Craftful Minds

Tracing Technical Individuality in Production Processes

Moiken Hinrichs

Social, Environmental, and Cultural Connectivity in Past Societies

ROOTS • Studies • RS | 07

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Foreword of the series editors

As the outcome of overarching, interdisciplinary scientific research efforts within the Excellence Cluster 'ROOTS – Social, Environmental and Cultural Connectivity in Past Societies' at Kiel University, we are pleased to present the seventh volume of the publication series **ROOTS Studies.** This book series of the Cluster of Excellence ROOTS addresses social, environmental and cultural phenomena as well as processes of past human development in light of the key concept of 'connectivity' and presents scientific research proceeding from the implementation of individual and cross-disciplinary projects. The results of specific research topics and themes across various formats, including monographs, edited volumes/proceedings and data collections, are the backbone of this book series. The published volumes serve as a mirror of the coordinated concern of ROOTS researchers and their partners, who explore the human-environmental relationship over a plurality of spatial and temporal scales within divergent scientific disciplines. The associated research challenges revolve around the premise that humans and environments have interwoven roots, which reciprocally influence each other, stemming from and yielding connectivities that can be identified and juxtaposed against current social issues and crises. The highly dynamic research agenda of the ROOTS Cluster, its diverse subclusters and state of the art research set the stage for particularly fascinating results.

This new book in the ROOTS Studies series deals intensively with the question of learning and knowledge transfer in the production of artefacts. With regard to bifacial flint production, the author succeeds in working out the individual differences but also the similarities in experimental production between different 'flint knappers' with a precision that has not been presented before. The individual and joint contributions of the processes of knowledge transmission become clear. This provides completely new possibilities for the reconstruction of paths of learning, especially in the Palaeolithic techno-complexes.

The editors of the **ROOTS Studies** series would like to take the opportunity to thank those colleagues involved in the successful realisation of the seventh volume. We are very grateful for the detailed and well-directed work of the ROOTS publication team. Specifically, we thank Andrea Ricci for his steady support and coordination efforts during the publication process, Tine Pape for image editing and the preparation of the cover design and Eileen Küçükkaraca for scientific editing. Moreover, we are indebted to the peer reviewers and our partners at Sidestone Press, Karsten Wentink, Corné van Woerdekom and Eric van den Bandt, for their support and their commitment to this publication.

Kiel, May 2024
Eileen Eckmeier, Martin Furholt, Lutz Käppel, Johannes Müller

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Thank you all.

Moiken Hinrichs

Abstract

The aim of this PhD thesis was to provide a framework for the identification and analysis of individual craftspeople in bifacial flint production. For a long time, research has concentrated on the finished tools, mostly the outstanding and beautiful pieces, and neglected the possibilities of production waste to identify differences in working approaches.

To identify technical traditions within technological systems and/or personal approaches to production, it is necessary to analyse the complete production process. Studies concerned with the process have mostly relied on typical production flakes that were easy to identify. This facilitates the identification of tool manufacture and prevents mixing with other production processes, but also prevents the actual identification of individual approaches to bifacial flint production. Typical flakes are typical because physical laws restrict the mode of possible removal. They are, by definition, strategic moments in the production process, which cannot be changed without altering the outcome, so everyone has to do it more or less in the same way. Personal or traditional approaches will not be found there, but rather in the small, flexible steps in between. This is what the volume presents.

By detailed analysis of the working procedures of modern knappers, combined with statistical analysis of technical attributes on the production flakes, the possibilities for the identification of differing approaches are explored. The analysis showed that the differences on personal or traditional levels are not to be found in the process of removal, but are more clearly distinguished in the preparation for removal. Likewise, the preferences for certain working techniques can

be reconstructed and used to distinguish between knappers' approaches. The results and the approach of the thesis can help us to gain a clearer picture of local technical traditions of flint production. They also offer opportunities to identify and analyse processes of knowledge transmission and by this to reconstruct possible paths of learning, contacts between groups and the development and change of technological systems.

Chapter 1: Introduction

This project started, like so many other dissertation projects, overambitious. The original application design was a comparative study of technological development in bifacial flint knapping from the Late Neolithic throughout the Bronze Age (ca. 2500-500 BCE) in Southern Scandinavia. Knapping assemblages from different chronological settings as well as various regional origins were meant to be analysed for differing production strategies to identify manufacturing traditions, 'schools of learning' or even fingerprints of individual knappers. Very early on, the framework was condensed to a more manageable scope for the set period of the project. The chronological setting was cut down to cover the final part of the Late Neolithic and the beginning of the Early Bronze Age, focusing geographically on Northern Denmark. Knapping products from various archaeological sites were meant to be analysed and compared in an effort to assess the possibility of traditionalised manufacturing strategies as well as the changing patterns of manufacture through time. Markers would have to be defined to assess which patterns in production were expressive for tradition and change. The aim was set for the highest resolution: to identify the individual working preferences of knappers. This would have been nearly impossible solely based on the mixed and fragmented state of archaeological inventories. Therefore, a smaller case study on material from contemporary knappers was essential. With experimental knapping sessions from Lejre (2006 and 2007) as well as Schleswig (2018), a large collection of replicated and well documented Early Bronze Age type sickles from various knappers were readily at hand. Additionally, knapping products of a Late Neolithic Type IC dagger replica was available to be compared to the sickle production. The comparison of a few modern inventories by two or three knappers was meant to form the basis of the analysis of archaeological assemblages.

And then the COVID-19 pandemic hit.

Lock-downs and travel restrictions left no way to gain access to museum collections and assess the available archaeological inventories, so the focus shifted gradually to the modern experimental collections. At one point, it had to be admitted that there was no possible way to include archaeological material in a satisfying way with the chosen time-consuming approach of attribute analysis and the fixed duration of the project. Thus, the project was restructured once more. A case study of contemporary knappers to identify individual technical patterns in the manufacturing process became the main purpose of the project. The aim was now set on the identification of technical differences corresponding to individual choices and preferences during the reduction process. More experimental inventories from the knappers were included and the recording became far more detailed than originally intended. Two additional knapping sessions were scheduled. One to have a comparison collection to the single dagger inventory and a second to witness the working mode of the only knapper who had not been captured on video or experienced in action to have a better common ground of comparison.

