       tibble_3.0.5
 [9] tidyverse_1.3.0   ggplot2_3.3.3     R.utils_2.10.1    R.oo_1.24.0
[13] R.methodsS3_1.8.1

loaded via a namespace (and not attached):
 [1] tidyselect_1.1.0  xfun_0.20         haven_2.3.1       colorspace_2.0-0
```

```
 [5] vctrs_0.3.6       generics_0.1.0    htmltools_0.5.1.1 yaml_2.2.1
 [9] rlang_0.4.10      pillar_1.4.7      glue_1.4.2        withr_2.4.1
[13] DBI_1.1.1         dbplyr_2.0.0      modelr_0.1.8      readxl_1.3.1
[17] lifecycle_0.2.0   munsell_0.5.0     gtable_0.3.0      cellranger_1.1.0
[21] rvest_0.3.6       evaluate_0.14     labeling_0.4.2    knitr_1.31
[25] broom_0.7.4       Rcpp_1.0.6        scales_1.1.1      backports_1.2.0
[29] jsonlite_1.7.2    farver_2.0.3      fs_1.5.0          gridExtra_2.3
[33] hms_1.0.0         digest_0.6.27     stringi_1.5.3     grid_4.0.2
[37] cli_2.3.0         magrittr_2.0.1    crayon_1.4.0      pkgconfig_2.0.3
[41] ellipsis_0.3.1    xml2_1.3.2        reprex_1.0.0      lubridate_1.7.9.2
[45] assertthat_0.2.1  rmarkdown_2.6     httr_1.4.2        rstudioapi_0.13
[49] R6_2.5.0          compiler_4.0.2
```

RStudio version 1.3.1073.

END OF SCRIPT

Import - Edge angle analysis - experimental data

Lisa Schunk

2021-02-04 16:28:44

Goal of the script

This script imports and merges all single CSV-files generated with the 'edge angle method'. The data derives from 3D models of artefacts from three different experiments: Initial experiment, arificial VS natural experiment, tool function experiment. The data always contain the 3D models from before, after 50, 250, 1000 and 2000 strokes.

The script will:

128. Read in the original CSV-files
129. Combine the data from all samples into one
130. Write an XLSX-file and save an R object ready for further analysis in R

```
dir_in <- "analysis/raw_data"
dir_out <- "analysis/derived_data/"
```

Raw data must be located in "analysis/raw_data".
Formatted data will be saved in "analysis/derived_data/". The knit directory for this script is the project directory.

Load packages

```
library(tidyverse)
Warning: package 'ggplot2' was built under R version 4.0.3
Warning: package 'readr' was built under R version 4.0.3
Warning: package 'dplyr' was built under R version 4.0.3
Warning: package 'forcats' was built under R version 4.0.3
library(R.utils)
library(openxlsx)
Warning: package 'openxlsx' was built under R version 4.0.3
library(tools)
```

List all files and get names of the files

```
# List all CSV files in dir_in
CSV_files <- list.files(dir_in, pattern = "\\.csv$", recursive = TRUE, full.names = TRUE)
```

Merge all files and format the data

```
# Create a list
data_final <- vector(mode = "list", length = length(CSV_files))
names(data_final) <- basename(CSV_files)

# For each sample
for (s in seq_along(data_final)) {
```

```r
    # Gets name of the experiment from path names
    exp <- dirname(dirname(dirname(CSV_files[s]))) %>%
          basename()

   # read the data files
   data_final[[s]] <- read.csv(CSV_files[s]) %>%
                      mutate(experiment = exp) %>%
                      select(experiment, everything()) %>%
                      rename(Angle_number = angel_number, Distance_origin =
                               dist.to.origin.on.curve..mm., Segment =
                               segment.on.section..mm.,Three_point =
                               angle.1..3.points...degree., Two_lines =
                               angle.2..2.constructed.lines...degree., Best_fit =
                               angle.3..2.BestFit.lines...degree.)
}

# rbind all files
data_final2 <- do.call(rbind, data_final)
# adds indices as row names
row.names(data_final2) <- 1:nrow(data_final2)

# split column section
underscore_split <- strsplit(data_final2[["section"]], "_")
underscore_bind <- do.call(rbind, underscore_split)
minus_split <- strsplit(underscore_bind[,1], "-")
minus_bind <- do.call(rbind, minus_split)
sample_ID <- paste(minus_bind[,1], minus_bind[,2], sep="-")

data_final3 <- data_final2 %>%
  mutate(ID = sample_ID, strokes = minus_bind[,3], edge = underscore_bind[,2],
         sec = underscore_bind[,4])

# extracts the raw material based on the ID
data_final3[grep("FLT", data_final3[["ID"]]), "Raw.material"] <- "flint"
data_final3[grep("LYDIT", data_final3[["ID"]]), "Raw.material"] <- "lydite"
data_final3[["Raw.material"]] <- factor(data_final3[["Raw.material"]])

data_final3[["Raw.material"]] <- factor(data_final3[["Raw.material"]])

# adds the contact/worked material
data_final3[grep("LYDIT4-1", data_final3[["ID"]]), "Contact.material"] <- "pork skin"
data_final3[grep("LYDIT4-4", data_final3[["ID"]]), "Contact.material"] <- "pork skin"
data_final3[grep("LYDIT4-6", data_final3[["ID"]]), "Contact.material"] <- "pork skin"
data_final3[grep("LYDIT4-2", data_final3[["ID"]]), "Contact.material"] <- "bone plate"
data_final3[grep("LYDIT4-3", data_final3[["ID"]]), "Contact.material"] <- "bone plate"
data_final3[grep("LYDIT4-8", data_final3[["ID"]]), "Contact.material"] <- "bone plate"
data_final3[grep("LYDIT4-5", data_final3[["ID"]]), "Contact.material"] <- "bos scapula"
data_final3[grep("LYDIT4-7", data_final3[["ID"]]), "Contact.material"] <- "bos scapula"
data_final3[grep("LYDIT4-12", data_final3[["ID"]]), "Contact.material"] <- "bos scapula"
data_final3[grep("LYDIT4-9", data_final3[["ID"]]), "Contact.material"] <- "skin pad"
data_final3[grep("LYDIT4-10", data_final3[["ID"]]), "Contact.material"] <- "skin pad"
data_final3[grep("LYDIT4-11", data_final3[["ID"]]), "Contact.material"] <- "skin pad"

data_final3[grep("FLT4-4", data_final3[["ID"]]), "Contact.material"] <- "pork skin"
data_final3[grep("FLT4-8", data_final3[["ID"]]), "Contact.material"] <- "pork skin"
data_final3[grep("FLT4-9", data_final3[["ID"]]), "Contact.material"] <- "pork skin"
data_final3[grep("FLT4-5", data_final3[["ID"]]), "Contact.material"] <- "bone plate"
data_final3[grep("FLT4-7", data_final3[["ID"]]), "Contact.material"] <- "bone plate"
```

```r
data_final3[grep("FLT4-10", data_final3[["ID"]]), "Contact.material"] <- "bone plate"
data_final3[grep("FLT4-15", data_final3[["ID"]]), "Contact.material"] <- "bos scapula"
data_final3[grep("FLT4-14", data_final3[["ID"]]), "Contact.material"] <- "bos scapula"
data_final3[grep("FLT4-6", data_final3[["ID"]]), "Contact.material"] <- "bos scapula"
data_final3[grep("FLT4-11", data_final3[["ID"]]), "Contact.material"] <- "skin pad"
data_final3[grep("FLT4-12", data_final3[["ID"]]), "Contact.material"] <- "skin pad"
data_final3[grep("FLT4-13", data_final3[["ID"]]), "Contact.material"] <- "skin pad"

data_final3[grep("initial_experiment", data_final3[["experiment"]]), "Contact.material"] <-
            "bone plate"
data_final3[grep("tool_function-experiment_cutting", data_final3[["experiment"]]),
            "Contact.material"] <- "bone plate"
data_final3[grep("tool_function-experiment_carving", data_final3[["experiment"]]),
            "Contact.material"] <- "bone plate"

data_final3[["experiment"]] <- factor(data_final3[["experiment"]])

# adds column about the task/movement
data_final3[grep("tool_function-experiment_cutting", data_final3[["experiment"]]),
            "Task"] <- "cutting"
data_final3[grep("tool_function-experiment_carving", data_final3[["experiment"]]),
            "Task"] <- "carving"
data_final3[grep("initial_experiment", data_final3[["experiment"]]), "Task"] <- "cutting"
data_final3[grep("'aVSn'-experiment", data_final3[["experiment"]]), "Task"] <- "cutting"
data_final3[grep("LYDIT5-14", data_final3[["ID"]]), "Task"] <- "scraping"

data_final3[["Task"]] <- factor(data_final3[["Task"]])