The differing backgrounds of the knappers and their learning trajectories made it possible to still include questions about knowledge transmission and its identification in the analysis of knapping products. Prior studies about identification of individuals mostly focused on finished tools (*e.g.* Whittaker 1987; Watts 2013; Stenak 2022a) and skill levels (*e.g.* Apel 2001; Eren *et al.* 2011; Torres and Preysler 2020). Furthermore, the analysis is often based on the recognisable typical production flakes (*e.g.* Apel 2001, 152-154). This makes the recognition of tool production easy and assures that more common flakes from different production processes are not mixed up in the analysis. The down side of this procedure is that these flakes are so typical because the execution is similar or nearly the same, regardless of who delivers the strike. Possibilities of drawing statements about individual preferences in the manufacturing process are rather slim, beside the identification of production type, mastered execution and skill level. For this reason, the entirety of knapping products from the manufacturing process was included in this study. Differences between knappers or learning traditions were not thought to be found in the execution of necessary steps in the production process, which tend to be more restricted by physical laws. In contrast, they were expected in the less structured steps in between. The preparation and maintenance of a bifaces edge is probably guided much more by individual choice than decortication or thinning. This makes their application to archaeological contexts for the posed questions more complex and difficult, as it is not possible to focus on certain types of flakes to get a nice answer. However, the approach is not restricted to biface production alone as preparation and maintenance of the edge is an inherent task in every knapping action.

In addition to pursuing questions about individual flexibility in the production process and the transmission and development of knowledge, a hope of this study was to shed more light upon the structure of biface production in the Late Neolithic and the Early Bronze Age. While the sickles usually receive little attention in research (*e.g.* Oldeberg 1932; Steensberg 1943; Lomborg 1960;

van Gijn 1988; van Gijn and Anderson 1999; Eriksen 2008; 2018), the daggers have been a centre of interest for a long time (*e.g.* Müller 1902; Lomborg 1973; Rasmussen 1990; Stafford 1998; 2003; Apel 2001; Callahan 2006; 2016; Nunn 2006; Frieman 2012b; Stenak 2022a; 2022b), although not always from the perspective of production or technology. While the actual process of manufacture has been described quite well, the organisation of production is still somewhat up to question (*e.g.* Olausson 1997; 2017; Sarauw 2007a; Apel 2008). The identification of individual knapper's fingerprints in flake assemblages can help us to gain more information on this topic. If the daggers were actually manufactured in an apprenticeship system with various persons contributing to the completion of an object, the differences would not only be visible in the varying levels of skill during the production, but also in the personal approach, provided that the system allowed for personal leeway and was not restricted by strict traditions. In the latter case, it would be more likely to be able to reconstruct local or regional traditions of manufacture, which likewise can be traced and compared to another as well as analysed for development, contact and transmission of knowledge.

For various reasons, it was decided to refrain from working solely with finished artefacts. The first is that most studies have already concentrated on such artefacts, while the majority of archaeological material that we have consists of production flakes. An approach to include these production flakes into the research to broaden the interpretation and gain new access to the topic is long overdue. Furthermore, if production was divided into steps and done by various persons, we will not gain insights into the persons involved except for the last person finishing the piece while working with completed objects. Another problem is that if an assignment of artefacts to individual knappers is based on the morphological features of the finished artefacts, this would lead to the sole identification of the exceptionally skilled knappers who are able to 'copy' their own work. Less skilled knappers would blur in the more diverse range of shapes of average artefacts. Again, we would mostly be rating skill and experience in manufacture, but not the personal or traditional take on the production. Moreover, if a craftsperson[1] is skilled enough to manufacture nearly identical pieces in a so varied raw material as flint, then there is a high probability that the knappers were also able to copy other people's work (*e.g.* Stenak 2022a). This would again lead to the question of how to determine if various objects were manufactured by the same person or if different craftspeople were copying the same object. Morphological analyses in reductive technologies are, in addition, not as reliable as they are in additive technologies like pottery making (*e.g.* Roux 2003; Gandon *et al.* 2018). A flint knapper cannot start out again or add some material to make up for failures as a potter can do. Likewise, flint knappers do not have the same extent of control over the quality and properties of their raw material. The form of the finished piece is thus influenced by more than the skill and experience of the person working. Good flint knappers can cope with material flaws, but they will still be forced to make admissions regarding the shape of an artefact (see also Fig. 5). But they will work the way they learned and practised more or less unaffected by variations in raw material and this is fossilised in and on the flakes left during the reduction.

The first step to uncover individual or traditional fingerprints will be taken in this study. Through detailed descriptive evaluation of the production sequences pursued by individual knappers and statistical analysis of technical attributes

1 Craftsperson or craftspeople is chosen as a gender-neutral term throughout the text. Craftsmen is only used when referring to the three artisans included in the study as they are all males.

on flakes, individual preferences concerning work strategies and the implementation of techniques are meant to be identified. Manufacturing processes are guided by technological traditions inherent in societies. People grow up as part of these traditions and learn how to do certain things, amongst others, how objects have to be made, used and perceived. While some traditions can be very strict and are meant to be followed according to the rule, others can be more flexible, acting more like a structuring suggestion how to proceed. Regardless of strict or more loose traditions, people tend to do things the way they learned and how they feel comfortable. This leaves marks in the production process, which cannot only be used to discern between different manufacturing traditions but can also show development of technological traditions through time. The goal here is to identify markers which are expressions of learned traditions and personal preferences. These results, drawn from the comparison of approaches of contemporary knappers, can then be used as approximations to the past behaviour of craftspersons and can offer insight to production structures, knowledge transmission and technological development in and between given societies.

A last remark shall be made concerning the craftsmen providing the material basis of the analysis. Best research practice is to anonymise the people involved, so no negative consequences can follow out of their involvement in the study as well as minimising bias due to (unconscious) opinions by the researcher. It was long debated to stick to the best practice, but in the end a decision to keep the names open was made. The involved knappers are all highly skilled and excel in their craft, no attempt to rate or evaluate their skill was made in this study and it was never a question that was pursued. The focus was always on the differences in approaches. As their backgrounds were rather important for the question of knowledge transmission, and all are very connected to other known knappers, it would not have been difficult to guess who was hidden behind the anonymisation by people remotely familiar with the contemporary flint knapping community. Finally, all three knappers dedicated their free time to participate in knapping sessions, some quite far away from home, and had to cope with overly interested researchers. This should be acknowledged accordingly and not by removing the individual from the data (yet again). The potential bias through the researcher is hopefully minimised by the dual approach of in-detail descriptions of the observed working procedures and the statistical analysis of the recorded attributes complementing each other.

To ease understanding and to prevent confusion, a glossary of the most common and important terms used in the text is included as an appendix.

Chapter 2: A short history of research

Research on stone tool technology is closely linked to experimental archaeology (see also Subchapter 3.2.1). As this study is not concerned with the history of experiments in archaeology or aims to contribute another solution to the seemingly endless debate about what experiments in archaeology should look like to be acceptable, this part will focus on the necessary points in history and point to far better and more comprehensive works for further reading (*e.g.* Johnson 1978; Whittaker 1994; Reeves Flores 2010; Muller 2017). Likewise, the research on Scandinavian bifacial tools will concentrate on parts necessary for the study.

2.1 Development of flint technology research in general

A fact that everyone agrees on is that experimental flint knapping has been part of archaeological research for as long as archaeology has existed as a science. The first attempts can be traced back to the beginning of the 19th century in Scandinavia and Great Britain and are mainly concerned with the distinction between man-made and natural objects as well as the utilisation and use of tools (Ascher 1961; Bonnichsen 1974; Malina 1983; Andraschko and Schmidt 1991; Richter 1991; Forrest 2008; Beck 2011; Bell 2014; Dillian 2019). Interest in the recreation of production processes starts to develop during the 1940s, while the focus on identifying technological information on flakes and using this information to distinguish between manufacturing traditions starts to play a bigger role from the 1970s onward (Malina 1983; Amick *et al.* 1989; Carrell 1992;

Carr and Bradbury 2010; Eigeland 2011; Reich and Linder 2014; Dillian 2019). Until then, most of the research was concerned with the finished products, mostly ignoring the vast quantities of knapping products. With the development and gradual accessibility of computers and software programmes, this started to change (Carr and Bradbury 2010, 72-73; Carlson 2018).

Theoretical and methodological discussions were not part of the early research. Only after World War II, researchers started to be more concerned about the methodology behind experimental approaches (Forrest 2008; Beck 2011; Bell 2014). A first attempt was made to establish experiments as a science and a method in France by A. Leroi-Gourhan (1980) with the development of the *chaîne opératoire* (Schlanger 1994, 144-145; Audouze 1999, 169; 2002; Reich and Linder 2014, 68). In the Anglo-American research, experiments began to be treated as a scientific method and become part of archaeological research in the 1960s. With the development of processual archaeology, more 'scientific' methods enter the research canon and experiments are used as a means to establish generalisations about properties and processes that are linked to the archaeological record (Shanks 1992; Sabloff 2005; Forrest 2008; Johnson 2008; Busuttil 2013; Johnson 2020). Archaeological research at that time sought closer connections to the reasoning of natural sciences, assuming that variability between cultures and societies can be explained on the basis of guiding laws and properties underlying cultural development (Johnson 2008). The most common approach is the *hypotheticodeductive* model, firmly linked to a positivist research tradition (Shanks 1992; Outram 2008; Petersson and Narmo 2011; Schenck 2015; Johnson 2020).

The interest in stone tool studies changed its focus around the same time. Not the objects and use continued to be the questions of research. Researchers started to turn towards questions regarding the production and life histories of objects (Olausson 2010; McCall 2012). In particular, the re-creation of manufacture is a main concern in French research. While processual researchers in the Americas could turn to ethnographic studies for analogies and/or inspirations for hypotheses to explain the patterns in the archaeological record, researchers interested in stone tool production in Europe had a problem (Sabloff 2005). There was no contemporary society left, which could explain or show the production of prehistoric flint knapping and craftsmen still knapping at that time did not follow prehistoric approaches. As a result, archaeologists started to become flint knappers themselves (Olausson 2010; Eigeland 2011). Prominent names, which are tightly associated with the shift from questions about why tools where made to questions about how they were made, include François Bordes and Jacques Tixier in France and Don Crabtree and Errett Callahan in the United States (Whittaker 1994; Olausson 2010, 38; McCall 2012, 160; Schiffer 2013, 46; Inizan and Roche 2018).

With the orientation of archaeology towards scientific practices as in the natural sciences and the quest to recreate prehistoric knapping processes, another experimental approach to technology was created: the identification and understanding of fracture mechanics. This became a more important topic in archaeology during the 1970s and 1980s (Johnson 1978; Malina 1983; Amick *et al.* 1989; Carrell 1992; Carr and Bradbury 2010; Eigeland 2011; Reich and Linder 2014; Dillian 2019). Some experiments focused on strictly controlled experiments in laboratory environments (*e.g.* Speth 1972; 1974; 1981; Dibble and Whittaker 1981; Cotterell *et al.* 1985; Cotterell and Kamminga 1987; Dibble and Pelcin 1995; Dibble 1997; Pelcin 1997a; 1997b; 1997c; 1998), while others relied on human knapped flakes (*e.g.* Newcomer 1971; 1975; Chandler and Ware 1976;

Magne and Pokotylo 1981; Roche and Tixier 1982; Tixier 1982; Amick *et al.* 1988; Hayden and Hutchings 1989; Odell 1989a; 1989b; Tomka 1989).

This divide in the experimental approach is also mirrored in the theoretical development from the 1980s onward. Critique of the processual research approach, especially the positivist tradition, and neglect of human influence in prehistory led to the re-orientation of research foci, summarised under the term post-processualism (Hodder 2005; Watson 2008a; Schenck 2015). Today, there is often still a divide between strictly controlled experiments, looking for the principles of knapping, and the more behavioural oriented approach, looking into questions on how, why and what is significant for the production and utilisation of tools.

This study is an attempt to bring the two aspects of research closer together. The recording and the statistical analysis are firmly based in research about fracture mechanics and (seemingly) objective mathematics. But they are underpinned with descriptions and observations from real life, uncontrolled experiments, which add context not only to the results obtained from the statistical analysis but also offer the possibility to assess the benefit and expressiveness of markers and results for the questions pursued.

2.2 Research on Late Neolithic bifacial tools

The development of flint technology in Scandinavia from the Late Neolithic to the Early Bronze Age (Table 1)[2] has mostly been analysed on the basis of the bifacially worked prestigious daggers of that time and region. Throughout time, they received the most attention and are often treated separately from the technological sphere in general. In fact, bifacial flaking was known in Scandinavia prior to the advent of the famous daggers, as was the dagger as an artefact (Olausson 2008, 30-31; Frieman 2012b, 453-454; Frieman and Eriksen 2015a). The earliest types of bifacial tools date back to Funnel Beaker times and are often interpreted as halberds (Müller 1888; Langenheim 1936; Kühn 1979; Rassmann 1993, 16-17; Ebbesen 1994; Olausson 2012, 222). Other tools said to be closely connected to the bifacial dagger, but possibly have a slightly earlier origin, are the so-called 'feeding knives'. The chronological setting is not that well understood, but they probably date back to the Middle Neolithic and Single Grave contexts (Brøndsted 1957, 326; Nielsen 1976; Ebbesen 1994, 103-104; Vandkilde 2005, 7). The first daggers appear around the same time in Europe, but do not originate in Scandinavia. Best known examples are the plano-convex Grand-Pressigny daggers from Central France, which have been copied in local material as far away as Northern Germany and Southern Scandinavia (Lomborg 1973, 87-91; Kühn 1979, 31-38; Rassmann 1993, 17-18; Siemann 2003, 101-106; Zimmermann 2007; Frieman 2012a, 83-85; 2012b, 453-454). From a technological point of view, it can be argued that the development of flint daggers in Southern Scandinavia is continuous from at least the Middle Neolithic onward. The techniques necessary to work bifacial artefacts were certainly present and could be employed to meet changing demands in the tool spectrum (Brøndsted 1957, 336; Kühn 1979, 38-40; Agthe 1989, 55-56; Frieman 2012b, 451; contra: Forssander 1936, 124-125; Vandkilde 2005, 15). Another point in favour of the continuous development of present technical and technological knowledge has been made by P. V. Hansen and B. Madsen (1983), whose study showed that the knowledge for the punched seams of the later dagger types has its roots in