# adds column about the edge angle
data_final3[grep("'aVSn'-experiment", data_final3[["experiment"]]), "Edge.angle"] <- "60°"

data_final3[grep("FLT8-1", data_final3[["ID"]]), "Edge.angle"] <- "45°"
data_final3[grep("FLT8-2", data_final3[["ID"]]), "Edge.angle"] <- "45°"
data_final3[grep("FLT8-3", data_final3[["ID"]]), "Edge.angle"] <- "45°"
data_final3[grep("LYDIT5-2", data_final3[["ID"]]), "Edge.angle"] <- "45°"
data_final3[grep("LYDIT5-3", data_final3[["ID"]]), "Edge.angle"] <- "45°"
data_final3[grep("LYDIT5-4", data_final3[["ID"]]), "Edge.angle"] <- "45°"
data_final3[grep("FLT8-4", data_final3[["ID"]]), "Edge.angle"] <- "35°"
data_final3[grep("FLT8-5", data_final3[["ID"]]), "Edge.angle"] <- "35°"
data_final3[grep("FLT8-6", data_final3[["ID"]]), "Edge.angle"] <- "35°"
data_final3[grep("LYDIT5-5", data_final3[["ID"]]), "Edge.angle"] <- "35°"
data_final3[grep("LYDIT5-6", data_final3[["ID"]]), "Edge.angle"] <- "35°"
data_final3[grep("LYDIT5-7", data_final3[["ID"]]), "Edge.angle"] <- "35°"

data_final3[grep("FLT8-10", data_final3[["ID"]]), "Edge.angle"] <- "45°"
data_final3[grep("FLT8-11", data_final3[["ID"]]), "Edge.angle"] <- "45°"
data_final3[grep("FLT8-12", data_final3[["ID"]]), "Edge.angle"] <- "45°"
data_final3[grep("LYDIT5-8", data_final3[["ID"]]), "Edge.angle"] <- "45°"
data_final3[grep("LYDIT5-9", data_final3[["ID"]]), "Edge.angle"] <- "45°"
data_final3[grep("LYDIT5-10", data_final3[["ID"]]), "Edge.angle"] <- "45°"
data_final3[grep("FLT8-7", data_final3[["ID"]]), "Edge.angle"] <- "35°"
data_final3[grep("FLT8-8", data_final3[["ID"]]), "Edge.angle"] <- "35°"
data_final3[grep("FLT8-9", data_final3[["ID"]]), "Edge.angle"] <- "35°"
data_final3[grep("LYDIT5-11", data_final3[["ID"]]), "Edge.angle"] <- "35°"
data_final3[grep("LYDIT5-12", data_final3[["ID"]]), "Edge.angle"] <- "35°"
data_final3[grep("LYDIT5-13", data_final3[["ID"]]), "Edge.angle"] <- "35°"
data_final3[grep("LYDIT5-14", data_final3[["ID"]]), "Edge.angle"] <- "35°"

data_final3[grep("FLT4-2", data_final3[["ID"]]), "Edge.angle"] <- "40°"
data_final3[grep("FLT4-3", data_final3[["ID"]]), "Edge.angle"] <- "60°"
```

```r
data_final3[grep("LYDIT1-2", data_final3[["ID"]]), "Edge.angle"] <- "40°"
data_final3[grep("LYDIT1-3", data_final3[["ID"]]), "Edge.angle"] <- "40°"
data_final3[grep("LYDIT1-4", data_final3[["ID"]]), "Edge.angle"] <- "40°"
data_final3[grep("LYDIT3-2", data_final3[["ID"]]), "Edge.angle"] <- "60°"
data_final3[grep("LYDIT3-3", data_final3[["ID"]]), "Edge.angle"] <- "60°"

data_final3[["Edge.angle"]] <- factor(data_final3[["Edge.angle"]])



# reorder columns
data_final3 <- data_final3[c(2, 1, 9:16, 3:8)]
```

Save data

Format name of output file

```r
file_out <- "EdgeAngle_experiment"
```

Write to XLSX

```r
write.xlsx(list(data = data_final3), file = paste0(dir_out, file_out, ".xlsx"))
```

Save R object

```r
saveObject(data_final, file = paste0(dir_out, file_out, ".Rbin"))
```

---

sessionInfo() and RStudio version

```
sessionInfo()
R version 4.0.2 (2020-06-22)
Platform: x86_64-w64-mingw32/x64 (64-bit)
Running under: Windows 10 x64 (build 19041)

Matrix products: default

locale:
[1] LC_COLLATE=German_Germany.1252  LC_CTYPE=German_Germany.1252
[3] LC_MONETARY=German_Germany.1252 LC_NUMERIC=C
[5] LC_TIME=German_Germany.1252

attached base packages:
[1] tools     stats     graphics  grDevices utils     datasets  methods
[8] base

other attached packages:
 [1] openxlsx_4.2.3    R.utils_2.10.1    R.oo_1.24.0       R.methodsS3_1.8.1
 [5] forcats_0.5.1     stringr_1.4.0     dplyr_1.0.3       purrr_0.3.4
 [9] readr_1.4.0       tidyr_1.1.2       tibble_3.0.6      ggplot2_3.3.3
[13] tidyverse_1.3.0

loaded via a namespace (and not attached):
 [1] tidyselect_1.1.0  xfun_0.20         haven_2.3.1       colorspace_2.0-0
 [5] vctrs_0.3.6       generics_0.1.0    htmltools_0.5.1.1 yaml_2.2.1
 [9] rlang_0.4.10      pillar_1.4.7      glue_1.4.2        withr_2.4.1
[13] DBI_1.1.1         dbplyr_2.0.0      modelr_0.1.8      readxl_1.3.1
[17] lifecycle_0.2.0   munsell_0.5.0     gtable_0.3.0      cellranger_1.1.0
[21] zip_2.1.1         rvest_0.3.6       evaluate_0.14     knitr_1.31
[25] broom_0.7.4       Rcpp_1.0.6        scales_1.1.1      backports_1.2.1
[29] jsonlite_1.7.2    fs_1.5.0          hms_1.0.0         digest_0.6.27
```

```
[33] stringi_1.5.3     grid_4.0.2        cli_2.3.0         magrittr_2.0.1
[37] crayon_1.4.0      pkgconfig_2.0.3   ellipsis_0.3.1    xml2_1.3.2
[41] reprex_1.0.0      lubridate_1.7.9.2 assertthat_0.2.1  rmarkdown_2.6
[45] httr_1.4.2        rstudioapi_0.13   R6_2.5.0          compiler_4.0.2
```

RStudio version 1.3.1073.

END OF SCRIPT

Plot - Edge angle analysis - experimental data

Lisa Schunk

2021-02-14 16:21:26

Goal of the script

This script plots all edge angle values. The three experiments will be treated separately.

```
dir_in <- "analysis/derived_data/"
dir_out <- "analysis/plots"
```

Raw data must be located in ~/analysis/derived_data/.
Formatted data will be saved in ~/analysis/plots.

The knit directory for this script is the project directory.

Load packages

```
library(openxlsx)
Warning: package 'openxlsx' was built under R version 4.0.3
library(readxl)
library(R.utils)
library(ggplot2)
Warning: package 'ggplot2' was built under R version 4.0.3
library(tools)
library(tidyverse)
Warning: package 'tidyverse' was built under R version 4.0.3
Warning: package 'tibble' was built under R version 4.0.3
Warning: package 'readr' was built under R version 4.0.3
Warning: package 'dplyr' was built under R version 4.0.3
library(patchwork)
Warning: package 'patchwork' was built under R version 4.0.3
library(ggsci)
library(ggfortify)
Warning: package 'ggfortify' was built under R version 4.0.3
library(wesanderson)
library(doBy)
Warning: package 'doBy' was built under R version 4.0.3
library(ggfortify)
```

Get name, path and information of the file

```
data_file <- list.files(dir_in, pattern = "\\.xlsx$", full.names = TRUE)
md5_in <- md5sum(data_file)
info_in <- data.frame(file = basename(names(md5_in)), checksum = md5_in, row.names = NULL)
```

The checksum (MD5 hashes) of the imported file is:

```
                      file                         checksum
1 EdgeAngle_experiment.xlsx ed7878fcffd202c8e363d138621a7ce7
```

Load data into R object

```
imp_data <- read.xlsx(xlsxFile = data_file, sheet = 1, startRow = 1, colNames = TRUE,
                      rowNames = FALSE, skipEmptyRows = FALSE)
str(imp_data)
'data.frame':	29933 obs. of  16 variables:
 $ section         : chr  "FLT4-10-1000strokes_E1_RE_SEC-01_local" "FLT4-10-1000strokes_E1_RE_SEC-01_local" "FLT4-10-1000strokes_E1_RE_SEC-01_local" "FLT4-10-1000strokes_E1_RE_SEC-01_local" ...
 $ experiment      : chr  "'aVSn'-experiment" "'aVSn'-experiment" "'aVSn'-experiment" "'aVSn'-experiment" ...
 $ ID              : chr  "FLT4-10" "FLT4-10" "FLT4-10" "FLT4-10" ...
 $ strokes         : chr  "1000strokes" "1000strokes" "1000strokes" "1000strokes" ...
 $ edge            : chr  "E1" "E1" "E1" "E1" ...
 $ sec             : chr  "SEC-01" "SEC-01" "SEC-01" "SEC-01" ...
 $ Raw.material    : chr  "flint" "flint" "flint" "flint" ...
 $ Contact.material: chr  "bone plate" "bone plate" "bone plate" "bone plate" ...
 $ Task            : chr  "cutting" "cutting" "cutting" "cutting" ...
 $ Edge.angle      : chr  "60°" "60°" "60°" "60°" ...
 $ Angle_number    : num  1 2 3 4 5 6 7 8 9 10 ...
 $ Distance_origin : num  1 2 3 4 5 6 7 8 9 10 ...
 $ Segment         : num  2 2 2 2 2 2 2 2 2 2 ...
 $ Three_point     : num  75.2 67 63.5 61.9 60.9 60.3 59.9 59.4 59.2 59 ...
 $ Two_lines       : num  68.1 58 57.1 56.9 57.2 57.7 56.7 56.7 57.1 57.2 ...
 $ Best_fit        : num  69.7 58.3 57 57 57.3 57 57.1 57.1 56.6 57.6 ...
```

The imported file is: "~/analysis/derived_data/EdgeAngle_experiment.xlsx"

Prepare variables

Define numeric variables

```
num.var <- 14:length(imp_data)
```

The following variables will be used:

```
[14] Three_point
[15] Two_lines
[16] Best_fit
```

Facet wrap to plot each experiment individually

Artfifical VS natural experiment

```
# selects only the data from the aVSn experiment
aVSn <- filter(imp_data, experiment == "'aVSn'-experiment")
aVSn <- filter(aVSn, Angle_number == "3" | Angle_number == "4" | Angle_number == "5" |
               Angle_number == "6")
aVSn <- filter(aVSn, sec == "SEC-02" | sec == "SEC-03" | sec == "SEC-04" | sec == "SEC-05" |
               sec == "SEC-06" | sec == "SEC-07" | sec == "SEC-08")

# adds a column that combines sample and location
aVSn_data <- unite(aVSn, ID_cycle, c(ID, strokes), remove = FALSE)

# computes the mean per sample
aVSn_mean <- summaryBy(. ~ ID_cycle+ID+strokes+Contact.material+Raw.material+Edge.angle, data = aVSn_data, FUN = mean)