2 Chronology is assembled based on: Vandkilde (1996), 140, fig. 134; Müller *et al.* (2010); Olausson (2013), 449, tab. 1; Wrobel Nørgaard (2018); Müller and Vandkilde (2021).

Age	Period	BCE
Early Bronze Age	III	1300-1100
	II	1500-1300
	I	1700-1500
Late Neolithic (Dagger Period)	LN II	1950-1700
	LN I	2350-1950
Middle Neolithic (Funnel Beaker)	MN V	2900-2800
	MN III-IV	3000-2900
	MN II	3100-3000
	MN I	3300-3100

Table 1. Overview of chronological periods in Southern Scandinavia with importance for the study.

flint axe manufacture (see also Kühn 1979, 40; Frieman 2012b, 443-444). Even the retention of cortex remnants on finished artefacts has an earlier origin and is known from Middle Neolithic axes (Rudebeck 1998; Frieman 2012b, 444).

A point, which has often been made, assumes that the heights in flint manufacture were only reached in Scandinavia due to the scarcity of available metal tools (*e.g.* Forssander 1936; Brøndsted 1957; 1958). In contrast, it could likewise be argued that the perfection of the craft was only possible because metal was available. For dagger production, it is often argued that certain parts of the manufacture would not have been possible without copper tipped pressure flakers, like the parallel edge-to-edge retouch of the type IC daggers or the finely stitched seams on type IV (*e.g.* Rassmann 1993, 72; Stafford 1998; 2003). As copper tools have been present through imports in Southern Scandinavia at least since early Funnel Beaker times, it cannot be ruled out that copper tipped pressure flakers were available, although no archaeological support exists (Vandkilde 1996; 2005; Klassen 2000; 2004; Barrowclough 2004; Strand Tanner 2015). Local metallurgy seems to have developed a lot earlier than previously thought, at least in form of re-casting (Gebauer *et al.* 2021). Due to this, it is not totally impossible that local flint knappers had access to copper tips, either by direct import or the recasting of imported goods.

One aspect that all agree on is the influence of metal forms on the flint daggers, especially strong in the later dagger types (Müller 1902, 132; Forssander 1936; Glob 1938, 42; Brøndsted 1957, 320-322; Rassmann 1993, 19; Sarauw 2009; Frieman 2012b, 447-449), but also at the beginning of the dagger development (Vandkilde 1996, 180; 2005, 15, 26; Olausson 2012, 225). However, the typological development of flint daggers is a continuous one, which does not show breaks. The influence of metal forms has thus only guiding effect on the technological and morphological development (Frieman 2012b, 441-442). To some extent, the influence of metal templates is also considered for the bifacial sickles (Glob 1938; Brøndsted 1957, 326; 1958, 13). The opposing opinion has likewise been voiced and maintains that bronze sickles could have been copied from Early Bronze Age flint sickles (Oldeberg 1932, 224-225; Steensberg 1943, 162; Lomborg 1960, 167-169; Rassmann 1993, 32). Another possible explanation for the similarity in the form of sickles of various materials is based on normative requirements needed for the function and use of the tool (Eriksen 2018, 289). In rare occasions, the copying of flint artefacts in metal has also been proposed for the flint daggers, but no real discussion has been concerned with the issue (*e.g.* Kühn 1979, 63).

A first closer analysis of Scandinavian daggers was conducted by S. Müller (1888; 1902). His typology already allows for a chronological development of forms, but also regional differing of contemporaneous trends. All later typologies are further developments from S. Müller's first suggestion. Today, E. Lomborg's (1973) typology is generally referred to. He has divided the daggers into six types, of which all have at least two subtypes based on the shape of the blade and the handle form. Types I-III encompass daggers of lanceolate shape and daggers that have a lanceolate shaped blade. Types IV-VI are made up of daggers with the broadest part of the blade closer to the handle (Rasmussen 1990; Vandkilde 1996, 13; Olausson 2012, 222-223). Only minor adjustments regarding chronology have been proposed for the typology. While E. Lomborg (1973) separated the Late Neolithic into three periods based on the occurrence of type I-III daggers, T. Madsen (1978) argued for a regional non-chronological variation between types I and II. H. Vandkilde (1996) supported the regional variation and proposed a division in two periods of the Late Neolithic, which is used today.

Already early in the research, the manufacture was considered or at least commented on as being exceptional, although typology, chronology and function have been the main questions pursued thus far (*e.g.* Müller 1897, 170-171; Forssander 1936, 124-127; Brøndsted 1957, 320; Lomborg 1960; Nielsen 1976; Arnold 1981a). The focus of research lay often on the long and well worked daggers, while the majority of pieces with less careful or skilful execution were neglected. This has certainly underpinned the interpretation of highly skilled and probably full-time experts and craftspeople responsible for the manufacture of flint daggers (Müller 1897; Brøndsted 1957, 327; Olausson 2008, 31; 2017, 133-134; Sarauw 2009, 32). With a closer look at the available artefacts, it becomes quite clear that a highly varying degree of skill and knowledge was involved in the manufacture and a lot of daggers are of quite average design (Sarauw 2009, 32; Olausson 2012). Likewise, with the focus on the prestigious daggers, the time for manufacture is often highly overrated. While a lanceolate type IC with edge-to-edge retouch or a type IVD fishtail dagger takes at best a couple of days (with breaks) to manufacture, more simple daggers can be worked in a couple of hours (Stafford 2003; Nunn 2006; Sarauw 2007a, 231-232; 2009, 33). This has also been observed in the experimental sessions used in this project (Table 2). Similarly, the requirements for raw material quality are lower for daggers of average length and technical execution (Sarauw 2007a, 236; Olausson 2012, 225). The evidence supports the notion that basically every person should have been able to produce a bifacial tool, when needed, at least during the Late Neolithic (Müller 1902, 128; Vandkilde 1996, 265; Sarauw 2007a, 251; Frieman 2012b, 452; Olausson 2012, 226-227; 2017, 133). This was about to change when knowledge declined and probably became more restricted with the transition to the Bronze Age (Lomborg 1960, 170; Eriksen 2007a; 2010). This can be seen when comparing the manufacture and maintenance of sickles. Daggers are often reworked quite heavily but in a qualitative good manner. Early Bronze Age sickles, on the other hand, show a decline in the knowledge of how to resharpen and rework the edge, which hints that knowledge of bifacial manufacture was not readily available to everyone any longer or at least the execution was poor due to a lack of experience (Winther Olesen and Eriksen 2007, 85; Eriksen 2010; 2018).