# gets new order
aVSn_mean$strokes <- factor(aVSn_mean$strokes, levels=c("before", "50strokes", "250strokes",
                                                "1000strokes", "2000strokes"))
```

```r
aVSn_mean$ID <- factor(aVSn_mean$ID, levels=c("FLT4-5", "FLT4-7", "FLT4-10", "FLT4-6",
                                       "FLT4-14", "FLT4-15","FLT4-11", "FLT4-12",
                                       "FLT4-13", "FLT4-4", "FLT4-8", "FLT4-9",
                                       "LYDIT4-2", "LYDIT4-3", "LYDIT4-8","LYDIT4-5",
                                       "LYDIT4-7", "LYDIT4-12", "LYDIT4-9",
                                       "LYDIT4-10", "LYDIT4-11", "LYDIT4-1",
                                       "LYDIT4-4", "LYDIT4-6"))

# gets the min/max range of the data set
range_var <- range(aVSn_mean[["Three_point.mean"]])

# plots
# plots first the lydit samples
p_lydite <- ggplot(data = aVSn_mean[grep("LYDIT", aVSn_mean[["ID_cycle"]]), ],
          aes(x = strokes, y = Three_point.mean, colour = Edge.angle)) +
          geom_point(size = 2) +
          geom_line(aes(group = ID)) +
          facet_wrap(ID ~ Contact.material, nrow = 4)+
          theme_classic()+
          xlab("strokes") + ylab(NULL) +
          labs(colour = "Edge angle") +
          coord_cartesian(ylim = range_var) +
          scale_colour_manual(values = "#CB2314") +
          scale_x_discrete(breaks = c("before", "50strokes", "250strokes" , "1000strokes",
                                  "2000strokes"), labels = c("0", "50", "250", "1000",
                                  "2000"))


# plots the flint samples
p_flint <- ggplot(data = aVSn_mean[grep("FLT", aVSn_mean[["ID_cycle"]]), ],
          aes(x = strokes, y = Three_point.mean, colour = Edge.angle)) +
          geom_point(size = 2) +
          geom_line(aes(group = ID)) +
          facet_wrap(ID ~ Contact.material, nrow = 4)+
          theme_classic()+
          xlab("strokes") + ylab(NULL) +
          labs(colour = "Edge angle") +
          coord_cartesian(ylim = range_var) +
          scale_colour_manual(values = "#CB2314") +
          scale_x_discrete(breaks = c("before", "50strokes", "250strokes" , "1000strokes",
                                  "2000strokes"), labels = c("0", "50", "250", "1000",
                                  "2000"))


# combines the flint and the lydite plots
p <- p_flint + p_lydite + plot_layout(guides = 'collect')


#save to PDF
file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "_aVSn_EA_plot", ".pdf")
ggsave(filename = file_out, plot = p, path = dir_out, device = "pdf")
```

Tool function experiment

```r
# selects only the data from the TFE experiment and the 'Three-point' method
#TFE <- imp_data[7460:20629,1:14]
TFE <- filter(imp_data, experiment == "tool_function-experiment_cutting" |
              experiment == "tool_function-experiment_carving")
TFE <- filter(TFE, Angle_number == "3" | Angle_number == "4" | Angle_number == "5" |
              Angle_number == "6")
TFE <- filter(TFE, sec == "SEC-02" | sec == "SEC-03" | sec == "SEC-04" | sec == "SEC-05" |
```

```r
          sec == "SEC-06" | sec == "SEC-07" | sec == "SEC-8")

# adds a column that combines sample and location
TFE_data <- unite(TFE, ID_cycle, c(ID, strokes), remove = FALSE)
TFE_mean <- summaryBy(. ~ ID_cycle + ID + strokes + Contact.material +
                Raw.material + Edge.angle + Task, data = TFE_data, FUN = mean)

# computes the mean per sample
TFE_final <- TFE_mean[c(0:49, 51:80, 83:122),]
# removes the test sample LYDIT5-14 (carving)

# gets new order
TFE_final$strokes <- factor(TFE_final$strokes, levels=c("before", "50strokes", "250strokes",
                                    "1000strokes", "2000strokes"))



# plots
# plots first the lydite samples
p_lydite2 <- ggplot(data = TFE_final[grep("LYDIT", TFE_final[["ID_cycle"]]), ],
        aes(x = strokes, y = Three_point.mean, colour = Edge.angle)) +
        geom_point(size = 2) +
        geom_line(aes(group = ID)) +
        facet_wrap(ID ~ Contact.material+Task, nrow = 3)+
        theme_classic()+
        xlab("strokes") + ylab(NULL) +
        labs(colour = "Edge angle") +
        ylim(30, 110) +
        scale_colour_manual(values = c("#046C9A", "#FAD510")) +
        scale_x_discrete(breaks = c("before", "50strokes", "250strokes" ,
                      "1000strokes", "2000strokes"), labels =
                     c("0", "50", "250", "1000", "2000"))



# plots the flint samples
p_flint2 <- ggplot(data = TFE_final[grep("FLT", TFE_final[["ID_cycle"]]), ],
       aes(x = strokes, y = Three_point.mean, colour = Edge.angle)) +
       geom_point(size = 2) +
       geom_line(aes(group = ID)) +
       facet_wrap(ID ~ Contact.material+Task, nrow = 3)+
       theme_classic()+
       xlab("strokes") + ylab(NULL) +
       labs(colour = "Edge angle") +
       ylim(30, 110) +
       #coord_cartesian(ylim = range_var) +
       scale_colour_manual(values = c("#046C9A", "#FAD510")) +
       scale_x_discrete(breaks = c("before", "50strokes", "250strokes" , "1000strokes",
                     "2000strokes"), labels = c("0", "50", "250", "1000",
                     "2000"))



# combines the flint and the lydite plots
p2 <- p_flint2 + p_lydite2 + plot_layout(guides = 'collect')



#save to PDF
  file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "_TFE_EA_plot", ".pdf")
  ggsave(filename = file_out, plot = p2, path = dir_out, device = "pdf", width = 370,
        height = 280, units = "mm")
```

Initial experiment

```
# selects only the data from the initial experiment
IE <- filter(imp_data, experiment == "initial_experiment")
# filters the first two and the two last sections out
IE <- filter(IE, Angle_number == "3" | Angle_number == "4" | Angle_number == "5" |
             Angle_number == "6")
IE <- filter(IE, sec == "SEC-02" | sec == "SEC-03" | sec == "SEC-04" | sec == "SEC-05" |
             sec == "SEC-06" | sec == "SEC-07" | sec == "SEC-8")


# adds a column that combines sample and location
IE_data <- unite(IE, ID_cycle, c(ID, strokes), remove = FALSE)

# computes the mean per sample
IE_mean <- summaryBy(. ~ ID_cycle + ID + strokes + Contact.material +
                   Raw.material + Edge.angle + Task, data = IE_data, FUN = mean)

# gets new order
IE_mean$strokes <- factor(IE_mean$strokes, levels=c("before", "50strokes", "250strokes",
                                             "1000strokes", "2000strokes"))



# plots
# plots the lydite and flint samples
p3 <- ggplot(data = IE_mean, aes(x = strokes, y = Three_point.mean, colour = Edge.angle)) +
          geom_point(size = 2) +
          geom_line(aes(group = ID)) +
          facet_wrap(ID ~ Contact.material+Task, ncol = 4)+
          theme_classic()+
          xlab("strokes") + ylab(NULL) +
          labs(colour = "Edge angle") +
          ylim(35, 130) +
          scale_colour_manual(values = c("#354823", "#CB2314")) +
          scale_x_discrete(breaks = c("before", "50strokes", "250strokes" , "1000strokes",
                                 "2000strokes"), labels = c("0", "50", "250", "1000",
                                 "2000"))



#save to PDF
file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "_IE_EA_plot", ".pdf")
ggsave(filename = file_out, plot = p3, path = dir_out, device = "pdf",width = 250,
      height = 170, units = "mm")
```

Show files information

```
files_out <- c(paste0(dir_out, file_out, ".xlsx"), paste0(dir_out, file_out, ".Rbin"))
md5_out <- md5sum(files_out)
info_out <- data.frame(files = basename(names(md5_out)), checksum = md5_out,
                   row.names = NULL)
```

The checksum (MD5 hashes) of the exported files are:

```
                                   files checksum
1 plotsEdgeAngle_experiment_IE_EA_plot.pdf.xlsx     <NA>
2 plotsEdgeAngle_experiment_IE_EA_plot.pdf.Rbin     <NA>
```

---

sessionInfo() and RStudio version

```
sessionInfo()
R version 4.0.2 (2020-06-22)
Platform: x86_64-w64-mingw32/x64 (64-bit)
Running under: Windows 10 x64 (build 19041)

Matrix products: default

locale:
[1] LC_COLLATE=German_Germany.1252  LC_CTYPE=German_Germany.1252
[3] LC_MONETARY=German_Germany.1252 LC_NUMERIC=C
[5] LC_TIME=German_Germany.1252

attached base packages:
[1] tools     stats     graphics  grDevices utils     datasets  methods
[8] base

other attached packages:
 [1] doBy_4.6.8          wesanderson_0.3.6 ggfortify_0.4.11  ggsci_2.9
 [5] patchwork_1.1.1   forcats_0.5.1     stringr_1.4.0     dplyr_1.0.3
 [9] purrr_0.3.4       readr_1.4.0       tidyr_1.1.2       tibble_3.0.5
[13] tidyverse_1.3.0   ggplot2_3.3.3     R.utils_2.10.1    R.oo_1.24.0
[17] R.methodsS3_1.8.1 readxl_1.3.1      openxlsx_4.2.3

loaded via a namespace (and not attached):
 [1] Rcpp_1.0.6        lattice_0.20-41   lubridate_1.7.9.2 assertthat_0.2.1
 [5] digest_0.6.27     R6_2.5.0          cellranger_1.1.0  backports_1.2.0
 [9] reprex_1.0.0      evaluate_0.14     httr_1.4.2        pillar_1.4.7
[13] rlang_0.4.10      rstudioapi_0.13   Matrix_1.2-18     rmarkdown_2.6
[17] labeling_0.4.2    munsell_0.5.0     broom_0.7.4       compiler_4.0.2
[21] Deriv_4.1.2       modelr_0.1.8      xfun_0.20         pkgconfig_2.0.3
[25] htmltools_0.5.1.1 tidyselect_1.1.0  gridExtra_2.3     crayon_1.4.0
[29] dbplyr_2.0.0      withr_2.4.1       MASS_7.3-53       grid_4.0.2
[33] jsonlite_1.7.2    gtable_0.3.0      lifecycle_0.2.0   DBI_1.1.1
[37] magrittr_2.0.1    scales_1.1.1      zip_2.1.1         cli_2.3.0
[41] stringi_1.5.3     farver_2.0.3      fs_1.5.0          xml2_1.3.2
[45] ellipsis_0.3.1    generics_0.1.0    vctrs_0.3.6       glue_1.4.2
[49] hms_1.0.0         yaml_2.2.1        colorspace_2.0-0  rvest_0.3.6
[53] knitr_1.31        haven_2.3.1
```

RStudio version 1.3.1073.

END OF SCRIPT

Import CSV from ConfoMap ISO25178 - use-wear archaeology & experiments

Lisa Schunk

2021-02-04 14:11:06

Goal of the script

This script formats the output resulting from applying a template computing ISO 25178 parameters in ConfoMap. The script will:

131. Read in the original Rbin-files
132. Format the data in order to make the three data sets fitting

133. Write an XLSX-file and save an R object ready for further analysis in R

```
dir_in <- "analysis/raw_data"
dir_out <- "analysis/derived_data/"
```

Raw data must be located in ~/analysis/raw_data.
Formatted data will be saved in ~/analysis/derived_data/.
The knit directory for this script is the project directory.

Load packages

```
library(openxlsx)
Warning: package 'openxlsx' was built under R version 4.0.3
library(tools)
library(R.utils)
library(chron)
library(tidyverse)
Warning: package 'ggplot2' was built under R version 4.0.3
Warning: package 'readr' was built under R version 4.0.3
Warning: package 'dplyr' was built under R version 4.0.3
Warning: package 'forcats' was built under R version 4.0.3
```

Get names, path and information of all files

```
data_files <- list.files(dir_in, pattern = "\\.Rbin$", full.names = TRUE)
md5_in <- md5sum(data_files)
info_in <- data.frame(files = basename(names(md5_in)), checksum = md5_in,
                      row.names = NULL)
```

The checksum (MD5 hashes) of the imported files are:

```
              files                         checksum
1 AvsN_use-wear.Rbin 0bbb6fa72fc579f481ad716752f28d5d
2  TFE_use-wear.Rbin 433a3db62e03eee5450b37da5616b1a7
3      Use-wear.Rbin 558d5b8d978e0d27f0cf6d308b0734de
```

Read in original CSV-files

```
# data from 'aVSn' experiment, tool function experiment and archaeology
AvsN_imp <- loadObject(data_files[1])
str(AvsN_imp)
'data.frame':   60 obs. of  55 variables:
 $ Sample                   : chr  "FLT4-12" "FLT4-12" "FLT4-12" "FLT4-12" ...
 $ Cycle                    : Factor w/ 2 levels "before","2000": 1 1 1 2 2 2 1 1 1 1 ...
 $ Location                 : chr  "B1" "B1" "B1" "B1" ...
 $ Area                     : chr  "01" "01" "01" "01" ...
 $ Spot                     : chr  "a" "b" "c" "a" ...
 $ Objective                : Factor w/ 2 levels "50x075","50x095": 2 2 2 2 2 2 1 1 1 1 ...
 $ Raw.material             : Factor w/ 2 levels "flint","lydite": 1 1 1 1 1 1 1 1 1 1 ...
 $ Contact.material         : chr  "skin pad" "skin pad" "skin pad" "skin pad" ...
 $ Analysis.date            : Date, format: "2020-08-17" "2020-08-17" ...
 $ Analysis.time            : 'times' num  14:48:58 14:49:34 14:50:09 14:50:43 14:51:18 ...
  ..- attr(*, "format")= chr "h:m:s"
```

```
 $ Acquisition.date.time   : chr  "7/20/2020 2:39:46 PM" "7/20/2020 2:55:08 PM" "7/20/2020 3:12:51 PM" "7/20/2020 
3:29:51 PM" ...
 $ Axis.length.X           : num  255 255 255 255 255 ...
 $ Axis.size.X             : num  1198 1198 1198 1198 1198 ...
 $ Axis.spacing.X          : num  0.213 0.213 0.213 0.213 0.213 ...
 $ Axis.length.Y           : num  255 255 255 255 255 ...
 $ Axis.size.Y             : num  1198 1198 1198 1198 1198 ...
 $ Axis.spacing.Y          : num  0.213 0.213 0.213 0.213 0.213 ...
 $ Axis.length.Z           : num  27287 27231 26655 13395 13291 ...
 $ Axis.size.Z             : num  63694 65201 63762 65466 65538 ...
 $ Axis.spacing.Z          : num  0.428 0.418 0.418 0.205 0.203 ...
 $ NM.points.ratio.Z       : num  0 0 0 0 0 0 0 0 0 0 ...
 $ Sq                      : num  160 151 196 227 160 ...
 $ Ssk                     : num  -0.0199 4.1704 2.0253 2.2084 2.0238 ...
 $ Sku                     : num  6.21 37.01 10.42 11.22 9.9 ...
 $ Sp                      : num  1153 1693 1606 1740 1174 ...
 $ Sv                      : num  716 594 406 473 321 ...
 $ Sz                      : num  1870 2286 2013 2212 1496 ...
 $ Sa                      : num  115.8 84.7 138.7 154.4 111.9 ...
 $ Smr                     : num  12.722 0.832 1.59 1.645 10.656 ...
 $ Smc                     : num  177 111 232 250 184 ...
 $ Sxp                     : num  362 192 211 245 175 ...
 $ Sal                     : num  5.94 7.73 8.18 12.2 8.71 ...
 $ Str                     : num  0.0746 0.669 0.226 0.6994 0.1989 ...
 $ Std                     : num  170 133 50.5 101 81.5 ...
 $ Sdq                     : num  0.1019 0.0833 0.1177 0.1378 0.1048 ...
 $ Sdr                     : num  0.513 0.337 0.68 0.916 0.54 ...
 $ Vm                      : num  0.0103 0.0176 0.0206 0.0263 0.0175 ...
 $ Vv                      : num  0.187 0.128 0.252 0.276 0.202 ...
 $ Vmp                     : num  0.0103 0.0176 0.0206 0.0263 0.0175 ...
 $ Vmc                     : num  0.119 0.073 0.133 0.143 0.106 ...
 $ Vvc                     : num  0.164 0.115 0.241 0.262 0.192 ...
 $ Vvv                     : num  0.0233 0.0128 0.0112 0.0138 0.0092 ...
 $ Maximum.depth.of.furrows: num  905 865 814 881 640 ...
 $ Mean.depth.of.furrows   : num  257 174 386 409 311 ...
 $ Mean.density.of.furrows : num  3081 3318 3101 3225 3191 ...
 $ First.direction         : num  1.69e+02 1.35e+02 8.76e-03 9.00e+01 9.00e+01 ...
 $ Second.direction        : num  180 90 135 135 45 ...
 $ Third.direction         : num  135 45 117 116 135 ...
 $ Isotropy                : num  6.16 66.63 52.93 77.77 55.86 ...
 $ epLsar                  : num  0.00356 0.00393 0.00189 0.00195 0.00041 ...
 $ NewEplsar               : num  0.0187 0.0188 0.0179 0.0179 0.0175 ...
 $ Asfc                    : num  1.145 0.703 1.494 2.067 1.207 ...
 $ Smfc                    : num  3.08 3.3 2.88 2.52 2.52 ...
 $ HAsfc9                  : num  0.201 0.636 0.191 0.512 0.239 ...
 $ HAsfc81                 : num  0.264 0.939 0.388 0.722 0.386 ...
 - attr(*, "comment")= Named chr [1:44] "µm" "points" "µm" "µm" ...
  ..- attr(*, "names")= chr [1:44] "Axis length - X" "Axis size - X" "Axis spacing - X" "Axis length - Y" ...
TFE_imp <- loadObject(data_files[2])
str(TFE_imp)
'data.frame':	24 obs. of  57 variables:
 $ Sample                  : chr  "FLT8-10" "FLT8-10" "FLT8-10" "FLT8-2" ...
 $ Cycle                   : chr  "2000" "2000" "2000" "2000" ...
 $ Location                : chr  "C1" "C1" "C1" "D1" ...
 $ Area                    : chr  "01" "01" "01" "01" ...
 $ Spot                    : chr  "a" "b" "c" "a" ...
 $ Objective               : chr  "50x095" "50x095" "50x095" "50x095" ...
 $ Raw.material            : Factor w/ 2 levels "flint","lydite": 1 1 1 1 1 1 1 1 1 1 ...
 $ Contact.material        : Factor w/ 1 level "bone plate": 1 1 1 1 1 1 1 1 1 1 ...
 $ Task                    : Factor w/ 2 levels "carving","cutting": 1 1 1 2 2 2 2 2 2 1 ...
 $ Edge.angle              : Factor w/ 2 levels "35°","45°": 2 2 2 2 2 2 1 1 1 1 ...
```