Knapper	Artefact	Time	Finished	Comments
A. Benke	Sickle 2018	01:50	yes	
	Dagger 2021	12:50	yes	Without grinding: 07:07
G. Nunn	1-34 2007	02:15	yes	
	2-35 2007	02:45	yes	
	3-33 2007	02:50	yes	
	6-47 2007	01:40	no	Endshock
	Dagger 2005	24:24	yes	Without grinding: 13:53
P. Wiking	2-10 2006	02:30	yes	
	1-36 2007	02:00	yes	
	2-32 2007	02:00	yes	
	3-31 2007	02:30	yes	
	4-38 2007	00:55	yes	
	5-49 2007	05:00	yes	
	6-41 2007	02:50	no	Endshock
	7-60 2007	02:00	yes	
	8-43 2007	01:10	yes	
	9-55 2007	01:15	yes	
	Laurel leaf 2022	00:59	yes	
	Sickle 1 2022	00:54	yes	
	Sickle 2 2022	00:42	yes	
	Dagger 5 2022	02:22	yes	Finished for grinding

Table 2. Summary of production time for all finished or nearly finished artefacts in the Lejre and Schleswig workshops (if available). Total time is often more a rough estimate, as smaller breaks during questioning are not included. All artefacts from 2006 and 2007 are sickles. The numbers in front of the year are the number of artefacts made during the session and the nodule number. All daggers belong to type I.

The difference in skill levels observable on daggers has led to the proposition of a dual function and production of daggers (Sarauw 2007a; Olausson 2012, 226-227; 2017, 133). The majority of daggers seem to have been highly regarded as every day tools, seen in the more mundane execution and quality of the artefacts as well as the heavy reworking, which occasionally ended in reworking the handle of lanceolate daggers to the blade, as the original blade had become too short to be resharpened (Müller 1888, 18; 1897, 131; Agthe 1989, 24-25; Olausson 2008, 32-34; 2012, 223-224; Sarauw 2009, 32). On the other end of the spectrum are the daggers most often found in funerary contexts, which are exceptionally long, well-worked and often unused. While the former could be worked with more or less effort by the majority of people, the latter ones needed more skill and experience to be manufactured and are thus proposed to have been specifically made by skilled craftspeople (Müller 1902, 166-167; Sarauw 2007a, 251; 2007b, 74; 2009, 38; Olausson 2012, 227-228). Likewise, the rather low total number of highly prestigious daggers in comparison to average pieces makes the hypothesis of dependent full-time specialist and strictly controlled knowledge in secluded workshops rather unlikely (Olausson 1997; 2017; Apel 2001; Sarauw 2007a, 251; Frieman 2012b, 445). For the Late Neolithic at least, population-wide access to the knowledge and means to manufacture a dagger seems to be the more reasonable hypothesis. The difference in design and elaboration is more probably a sign of talent and skill gained by individuals of that time.

Like humans today, past craftspeople quite certainly had an ego and were interested in pushing the borders of their skill, not only in competition with each other, but also to become personally better than before. The production of an object, especially in handcrafts, is not only about meeting a demand in society but is also influenced to a certain extent by a personal demand on the execution of a craft by a craftsperson (*e.g.* Olausson 2017, 10-11). Hints for this can be seen in the type I dagger. The subtype IC does not have functional advantages compared to the other subtypes, more precisely, there are no differences in the manufacturing process itself. The differences between type IB and IC are merely additional production steps. They are not required for a functional tool and contribute solely to the aesthetic of the object. But, these extra steps show differences in time investment, knowledge and skill of the person manufacturing such objects. It has been proposed that the subtype IC has been manufactured by very few craftspeople over a more restricted time span than the period in which the type I dagger was common (*e.g.* Sarauw 2007a, 251; Frieman 2012b, 452), and thus shows the development and skill of some few individuals, who possessed an innate talent and were able to invest time to surpass the general level of expertise and knowledge. But it does not appear that a greater talent and skill in flint knapping provided craftspersons with a higher status in society itself. At least, their role was not represented or emphasised in funerary contexts as far as archaeology has been able to trace (Sarauw 2007a, 251; 2009, 37). The structure of production changes quite likely with the transition to the Early Bronze Age; the number of daggers of type IV-VI are most often significantly lower than of type I (Apel 2001, chap. 9; Frieman 2012b, 445), which could hint at a more specialised production, especially for the type IV fish-tail daggers. Even production by the same individual has been proposed for the very exceptional pieces such as the Hindsgavl (DK), Svasstorp (SE) and Skattelöv (SE) daggers (Callahan 2006, 119; Olausson 2017, 9; see also: Stenak 2022a, 39-49).

This divide of the technological sphere of flint working becomes more apparent in the Early Bronze Age and continues throughout the Late Bronze Age (*e.g.* Eriksen 2008; Goldhammer 2015). Bifacial sickles appear during the Late Neolithic, around the same time as the other bifacial artefacts, and continue to be produced and used in the Early Bronze Age after which they cease to exist (Oldeberg 1932, 221; Steensberg 1943; Brøndsted 1957, 326; Lomborg 1960; Rassmann 1993, 29-32; Eriksen 2018; Winther Johannsen 2023, 4). As they are seldomly found in graves, the dating and chronological setting have to rely on associated artefacts in hoards and depositions as well as stratigraphic evidence from settlements (Müller 1897, 125; Oldeberg 1932, 215; Lomborg 1960, 164-166; Kühn 1979, 66; Rassmann 1993, 31-32). There is no clear cut typological or chronological divide up to date, but from evidence it is quite obvious that the crescent-shaped sickle is the earlier type, belonging in the Late Neolithic, while the asymmetric sickle is a later, Early Bronze Age type (Glob 1938; Kühn 1979; Rassmann 1993, 32; Jensen 2001; Eriksen 2018). The function of the artefact has been discussed controversially. The first, most likely interpretation assumed that it was a saw-like implement due to some specimen showing a quite distinct serration of the cutting edge (Müller 1897, 125; Oldeberg 1932; Forssander 1936; Steensberg 1943, 6). The discussion was only concluded, when experimental studies and use-wear analysis were conducted. They demonstrated that the artefacts were not useful for cutting wood and further that the luster on the edge originated from the cutting of cereals (Oldeberg 1932; Steensberg 1943; Kühn 1979, 65). Early on, the technical relationship to bifacial daggers was noted and often rated as being not so finely executed (Brøndsted 1957, 326-327; Kühn 1979, 65-66). It can be noted that the bifacial work during the Bronze Age is often cruder than during the Late Neolithic, although the method is not generally less carefully executed. However, a greater span in the ability to work bifaces and flint in general is apparent (Lomborg 1960, 170; Eriksen 2010; 2018).