```
 $ Analysis.date           : Date, format: "2020-08-27" "2020-08-27" ...
 $ Analysis.time           : 'times' num  15:01:32 15:02:11 15:02:48 15:03:28 15:04:06 ...
  ..- attr(*, "format")= chr "h:m:s"
 $ Acquisition.date.time   : chr  "8/27/2020 11:10:06 AM" "8/27/2020 11:41:47 AM" "8/27/2020 11:54:14 AM"
"8/26/2020 4:10:04 PM" ...
 $ Axis.length.X           : num  255 255 255 255 255 ...
 $ Axis.size.X             : num  1198 1198 1198 1198 1198 ...
 $ Axis.spacing.X          : num  0.213 0.213 0.213 0.213 0.213 ...
 $ Axis.length.Y           : num  255 255 255 255 255 ...
 $ Axis.size.Y             : num  1198 1198 1198 1198 1198 ...
 $ Axis.spacing.Y          : num  0.213 0.213 0.213 0.213 0.213 ...
 $ Axis.length.Z           : num  34010 95224 7771 60579 60641 ...
 $ Axis.size.Z             : num  73180 61441 61664 52314 57436 ...
 $ Axis.spacing.Z          : num  0.465 1.55 0.126 1.158 1.056 ...
 $ NM.points.ratio.Z       : num  0 0 0 0 0 0 0 0 0 0 ...
 $ Sq                      : num  1640 7217 315 2525 1718 ...
 $ Ssk                     : num  -0.626 0.517 -1.202 -0.51 -1.432 ...
 $ Sku                     : num  7.12 4.34 6.34 6.94 12.01 ...
 $ Sp                      : num  5603 24832 716 8900 5842 ...
 $ Sv                      : num  7354 24749 1929 12958 11581 ...
 $ Sz                      : num  12956 49581 2645 21858 17423 ...
 $ Sa                      : num  1080 5359 239 1814 1117 ...
 $ Smr                     : num  0.887 0.151 84.156 0.519 0.768 ...
 $ Smc                     : num  1669 8453 350 2620 1633 ...
 $ Sxp                     : num  4454 13827 770 5202 3974 ...
 $ Sal                     : num  19.3 18.3 11.3 20.1 17.7 ...
 $ Str                     : num  0.26 NA 0.286 NA 0.154 ...
 $ Std                     : num  159 169 156 148 148 ...
 $ Sdq                     : num  0.269 1.165 0.166 0.336 0.294 ...
 $ Sdr                     : num  3.01 19.2 1.35 4.62 3.61 ...
 $ Vm                      : num  0.1354 0.6714 0.0093 0.1819 0.1149 ...
 $ Vv                      : num  1.804 9.125 0.359 2.802 1.748 ...
 $ Vmp                     : num  0.1354 0.6714 0.0093 0.1819 0.1149 ...
 $ Vmc                     : num  0.928 5.19 0.266 1.856 1.034 ...
 $ Vvc                     : num  1.553 8.34 0.309 2.488 1.485 ...
 $ Vvv                     : num  0.2512 0.7845 0.0502 0.314 0.2637 ...
 $ Maximum.depth.of.furrows: num  7251 27509 2061 7182 6417 ...
 $ Mean.depth.of.furrows   : num  1161 8568 433 2115 1408 ...
 $ Mean.density.of.furrows : num  2724 2613 3036 2486 2519 ...
 $ First.direction         : num  90 169 90 135 135 ...
 $ Second.direction        : num  135 174 154 154 154 ...
 $ Third.direction         : num  0.0017 179.9953 135.0327 0.0028 161.4949 ...
 $ Isotropy                : num  18.3 NA 38.2 NA 35.8 ...
 $ epLsar                  : num  0.00234 0.00814 0.00109 0.00501 0.00521 ...
 $ NewEplsar               : num  0.0185 0.021 0.0178 0.0199 0.02 ...
 $ Asfc                    : num  4.31 37.84 2.9 5.11 4.67 ...
 $ Smfc                    : num  4.93 759.24 3.3 32.33 6.9 ...
 $ HAsfc9                  : num  0.6628 6.9889 0.0727 0.5633 0.4985 ...
 $ HAsfc81                 : num  0.708 6.728 0.198 1.53 1.352 ...
 - attr(*, "comment")= Named chr [1:44] "µm" "points" "µm" "µm" ...
  ..- attr(*, "names")= chr [1:44] "Axis length - X" "Axis size - X" "Axis spacing - X" "Axis length - Y" ...
Arch_imp <- loadObject(data_files[3])
str(Arch_imp)
'data.frame':   150 obs. of  57 variables:
 $ Sample                  : chr  "MU-232" "MU-232" "MU-232" "MU-003" ...
 $ Site                    : Factor w/ 3 levels "Balve","Buhlen",..: 1 1 1 1 1 1 1 1 1 1 ...
 $ Tool.type               : Factor w/ 4 levels "Keilmesser","Pradnik scraper",..: 1 1 1 1 1 1 1 1 1 4 ...
 $ Raw.material            : Factor w/ 2 levels "flint","lydite": 2 2 2 2 2 2 2 2 2 2 ...
 $ Location                : chr  "B" "B" "B" "D" ...
 $ Sublocation             : chr  "2" "2" "2" "1" ...
 $ Area                    : chr  "01" "01" "01" "01" ...
```

```
$ Spot                    : chr  "a" "b" "c" "a" ...
$ Usewear.type            : Factor w/ 11 levels "A","B","B2","C",..: 9 9 9 2 2 2 4 4 4 3 ...
$ Objective               : Factor w/ 3 levels "20x07","50x075",..: 1 1 1 3 3 3 2 2 2 3 ...
$ Analysis.date           : Date, format: "2020-09-07" "2020-09-07" ...
$ Analysis.time           : 'times' num  15:08:03 15:08:27 15:08:51 15:09:16 15:09:41 ...
 ..- attr(*, "format")= chr "h:m:s"
$ Acquisition.date.time   : chr  "07.07.2020 16:58" "07.08.2020 10:35" "07.08.2020 12:10" "07.03.2020 10:44" ...
$ Axis.length.X           : num  255 255 255 255 255 ...
$ Axis.size.X             : num  1198 1198 1198 1198 1198 ...
$ Axis.spacing.X          : num  0.213 0.213 0.213 0.213 0.213 ...
$ Axis.length.Y           : num  255 255 255 255 255 ...
$ Axis.size.Y             : num  1198 1198 1198 1198 1198 ...
$ Axis.spacing.Y          : num  0.213 0.213 0.213 0.213 0.213 ...
$ Axis.length.Z           : num  249564 99661 162726 38576 39610 ...
$ Axis.size.Z             : num  65505 35461 32419 65340 66654 ...
$ Axis.spacing.Z          : num  3.81 2.81 5.019 0.59 0.594 ...
$ NM.points.ratio.Z       : num  0 0 0 0 0 0 0 0 0 0 ...
$ Sq                      : num  3243 2493 4332 1912 1936 ...
$ Ssk                     : num  0.0634 -0.9445 0.1816 -0.058 -0.2928 ...
$ Sku                     : num  3.46 7.36 3.08 3.75 3.47 ...
$ Sp                      : num  10477 7460 12748 6231 5796 ...
$ Sv                      : num  10005 12962 16115 6843 6575 ...
$ Sz                      : num  20482 20422 28864 13075 12371 ...
$ Sa                      : num  2506 1813 3409 1464 1495 ...
$ Smr                     : num  0.551 0.697 0.388 0.784 0.586 ...
$ Smc                     : num  3754 2956 5778 2454 2429 ...
$ Sxp                     : num  6582 4878 7854 3949 4400 ...
$ Sal                     : num  25.9 20.5 23.4 24.4 24.9 ...
$ Str                     : num  0.321 0.215 0.241 0.784 0.767 ...
$ Std                     : num  42.5 93 51 103.7 106.7 ...
$ Sdq                     : num  0.603 0.376 0.557 0.301 0.298 ...
$ Sdr                     : num  9.99 5.11 10.54 4.13 4.09 ...
$ Vm                      : num  0.2094 0.1157 0.2311 0.0944 0.0828 ...
$ Vv                      : num  3.96 3.07 6.01 2.55 2.51 ...
$ Vmp                     : num  0.2094 0.1157 0.2311 0.0944 0.0828 ...
$ Vmc                     : num  2.78 1.82 3.63 1.59 1.6 ...
$ Vvc                     : num  3.56 2.73 5.53 2.31 2.24 ...
$ Vvv                     : num  0.403 0.342 0.48 0.238 0.275 ...
$ Maximum.depth.of.furrows: num  12698 14381 16377 7155 7130 ...
$ Mean.depth.of.furrows   : num  2586 2471 3670 2350 2229 ...
$ Mean.density.of.furrows : num  2987 1790 1901 2032 2098 ...
$ First.direction         : num  44.9809 90.00638 89.98321 0.01527 0.00574 ...
$ Second.direction        : num  26.5 135 63.5 116.5 135 ...
$ Third.direction         : num  63.5 116.4 45 135 90 ...
$ Isotropy                : num  13.5 64.5 14.9 87 86.3 ...
$ epLsar                  : num  0.00368 0.0024 0.00301 0.00161 0.00236 ...
$ NewEplsar               : num  0.0181 0.0177 0.0179 0.0171 0.0171 ...
$ Asfc                    : num  12.8 6.85 12.12 5.51 5.36 ...
$ Smfc                    : num  2.51 67.38 48.16 94.68 55.32 ...
$ HAsfc9                  : num  0.629 0.444 0.496 0.666 0.75 ...
$ HAsfc81                 : num  0.81 2.106 1.515 0.845 0.704 ...
- attr(*, "comment")= Named chr [1:44] "µm" "points" "µm" "µm" ...
 ..- attr(*, "names")= chr [1:44] "Axis length - X" "Axis size - X" "Axis spacing - X" "Axis length - Y" ...
```

Add columns with further information

```
location <- substr(AvsN_imp["Location"][,1], 1, 1)
sublocation <- substr(AvsN_imp["Location"][,1], 2, 2)

AvsN_imp$Location = location
AvsN_imp$Sublocation = sublocation
```

```
location <- substr(TFE_imp["Location"][,1], 1, 1)
sublocation <- substr(TFE_imp["Location"][,1], 2, 2)