Technical analysis of bifacial production has been part of research since S. Müller (1897, 170-172), although no detailed studies were conducted (*e.g.* Lomborg 1973; Ebbesen 1994). The focus was set on the general procedure of the bifacial method as well as on technical oddities. Traces of grinding were discovered quite early on, not only on the lanceolate daggers, but also on the halberds and feeding knives, and were interpreted as a shortcut during reduction, when tough material increased the risk of failure (Müller 1897, 172; Langenheim 1936; Brøndsted 1957, 320; Nielsen 1976, 114; Kühn 1979; Rassmann 1993; Ebbesen 1994, 107-110). E. Lomborg (1973, 31) was the first to propose the grinding of dagger blades as a technical necessity for successful edge-to-edge pressure flaking. Detailed studies were conducted much later and often focused on the famous fishtail daggers, which today are said to be one of the most complex and difficult artefacts to manufacture (Stafford 1998; Apel 2001; Callahan 2006; 2016; Nunn 2006; Olausson 2008, 31; contra: Stafford 2003).

Besides uncovering the means to produce bifacial daggers, a constant topic in research is concerned with the function and use of daggers (Apel 2001, 311; Frieman and Eriksen 2015b). Most often, they have been interpreted as some kind of status symbol associated with the male sphere and an ideal of a warrior class (Sarauw 2007b; 2009, 36; Madsen 2018, 41-43). The use is more controversially debated and split between the interpretation as a weapon (Müller 1888; Brøndsted 1957; Lomborg 1973), a ritual object (Rydbeck 1934; Stensköld 2004; Skak-Nielsen 2009; van Gijn 2010; 2015), and an everyday tool (Sarauw 2007a; Frieman 2012b, 446; Varberg 2015, 99-100). Often, there is an either-or attitude, denying the possibility of multiple purposes (Frieman 2012b). From archaeological evidence so far, it seems reasonable to assume that daggers as an object class did not serve solely one purpose, but the type of use was to some extent tied to the elaboration of manufacture (Müller 1897, 131; 1902, 167; Sarauw 2007a; Frieman 2010; Olausson 2012; 2017; Varberg 2015, 101). This means that exceptionally well-made daggers, most often found in graves and hoards, could have had a higher symbolic value and a different purpose than more average pieces used in everyday contexts.

As demonstrated above, questions about who made bifacial tools are often treated more as an afterthought and in connection with exceptional craftsmanship. We know that it takes time to learn and master flint knapping (*e.g.* Pelegrin 1990; Grimm 2000; Apel 2001, 37; Geribàs *et al.* 2010; Maloney 2019). Time and accessible raw materials are of essence to practice one's skill and develop experience, especially about things that can go wrong and how to prevent mistakes. Skill is thus most often used as a proxy to distinguish individual knappers from one another (*e.g.* Callahan 2006; Sarauw 2007a, 239; Eriksen 2010; Eren *et al.*

2011; Kolhatkar 2022; Stenak 2022a). It can also be used to distinguish between experience and help to discover how transmission of knowledge was structured (*e.g.* Stout 2005; Gandon *et al.* 2020). But to some extent, the concentration on finished artefacts or typical knapping products is limiting. As has been mentioned before, when analysing the finished tools, it is often only daggers which are looked at while all the other bifacial tools are mostly ignored. Furthermore, the focus lies on the exceptionally well-made pieces and objects which mostly have not been used, as the partly extensive resharpening and reworking of the dagger blades not only hampers the assignment to types, but also leaves almost no traces of the original finished surface. Thus, there is almost no way to discern, if a very nicely resharpened dagger was equally well produced or if a very bad reworking covers an exceptionally executed dagger. Likewise, the focus on finished objects restricts the analysis to the last few production steps. True, if the finished piece is very well manufactured, all steps of the production must have been met and executed in a sufficient manner. But if the last finish has been done by a master of the craft, as proposed by J. Apel (2001, chap. 2; 2008), faults in the earlier execution can be hidden behind the final step. Likewise, a misinterpretation of the skill will be made when concluding that there were some critical faults but they were skilfully mended in the end (see also Callahan 2016, 58).

Beyond that, the last step of production cannot be used as evidence for the proposed division in production or an apprenticeship system. If more than one person was involved in the production of an artefact, this should be detectable in the knapping products and the production sequence, especially when the involved persons differ in their skill and experience. Similarly, if the interpretation is based on characteristic flakes from the production process, only the typical steps are compared (*e.g.* Apel 2001, chap. 5). These flakes are characteristic because there are more than traditional restrictions, which lead to a similar way of removing the flakes. It could be argued for a technical necessity to remove such flakes in a given manner, which does not cover personal approaches (see further Subchapter 3.1.1). We need to analyse the complete production process to answer questions about the production structure (Young and Bonnichsen 1985; Maloney 2019, 4). This means that we have to analyse all steps in the process, not only the recognisable ones, which would also help us to gain deeper insights into the technological sphere in general.

Up to now, there has been little concern about how the morphological distinct forms differ in production. It is more or less assumed that production was similar regardless of region or time setting. But the regional trends in morphology could also be an expression of slightly differing technical traditions, not in the overall method, but in the smaller, less restricted production steps. Technical preferences or restructuring of sequences by individual craftspeople would be more clearly visible in the detailed analysis of the complete process (Young and Bonnichsen 1985, 92-93). Likewise, the encapsulation of production is only proposed for the daggers, but what about the other bifaces? If it was necessary to be accepted as an apprentice to be able to learn how to knap daggers, would not the same be true for sickles or feeding knives? Were there different manufacturing traditions in action concerning the various object types, or did the excellent craftspeople of the time knap mundane tools, too? Moreover, how different was the bifacial method from other parts of flint technology at the time? To answer these questions and to get into the details of the structures of flint knapping traditions, we have to be able to identify diverse traditions inside a technological system in the first place. For this, not only the *chaîne opératoire* approach but also technical attribute analysis seems to be the most promising procedure in order to observe variations in what to do at which step and how a behaviour is structured by tradition and experience. People learn how to do things in a socially accepted way. We are taught how to do things and mostly do not consider different ways to achieve the same goal (*e.g.* Dobres 2000, chap. 5). Thus, people from different traditions will do things slightly different, even when doing the same thing. These differences have been used as cultural markers and have been compared between groups and chronological settings.