TFE_imp$Location = location
TFE_imp$Sublocation = sublocation

# adds the name of the experiment as "site"
AvsN_imp[grep("LYDIT4-", AvsN_imp[["Sample"]]), "Site"] <- "aVSn"
AvsN_imp[grep("FLT4-", AvsN_imp[["Sample"]]), "Site"] <- "aVSn"
TFE_imp[grep("LYDIT5-", TFE_imp[["Sample"]]), "Site"] <- "TFE"
TFE_imp[grep("FLT8-", TFE_imp[["Sample"]]), "Site"] <- "TFE"

AvsN_imp[["Site"]] <- factor(AvsN_imp[["Site"]])
TFE_imp[["Site"]] <- factor(TFE_imp[["Site"]])

# adds the tool type
AvsN_imp[grep("aVSn", AvsN_imp[["Site"]]), "Tool.type"] <- "Standard sample"
TFE_imp[grep("TFE", TFE_imp[["Site"]]), "Tool.type"] <- "Standard sample"

AvsN_imp[["Tool.type"]] <- factor(AvsN_imp[["Tool.type"]])
TFE_imp[["Tool.type"]] <- factor(TFE_imp[["Tool.type"]])

# adds a column for "use-wear type" based on cycle
AvsN_imp$Usewear.type <- AvsN_imp$Cycle
TFE_imp$Usewear.type <- TFE_imp$Cycle

# adds the contact material
Arch_imp[grep("lydite", Arch_imp[["Raw.material"]]), "Contact.material"] <- "unknown"
Arch_imp[grep("flint", Arch_imp[["Raw.material"]]), "Contact.material"] <- "unknown"

# adds the task
Arch_imp[grep("lydite", Arch_imp[["Raw.material"]]), "Task"] <- "unknown"
Arch_imp[grep("flint", Arch_imp[["Raw.material"]]), "Task"] <- "unknown"
AvsN_imp[grep("aVSn", AvsN_imp[["Site"]]), "Task"] <- "cutting"

# adds the edge angle
Arch_imp[grep("lydite", Arch_imp[["Raw.material"]]), "Edge.angle"] <- "unknown"
Arch_imp[grep("flint", Arch_imp[["Raw.material"]]), "Edge.angle"] <- "unknown"
AvsN_imp[grep("aVSn", AvsN_imp[["Site"]]), "Edge.angle"] <- "60°"
```

Keeps only interesting columns and orders them

```
# deletes non-important columns
AvsN_imp$Cycle <- NULL
TFE_imp$Cycle <- NULL

# orders the columns in an identical way
AvsN_imp <- AvsN_imp[c(1, 56:57, 6, 2, 55, 3:4, 58, 7, 59:60, 5, 8:54)]
TFE_imp <- TFE_imp[c(1, 58:59, 6, 2, 57, 3:4, 60,7:9, 5, 10:56)]
Arch_imp <- Arch_imp[c(1:9, 58:60, 10:57)]
```

Merges the three datasets

```
# check pairwise if the three lines of headers are identical among the datasets
# merges the data based on the three lines of headers while they get only
# used in the first file

comp <- all(sapply(list(colnames(AvsN_imp), colnames(TFE_imp)),
                   FUN = identical, colnames(Arch_imp)))
if (comp == TRUE) {
  merged_data <- full_join(AvsN_imp, TFE_imp) %>% full_join(Arch_imp)
```

```
} else {
  stop("The headers are not identical among the datasets")
}
str(merged_data)
'data.frame':   234 obs. of  60 variables:
 $ Sample                  : chr  "FLT4-12" "FLT4-12" "FLT4-12" "FLT4-12" ...
 $ Site                    : Factor w/ 5 levels "aVSn","TFE","Balve",..: 1 1 1 1 1 1 1 1 1 1 ...
 $ Tool.type               : Factor w/ 5 levels "Standard sample",..: 1 1 1 1 1 1 1 1 1 1 ...
 $ Raw.material            : Factor w/ 2 levels "flint","lydite": 1 1 1 1 1 1 1 1 1 1 ...
 $ Location                : chr  "B" "B" "B" "B" ...
 $ Sublocation             : chr  "1" "1" "1" "1" ...
 $ Area                    : chr  "01" "01" "01" "01" ...
 $ Spot                    : chr  "a" "b" "c" "a" ...
 $ Usewear.type            : chr  "before" "before" "before" "2000" ...
 $ Contact.material        : chr  "skin pad" "skin pad" "skin pad" "skin pad" ...
 $ Task                    : chr  "cutting" "cutting" "cutting" "cutting" ...
 $ Edge.angle              : chr  "60°" "60°" "60°" "60°" ...
 $ Objective               : chr  "50x095" "50x095" "50x095" "50x095" ...
 $ Analysis.date           : Date, format: "2020-08-17" "2020-08-17" ...
 $ Analysis.time           : 'times' num  14:48:58 14:49:34 14:50:09 14:50:43 14:51:18 ...
  ..- attr(*, "format")= chr "h:m:s"
 $ Acquisition.date.time   : chr  "7/20/2020 2:39:46 PM" "7/20/2020 2:55:08 PM" "7/20/2020 3:12:51 PM" "7/20/2020 3:29:51 PM" ...
 $ Axis.length.X           : num  255 255 255 255 255 ...
 $ Axis.size.X             : num  1198 1198 1198 1198 1198 ...
 $ Axis.spacing.X          : num  0.213 0.213 0.213 0.213 0.213 ...
 $ Axis.length.Y           : num  255 255 255 255 255 ...
 $ Axis.size.Y             : num  1198 1198 1198 1198 1198 ...
 $ Axis.spacing.Y          : num  0.213 0.213 0.213 0.213 0.213 ...
 $ Axis.length.Z           : num  27287 27231 26655 13395 13291 ...
 $ Axis.size.Z             : num  63694 65201 63762 65466 65538 ...
 $ Axis.spacing.Z          : num  0.428 0.418 0.418 0.205 0.203 ...
 $ NM.points.ratio.Z       : num  0 0 0 0 0 0 0 0 0 0 ...
 $ Sq                      : num  160 151 196 227 160 ...
 $ Ssk                     : num  -0.0199 4.1704 2.0253 2.2084 2.0238 ...
 $ Sku                     : num  6.21 37.01 10.42 11.22 9.9 ...
 $ Sp                      : num  1153 1693 1606 1740 1174 ...
 $ Sv                      : num  716 594 406 473 321 ...
 $ Sz                      : num  1870 2286 2013 2212 1496 ...
 $ Sa                      : num  115.8 84.7 138.7 154.4 111.9 ...
 $ Smr                     : num  12.722 0.832 1.59 1.645 10.656 ...
 $ Smc                     : num  177 111 232 250 184 ...
 $ Sxp                     : num  362 192 211 245 175 ...
 $ Sal                     : num  5.94 7.73 8.18 12.2 8.71 ...
 $ Str                     : num  0.0746 0.669 0.226 0.6994 0.1989 ...
 $ Std                     : num  170 133 50.5 101 81.5 ...
 $ Sdq                     : num  0.1019 0.0833 0.1177 0.1378 0.1048 ...
 $ Sdr                     : num  0.513 0.337 0.68 0.916 0.54 ...
 $ Vm                      : num  0.0103 0.0176 0.0206 0.0263 0.0175 ...
 $ Vv                      : num  0.187 0.128 0.252 0.276 0.202 ...
 $ Vmp                     : num  0.0103 0.0176 0.0206 0.0263 0.0175 ...
 $ Vmc                     : num  0.119 0.073 0.133 0.143 0.106 ...
 $ Vvc                     : num  0.164 0.115 0.241 0.262 0.192 ...
 $ Vvv                     : num  0.0233 0.0128 0.0112 0.0138 0.0092 ...
 $ Maximum.depth.of.furrows: num  905 865 814 881 640 ...
 $ Mean.depth.of.furrows   : num  257 174 386 409 311 ...
 $ Mean.density.of.furrows : num  3081 3318 3101 3225 3191 ...
 $ First.direction         : num  1.69e+02 1.35e+02 8.76e-03 9.00e+01 9.00e+01 ...
 $ Second.direction        : num  180 90 135 135 45 ...
 $ Third.direction         : num  135 45 117 116 135 ...
 $ Isotropy                : num  6.16 66.63 52.93 77.77 55.86 ...
```

```
 $ epLsar              : num  0.00356 0.00393 0.00189 0.00195 0.00041 ...
 $ NewEplsar           : num  0.0187 0.0188 0.0179 0.0179 0.0175 ...
 $ Asfc                : num  1.145 0.703 1.494 2.067 1.207 ...
 $ Smfc                : num  3.08 3.3 2.88 2.52 2.52 ...
 $ HAsfc9              : num  0.201 0.636 0.191 0.512 0.239 ...
 $ HAsfc81             : num  0.264 0.939 0.388 0.722 0.386 ...
```

Save data

Format name of output file

```
file_out <- "Use-wear_all"
```

The files will be saved as "~/Use-wear_all.[ext]".

Write to XLSX

```
write.xlsx(list(data = merged_data),
           file = paste0(dir_out, file_out, ".xlsx"))
```

Save R object

```
saveObject(merged_data, file = paste0(dir_out, file_out, ".Rbin"))
```

---

sessionInfo() and RStudio version

```
sessionInfo()
R version 4.0.2 (2020-06-22)
Platform: x86_64-w64-mingw32/x64 (64-bit)
Running under: Windows 10 x64 (build 19041)