This is why this study is not concerned with finished artefacts, but focusses on knapping products (see also Carr and Bradbury 2010, 73). Skill is not a question, which has been pursued here, as the goal is to identify possibilities to distinguish between individual or personal ways of knapping and technical traditions on a very small-scale, detailed level. This is done by comparing technical attributes on flakes between various knappers and their approaches to the material. With a positive result, this would open up a new pathway to obtain additional information about technological systems from the very vast find category of flakes. Furthermore, this study has the potential to develop interpretations about who made certain tools on a more objective level than having to rely on morphological characteristics and modern experts' opinions. It could also open up a broader identification of craftspeople, since not only the very few, very skilled knappers can be identified but also individual variations on a more basic level. At least, it could be possible to identify groups of people, who followed the same traditional rules during production. Additionally, technical fingerprints based on attributes would not only allow an assessment of the skill level of craftspeople but could also help to distinguish persons with the same skill level from each other. A further benefit of the approach could be the possibility to more easily detect developments in the technological tradition or at least observe them earlier. When new techniques are introduced or the production structure is changed, this will appear on the knapping products but not necessarily on the finished objects.

Chapter 3: Theory, method and terminology

The following chapter will briefly discuss the theoretical and methodological background used in this thesis. Especially the theoretical background will be limited to the most necessary topics as good and exhausting discussions have been made elsewhere (cf. technology*:* Johnson 1978; Schlanger 1994; Audouze 1999; Dobres 1999; Apel 2001; Andrefsky 2005; Shott 2007; Soressi and Geneste 2011; Pelegrin 2015; cf. transmission: Dunnell 1980; Shennan 2002; 2008; Schönpflug 2009). Definitions and concepts as well as analyses used in the study will be summarised briefly in terms of their application.

3.1 Theory

3.1.1 Technique and technology

> *"Artifacts are tactile things, but technology is far more than just objects. It is knowledge, skill, time, effort, mistakes, injuries, social interaction, humor, frustration, transformation, construction, success, and failure." (Clarkson and Shipton 2015, 159)*

As the quote above shows, technology and tools are not the same thing. The latter is often an integral part of the former, but technology is better thought of as a frame that structures actions. Likewise, technologies do not only concern technical procedures. Every action in life is part of a technology (Mauss 1973; Lemonnier 1992, chap. 1; Schlanger 1994; Schenck 2015). This means also that there is not just one technology present in a given society, but a set of technologies which structures various parts of daily life. Technologies depend on the demands of the society and live, develop and die as the demands change. They are deeply rooted in social structures and influenced by needs and traditions at least as much as they influence them (Schiffer and Skibo 1987, 598; Lemonnier 1993a; Apel 2001, 23; Schlanger 2006; Bamforth and Finlay 2008, 9). By this, they are far more than a simple set of tools. Technologies are structured systems encompassing artefacts, behaviours and knowledge passed down through generations (Mauss 1973; Schiffer and Skibo 1987, 595; Bamforth and Bleed 1997, 111; Apel 2001, 18; Jordan 2014, 1). They include techniques – modes of action – which too are bound by tradition. Different techniques can perform the same task, but they are assembled in meaningful systems of procedure – an operational sequence or *chaîne opératoire* – which specifies how to proceed in a given technological system and thus the application cannot be treated as a totally free choice by the person in action (Mauss 1973; Lemonnier 1986; 1992, chap. 1; 1993a; Schlanger 1994; 2006). Techniques are not only the choice of tools but also include gestures and positions of either body or tool (Inizan *et al.* 1999, 30).

The *chaîne opératoire* has been defined as the transition of raw material from a natural to a manufactured stage by a sequence of operations or, in a more general way, the transformation of any matter including the human body (Leroi-Gourhan 1980; Lemonnier 1992, 25-26; Schlanger 2005, 18). It was M. Mauss (1973) who first suggested to pay closer attention to chains of sequences in actions and A. Leroi-Gourhan (1980) who developed and named the concept for archaeology (Audouze 1999; 2002; Apel 2001, 23-24; Schlanger 2005). P. Lemonnier (1986) added another dimension to the concept, as he distinguished two types of events. Inside an action sequence, there are events which are variable and flexible and can be replaced by similar events without risking the outcome of the action, which he termed technical variants. In contrast, there are strategic and fixed events, called strategic operations or moments, which cannot be replaced, cancelled or delayed without altering the outcome. These give a frame to the *chaîne opératoire*, in which the variants can happen. By describing the sequence, the strategic moments can be recognised and variants become visible and comparable (Lemonnier 1986, 154; 1992; Schlanger 1994, 145; 2005, 20; Audouze 1999). These alternatives in the technical variants are socially specific. They are the choice of a given society to act in such a way, and by this they can help to reconstruct and understand a society's relation to various fields influencing technology (Lemonnier 1992; Audouze 2002; Schlanger 2005; Desrosiers 2007, 18; Soressi and Geneste 2011, 336).

Due to this, in French flint knapping research a major part of the analysis is concerned with identification and description of recordable sequences which mark changes in the production (Leroi-Gourhan 1980; Pelegrin 1990, 116-117; Desrosiers 2007, 20). High priority is given to the identification of changing motives in the production by using experimental references. Even skilled flint knappers can get into the awkward situation of not being able to pinpoint the reason for their conviction to change into another stage of work. They simply know that they do this. The *chaîne opératoire* approach seeks to dispel these gut feelings and implicit knowledge by identifying and describing all technical choices during production. But, as J. Pelegrin (2000, 74) states: "*on ne peut reconnaître que ce que l'on connaît.*"[3]

3 "one can only recognise what one knows" [translation by the author].

Simply put, if we want to identify varying technical applications, we need to know which kind of markers they leave on the material. This is why experimental knapping has a high priority in French research. However, one should keep in mind that experimental comparison is by no means a panacea to technological reconstruction. It is an immense help in defining and identifying technical choices and differences by showing which markers are expressive for given techniques as well as pointing to unknown markers, where the process of creation has yet to be described. But they have also shown that there is a huge overlap in markers and characteristics. Different techniques can leave the same attributes on artefacts and effectively end up with technically the same product. The reverse can be true too: totally different markers and products are achieved while the same technique has been used. Effectively, this is the reason why the *chaîne opératoire* approach is so concerned about detailed descriptions, extensive experimental collections and cautious interpretations of observed processes. This is also one of the biggest points for critique of the *chaîne opératoire* – its focus on the details in the production process while losing sight of the entire system (*e.g.* Skibo and Schiffer 2008). But, as A. Leroi-Gourhan (1980) argued: we need the detailed descriptions and insights of the technical systems to achieve an understanding of the technological and social system before we can start to compare them with one another, be it contemporaneous systems or one system through time (see also Audouze 2002, 284).