Matrix products: default

locale:
[1] LC_COLLATE=German_Germany.1252  LC_CTYPE=German_Germany.1252   
[3] LC_MONETARY=German_Germany.1252 LC_NUMERIC=C                   
[5] LC_TIME=German_Germany.1252    

attached base packages:
[1] tools     stats     graphics  grDevices utils     datasets  methods  
[8] base     

other attached packages:
 [1] forcats_0.5.1     stringr_1.4.0     dplyr_1.0.3       purrr_0.3.4      
 [5] readr_1.4.0       tidyr_1.1.2       tibble_3.0.6      ggplot2_3.3.3    
 [9] tidyverse_1.3.0   chron_2.3-56      R.utils_2.10.1    R.oo_1.24.0      
[13] R.methodsS3_1.8.1 openxlsx_4.2.3   

loaded via a namespace (and not attached):
 [1] tidyselect_1.1.0  xfun_0.20         haven_2.3.1       colorspace_2.0-0 
 [5] vctrs_0.3.6       generics_0.1.0    htmltools_0.5.1.1 yaml_2.2.1       
 [9] rlang_0.4.10      pillar_1.4.7      withr_2.4.1       glue_1.4.2       
[13] DBI_1.1.1         dbplyr_2.0.0      modelr_0.1.8      readxl_1.3.1     
[17] lifecycle_0.2.0   munsell_0.5.0     gtable_0.3.0      cellranger_1.1.0 
[21] rvest_0.3.6       zip_2.1.1         evaluate_0.14     knitr_1.31       
[25] broom_0.7.4       Rcpp_1.0.6        backports_1.2.1   scales_1.1.1     
[29] jsonlite_1.7.2    fs_1.5.0          hms_1.0.0         digest_0.6.27    
[33] stringi_1.5.3     grid_4.0.2        cli_2.3.0         magrittr_2.0.1   
[37] crayon_1.4.0      pkgconfig_2.0.3   ellipsis_0.3.1    xml2_1.3.2       
[41] reprex_1.0.0      lubridate_1.7.9.2 rstudioapi_0.13   assertthat_0.2.1 
[45] rmarkdown_2.6     httr_1.4.2        R6_2.5.0          compiler_4.0.2   
```

RStudio version 1.3.1073.

END OF SCRIPT

Plots - use-wear archaeology & experiments

Lisa Schunk

2021-02-14 14:49:24

Goal of the script

This script combines the results from the quantitative use-wear analysis performed on archaeological samples as well as on standard samples used during two experiments (aVSn and TFE)

```
dir_in <- "analysis/derived_data/"
dir_out <- "analysis/plots"
```

Raw data must be located in ~/analysis/derived_data/.
Formatted data will be saved in ~/analysis/plots. The knit directory for this script is the project directory.

Load packages

```
library(R.utils)
library(ggplot2)
Warning: package 'ggplot2' was built under R version 4.0.3
library(tools)
library(tidyverse)
Warning: package 'tidyverse' was built under R version 4.0.3
Warning: package 'tibble' was built under R version 4.0.3
Warning: package 'readr' was built under R version 4.0.3
Warning: package 'dplyr' was built under R version 4.0.3
library(patchwork)
Warning: package 'patchwork' was built under R version 4.0.3
library(doBy)
Warning: package 'doBy' was built under R version 4.0.3
library(ggrepel)
Warning: package 'ggrepel' was built under R version 4.0.3
library(openxlsx)
Warning: package 'openxlsx' was built under R version 4.0.3
library(wesanderson)
library(ggfortify)
```

Get name, path and information of the file

```
data_file <- list.files(dir_in, pattern = "\\.Rbin$", full.names = TRUE)
md5_in <- md5sum(data_file)
info_in <- data.frame(file = basename(names(md5_in)), checksum = md5_in, row.names = NULL)
```

The checksum (MD5 hashes) of the imported file is:

```
            file                         checksum
1 Use-wear_all.Rbin 112c1ab2c73b661bfc7a8791fab8d25d
```

Load data into R object

```
imp_data <- loadObject(data_file)
str(imp_data)
'data.frame':   234 obs. of  60 variables:
 $ Sample                 : chr  "FLT4-12" "FLT4-12" "FLT4-12" "FLT4-12" ...
 $ Site                   : Factor w/ 5 levels "aVSn","TFE","Balve",..: 1 1 1 1 1 1 1 1 1 1 ...
```

```
 $ Tool.type               : Factor w/ 5 levels "Standard sample",..: 1 1 1 1 1 1 1 1 1 1 ...
 $ Raw.material            : Factor w/ 2 levels "flint","lydite": 1 1 1 1 1 1 1 1 1 1 ...
 $ Location                : chr  "B" "B" "B" "B" ...
 $ Sublocation             : chr  "1" "1" "1" "1" ...
 $ Area                    : chr  "01" "01" "01" "01" ...
 $ Spot                    : chr  "a" "b" "c" "a" ...
 $ Usewear.type            : chr  "before" "before" "before" "2000" ...
 $ Contact.material        : chr  "skin pad" "skin pad" "skin pad" "skin pad" ...
 $ Task                    : chr  "cutting" "cutting" "cutting" "cutting" ...
 $ Edge.angle              : chr  "60°" "60°" "60°" "60°" ...
 $ Objective               : chr  "50x095" "50x095" "50x095" "50x095" ...
 $ Analysis.date           : Date, format: "2020-08-17" "2020-08-17" ...
 $ Analysis.time           : 'times' num  0.617 0.618 0.618 0.619 0.619 ...
  ..- attr(*, "format")= chr "h:m:s"
 $ Acquisition.date.time   : chr  "7/20/2020 2:39:46 PM" "7/20/2020 2:55:08 PM" "7/20/2020 3:12:51 PM" "7/20/2020
3:29:51 PM" ...
 $ Axis.length.X           : num  255 255 255 255 255 ...
 $ Axis.size.X             : num  1198 1198 1198 1198 1198 ...
 $ Axis.spacing.X          : num  0.213 0.213 0.213 0.213 0.213 ...
 $ Axis.length.Y           : num  255 255 255 255 255 ...
 $ Axis.size.Y             : num  1198 1198 1198 1198 1198 ...
 $ Axis.spacing.Y          : num  0.213 0.213 0.213 0.213 0.213 ...
 $ Axis.length.Z           : num  27287 27231 26655 13395 13291 ...
 $ Axis.size.Z             : num  63694 65201 63762 65466 65538 ...
 $ Axis.spacing.Z          : num  0.428 0.418 0.418 0.205 0.203 ...
 $ NM.points.ratio.Z       : num  0 0 0 0 0 0 0 0 0 0 ...
 $ Sq                      : num  160 151 196 227 160 ...
 $ Ssk                     : num  -0.0199 4.1704 2.0253 2.2084 2.0238 ...
 $ Sku                     : num  6.21 37.01 10.42 11.22 9.9 ...
 $ Sp                      : num  1153 1693 1606 1740 1174 ...
 $ Sv                      : num  716 594 406 473 321 ...
 $ Sz                      : num  1870 2286 2013 2212 1496 ...
 $ Sa                      : num  115.8 84.7 138.7 154.4 111.9 ...
 $ Smr                     : num  12.722 0.832 1.59 1.645 10.656 ...
 $ Smc                     : num  177 111 232 250 184 ...
 $ Sxp                     : num  362 192 211 245 175 ...
 $ Sal                     : num  5.94 7.73 8.18 12.2 8.71 ...
 $ Str                     : num  0.0746 0.669 0.226 0.6994 0.1989 ...
 $ Std                     : num  170 133 50.5 101 81.5 ...
 $ Sdq                     : num  0.1019 0.0833 0.1177 0.1378 0.1048 ...
 $ Sdr                     : num  0.513 0.337 0.68 0.916 0.54 ...
 $ Vm                      : num  0.0103 0.0176 0.0206 0.0263 0.0175 ...
 $ Vv                      : num  0.187 0.128 0.252 0.276 0.202 ...
 $ Vmp                     : num  0.0103 0.0176 0.0206 0.0263 0.0175 ...
 $ Vmc                     : num  0.119 0.073 0.133 0.143 0.106 ...
 $ Vvc                     : num  0.164 0.115 0.241 0.262 0.192 ...
 $ Vvv                     : num  0.0233 0.0128 0.0112 0.0138 0.0092 ...
 $ Maximum.depth.of.furrows: num  905 865 814 881 640 ...
 $ Mean.depth.of.furrows   : num  257 174 386 409 311 ...
 $ Mean.density.of.furrows : num  3081 3318 3101 3225 3191 ...
 $ First.direction         : num  1.69e+02 1.35e+02 8.76e-03 9.00e+01 9.00e+01 ...
 $ Second.direction        : num  180 90 135 135 45 ...
 $ Third.direction         : num  135 45 117 116 135 ...
 $ Isotropy                : num  6.16 66.63 52.93 77.77 55.86 ...
 $ epLsar                  : num  0.00356 0.00393 0.00189 0.00195 0.00041 ...
 $ NewEplsar               : num  0.0187 0.0188 0.0179 0.0179 0.0175 ...
 $ Asfc                    : num  1.145 0.703 1.494 2.067 1.207 ...
 $ Smfc                    : num  3.08 3.3 2.88 2.52 2.52 ...
 $ HAsfc9                  : num  0.201 0.636 0.191 0.512 0.239 ...
 $ HAsfc81                 : num  0.264 0.939 0.388 0.722 0.386 ...
```

The imported file is: "~/analysis/derived_data/Use-wear_all.Rbin"

Prepare variables

Define numeric variables

```
num.var <- 27:length(imp_data)
```

The following variables will be used:

```
[27] Sq
[28] Ssk
[29] Sku
[30] Sp
[31] Sv
[32] Sz
[33] Sa
[34] Smr
[35] Smc
[36] Sxp
[37] Sal
[38] Str
[39] Std
[40] Sdq
[41] Sdr
[42] Vm
[43] Vv
[44] Vmp
[45] Vmc
[46] Vvc
[47] Vvv
[48] Maximum.depth.of.furrows
[49] Mean.depth.of.furrows
[50] Mean.density.of.furrows
[51] First.direction
[52] Second.direction
[53] Third.direction
[54] Isotropy
[55] epLsar
[56] NewEplsar
[57] Asfc
[58] Smfc
[59] HAsfc9
[60] HAsfc81
```

Plot each of the selected numeric variables

Boxplot of all the variables combined with the artefact category (without outliers)

```
# excludes the outliers (from both data sets)
# adds the indices as row numbers
imp_data <- imp_data %>% mutate(id = row_number())
imp_data2 <- imp_data[-c(19, 20, 55, 59, 62, 70, 139, 147, 199, 200), ]



arch <- filter(imp_data2, Site == "Balve" | Site == "Buhlen" | Site == "Ramioul")
exp <- filter(imp_data2, Site == "aVSn" | Site == "TFE")
```

```r
# converts the data into factor
arch[["Tool.type"]] <- factor(arch[["Tool.type"]])
exp[["Tool.type"]] <- factor(exp[["Tool.type"]])

# colours archaeological data
custom.col2 <- data.frame(type = levels(arch$Tool.typ),
                          col = c( "#0B775E", "#E1BD6D", "#F2300F", "#35274A"))
arch$col <- custom.col2[arch$Tool.typ %in% levels(arch[["Tool.type"]]), "col"]

# colours experimental data
# Darjeeling1 = c("#FF0000", "#00A08A", "#F2AD00", "#F98400", "#5BBCD6")
custom.col6 <- data.frame(type = levels(exp$Tool.typ), col = "#F98400")
exp$col <- custom.col6[exp$Tool.typ %in% levels(exp[["Tool.type"]]), "col"]

# gets new order
exp$Usewear.type <- factor(exp$Usewear.type, levels=c("before", "2000"))


# plot tool type
for (i in num.var){

  # gets the min/max range of the data set
range_var <- range(imp_data2[[i]])


  p_arch <- ggplot(data = arch, aes_string(x = "Usewear.type", y = names(imp_data)[i],
                                           fill = "Tool.type")) +
           geom_boxplot(outlier.size = 0.7, lwd = 0.2) +
           theme_classic() +
           coord_cartesian(ylim = range_var) +
           labs( x = "use-wear type", title = "  ") +
           labs(y = gsub("\\.", "  ", names(imp_data)[i])) +
           labs(fill = "artefact category") +
           scale_fill_manual(values = arch$col)


  p_exp <- ggplot(data = exp, aes_string(x = "Usewear.type", y = names(imp_data)[i],
                                         fill = "Tool.type")) +
          geom_boxplot(outlier.size = 0.7, lwd = 0.2) +
          theme_classic() +
          coord_cartesian(ylim = range_var) +
          labs( x = "use-wear type", title = "  ") +
          labs(y = gsub("\\.", "  ", names(imp_data)[i])) +
          labs(fill = "artefact category") +
          scale_fill_manual(values = exp$col)


  # combines the plots
  p <- p_arch + p_exp + plot_layout(width = c(4, 1), guides = 'collect')

   # saves the plots
  file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "_boxplot_arch.exp_",
                     names(imp_data)[i], ".pdf")
    ggsave(filename = file_out, plot = p, path = dir_out, device = "pdf",
           width = 250, height = 170, units = "mm")

}
Warning: Removed 9 rows containing non-finite values (stat_boxplot).
Warning: Removed 8 rows containing non-finite values (stat_boxplot).
```

```
Warning: Removed 3 rows containing non-finite values (stat_boxplot).
```

Principal component analysis (without outliers)

```
# PCA use-wear types
# removes rows with na values
data_pca <- na.omit(imp_data2)
# uses for the PCA only selected variables: Sq, SSK, Vmc, Isotropy, Mean density of furrows,  Asfc, HAsfc9
imp_data.pca <- prcomp(data_pca[, c(27:28, 45, 50, 54, 57, 59)], scale. = TRUE)
# converts the data into factor
data_pca[["Usewear.type"]] <- factor(data_pca[["Usewear.type"]])



custom.col1 <- data.frame(type = levels(data_pca$Usewear.typ),
                          col = c("#FD6467", "#999999", "#52854c", "#c3d7a4", "#00A08A",
                                  "#487bb6", "#9a0f0f", "#fdbf6f", "#d16103", "#ffdb6d",
                                  "#985633", "#134680", "#05100c"))
data_pca$col <- custom.col1[data_pca$Usewear.typ, "col"]



# Using ggfortify
PCA<- autoplot(imp_data.pca, data = data_pca, colour = "Usewear.type", size = 2,
                        loadings = TRUE, loadings.colour = "black", loadings.label = TRUE,                          loadings.label.colour
= "black",
                        loadings.label.size  = 4, loadings.label.repel = TRUE,
                        frame = TRUE, frame.type = "convex", frame.colour = "Usewear.type",
                        frame.alpha = 0) +
       theme_classic() +
       scale_colour_manual(values = custom.col1$col)
Warning: `select_()` is deprecated as of dplyr 0.7.0.
Please use `select()` instead.
This warning is displayed once every 8 hours.
Call `lifecycle::last_warnings()` to see where this warning was generated.
Warning: `group_by_()` is deprecated as of dplyr 0.7.0.
Please use `group_by()` instead.
See vignette('programming') for more help
This warning is displayed once every 8 hours.
Call `lifecycle::last_warnings()` to see where this warning was generated.
# saves the plot
file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "_PCA_all.data", ".pdf")
ggsave(filename = file_out, plot = PCA, path = dir_out, device = "pdf")
```

(facet plot = 1 plot for flint, 1 plot for lydite)

```
# selects only the data from after 2000 strokes on the bone plate (experimental data)
exp2000 <- filter(exp, Usewear.type == "2000" & Contact.material == "bone plate")

for (i in num.var){
  #plot
  range_var <- range(exp2000[[i]]) # gets the min/max range of the data set

    p <- ggplot(data = exp2000, aes_string(x = "Task", y = names(exp2000)[i],
            colour = "Edge.angle")) +
         # avoids overplotting
         scale_color_manual(values=c("#046C9A","#FAD510", "#CB2314")) +
         geom_jitter(size = 3,  position = position_jitter(width = 0.35, seed = 1)) +
         coord_cartesian(ylim = range_var) +
         theme_classic() +
         # removes the "." between "Edge.angle" in the legend
         labs(colour = gsub("\\.", "  ", "Edge.angle")) +
         # removes the "." between the variable names
         labs(y = gsub("\\.", "  ", names(exp2000)[i])) +
```

```
    # combines the flint and the lydite plot into one
      facet_wrap(~Raw.material)

  #save to PDF
  file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "_exp_2000_plot_",
                     names(imp_data)[i], ".pdf")
  ggsave(filename = file_out, plot = p, path = dir_out, device = "pdf")
}
Warning: Removed 2 rows containing missing values (geom_point).

Warning: Removed 2 rows containing missing values (geom_point).
```

The files will be saved as "~/analysis/plots.[ext]".

---

sessionInfo() and RStudio version

```
sessionInfo()
R version 4.0.2 (2020-06-22)
Platform: x86_64-w64-mingw32/x64 (64-bit)
Running under: Windows 10 x64 (build 19041)

Matrix products: default

locale:
[1] LC_COLLATE=German_Germany.1252  LC_CTYPE=German_Germany.1252
[3] LC_MONETARY=German_Germany.1252 LC_NUMERIC=C
[5] LC_TIME=German_Germany.1252

attached base packages:
[1] tools     stats     graphics  grDevices utils     datasets  methods
[8] base

other attached packages:
 [1] ggfortify_0.4.11  wesanderson_0.3.6 openxlsx_4.2.3    ggrepel_0.9.1
 [5] doBy_4.6.8        patchwork_1.1.1   forcats_0.5.1     stringr_1.4.0
 [9] dplyr_1.0.3       purrr_0.3.4       readr_1.4.0       tidyr_1.1.2
[13] tibble_3.0.5      tidyverse_1.3.0   ggplot2_3.3.3     R.utils_2.10.1
[17] R.oo_1.24.0       R.methodsS3_1.8.1

loaded via a namespace (and not attached):
 [1] Rcpp_1.0.6        lubridate_1.7.9.2 lattice_0.20-41   assertthat_0.2.1
 [5] digest_0.6.27     R6_2.5.0          cellranger_1.1.0  backports_1.2.0
 [9] reprex_1.0.0      evaluate_0.14     httr_1.4.2        pillar_1.4.7
[13] rlang_0.4.10      readxl_1.3.1      rstudioapi_0.13   Matrix_1.2-18
[17] rmarkdown_2.6     labeling_0.4.2    munsell_0.5.0     broom_0.7.4
[21] compiler_4.0.2    Deriv_4.1.2       modelr_0.1.8      xfun_0.20
[25] pkgconfig_2.0.3   htmltools_0.5.1.1 tidyselect_1.1.0  gridExtra_2.3
[29] crayon_1.4.0      dbplyr_2.0.0      withr_2.4.1       MASS_7.3-53
[33] grid_4.0.2        jsonlite_1.7.2    gtable_0.3.0      lifecycle_0.2.0
[37] DBI_1.1.1         magrittr_2.0.1    scales_1.1.1      zip_2.1.1
[41] cli_2.3.0         stringi_1.5.3     farver_2.0.3      fs_1.5.0
[45] xml2_1.3.2        ellipsis_0.3.1    generics_0.1.0    vctrs_0.3.6
[49] glue_1.4.2        hms_1.0.0         yaml_2.2.1        colorspace_2.0-0
[53] rvest_0.3.6       knitr_1.31        haven_2.3.1
```

RStudio version 1.3.1073.

END OF SCRIPT

ERKLÄRUNG

gemäß § 6 Abs.2 g) und h) der Promotionsordnung der Fachbereiche 02, 05, 06, 07, 09, 10 vom 4. April 2016

Hiermit erkläre ich, **Lisa Schunk**, dass ich die eingereichte Dissertation selbstständig, ohne fremde Hilfe und mit keinen anderen als den darin angegebenen Hilfsmitteln angefertigt habe, dass die wörtlichen oder dem Inhalt nach aus fremden Arbeiten entnommenen Stellen, Zeichnungen, Skizzen, bildliche Darstellungen und dergleichen als solche genau kenntlich gemacht sind.

Ich habe zudem von der Ordnung zur Sicherung guter wissenschaftlicher Praxis in Forschung und Lehre und zum Verfahren zum Umgang mit wissenschaftlichem Fehlverhalten Kenntnis genommen.
Ich erkläre, keine Hilfe von kommerziellen Promotionsberatern in Anspruch genommen zu haben.

Koblenz, 15. Februar 2021

(Lisa Schunk)