The *chaîne opératoire* offers insights not only to technological choices of given societies, but also into the structure of learning systems and the transmission of knowledge (Cavalli-Sforza 1986; Henrich 2001; Jordan 2014; Tostevin 2019a). Humans are social beings and most knowledge is transmitted through social learning, which means it has been taught to us by other people – parents, teachers or other unrelated individuals. This kind of transmission creates a system of social tradition, which ensures that knowledge is passed on down to further generations without a total loss of knowledge each time when an individual in possession of the knowledge vanishes. Transmission is not always a stable process. It is still a choice how or if one should use the acquired knowledge. Knowledge can be modified for better or worse or be dropped altogether. Reproduction of social and technological knowledge is thus an active process carried out by people intertwined with the social system that they are living in (Henrich 2001; Jordan 2014). This can create stable technological systems over time or rapid changing and/or adapting traditions, which can be traced and described, if a technology's *chaîne opératoire* is analysed diachronically.

Knowledge is a key concept within technology. Without knowledge, no technology could exist in the first place. In manufacturing processes, technological knowledge structures the production and application of tools, but it also offers possibilities in handling and problem-solving strategies (Schiffer and Skibo 1987, 597; Pelegrin 1990, 118; Lemonnier 1993a; Bamforth and Bleed 1997, 111). Knowledge and behaviour contained in a technological system do not solely structure the selection of raw materials, the form of artefacts and the proper use of produced tools but also have a strong influence on the production process itself. Knowing where to gather suitable raw materials[4] and how to proceed can vary greatly between people and societies even if the final product looks similar or the same. Change and replacement of knowledge and techniques can thus be traced

4 Suitable does not always mean best kind of material, but rather familiar material or material properties. Even this choice can be guided more through traditions than actual demand for the artefact (Olausson 2010, 40).

and referred back to changing social and environmental conditions. A variety of concepts are concerned with the structure of knowledge and transmission, a few will be summarised here.

Schiffer and Skibo (1987, 597) subdivide technological knowledge into three components: recipes of action, teaching frameworks and techno-science, with the last one being more or less invisible outside of modern sciences (Apel 2001, 20-21). An example for techno-science in flint working would be fracture mechanics. Modern experimentation and science have given us knowledge about the physical principles behind flaking, but this knowledge is technically not required – or at least not consciously required – for successful reduction. The explanation why it works is not as important as the knowledge that it works. Recipes of actions are essentially the knowledge of (social) rules structuring the production process, including the choice of raw material and tools, the stages to be taken for a successful production as well as alternative routes and problem-solving strategies (Schiffer and Skibo 1987, 597), which essentially represent the *chaîne opératoire* in French research.

Pelegrin (1990, 118; 2000) divides knowledge into two categories: knowledge (*connaissance*) and know-how (*savoir-faire*), with knowledge being the conscious part which can be transmitted and explained and know-how being subconscious memories which have to be acquired through practice (Apel 2001, 27-28; Olausson 2012, 213). Schiffer and Skibo's (1987, 597) teaching framework also emphasises this distinction, as the framework does not solely structure the transmission of knowledge from teacher to pupil but also includes the opportunity to practice the acquired knowledge. The bifacial method is a remarkable example for the division of knowledge. The sequence of actions and aims during production is rather easily explained and can be demonstrated without major difficulties. But the actual execution and mastering of certain production steps can be quite challenging, as a lot of experience and muscle memory, which cannot be influenced and controlled directly given the swiftness of strikes, are needed, which cannot be put into words and transmitted to another person, but have to be learned by practice (Apel 2001; 2008, 103-104).

Regardless of the name – *chaîne opératoire*, recipe of action, behavioural chain, operational or reduction[5] sequence – all backgrounds and methods pursue more or less the same goal: to learn about ancient human societies and people by analysing technological choices. In this thesis, I will refer back to the *chaîne* or *schéma opératoire* when the technological context of production is meant with its entire implications, technical as well as mental. Looking purely at the mechanical work during manufacture, either reduction or production sequence is chosen to highlight the differences in the analytic part.

To answer the question of developing technological systems and changing applications of tools, it is essential to identify the *chaîne opératoire* of a technology at a given time and space. The space being a critical part of the question here, because it is known that the Scandinavian bifacial flint daggers are not solely chronologically successive but also encompass local contemporary varieties (Madsen 1978). Regional workshops and secluded areas for production and training of apprentices have been posited (Apel 2000; 2005). This could prompt

5 The semantic difference of 'reduction sequence' compared to the other terms has to be kept in mind when dealing with technological studies. For reductive technologies, such as flint knapping, the use of the term is possible. But the term would be greatly misleading if applied to additive technologies such as the production of ceramics (Audouze 2002, 287).

technical variants between the regional methods, while the strategic operations have to be the same. This is traceable through close analysis of the production sequences. To do this – and referring back to J. Pelegrin – one must be familiar with the sequence to be able to identify the differences. This is where modern knappers enter the study. What does the production sequence of a biface look like? What are the stable and flexible events in the process? Do they differ between types of bifaces? Are they expressive enough to enable differentiation between knappers or production approaches, since we are still moving within the same technological system and method? Moreover, can we measure and quantify the differences so that non-experts in flint knapping are able to identify them? These are questions which cannot be pursued satisfactorily from the archaeological inventories, given their fragmented and often mixed states. But if a base for them can be established, a means of how to trace the questions, hints and answers can in turn be established for the archaeological record.

Most research on bifaces has focused on the finished objects and often used symmetry, length and execution of the final knapping to distinguish skilled knappers and beginners – and everyone in between (*e.g.* Kelterborn 1984; Dibble 2003; Callahan 2016; Olausson *et al.* 2017; Stenak 2022a). Analyses of knapping products have been done in some cases, mostly to identify the skill of knappers present or to ascertain if bifaces were produced at a given site (*e.g.* Shott 1996; Apel 2001; Titmus and Woods 2003; Walter *et al.* 2013). Most often the identification of typical flakes from production stages, like the thinning of the biface, are used to answer these questions. It is clearly the fastest way to determine if certain stages in production have been mastered and to identify the techniques in use during these stages. But it focuses only on certain parts of the entire knapping process. The devil hides in the detail. The origin of the resemblance lies in the similar execution during the removal of the flakes. The aim of the flake and sequence in question does not leave much leeway in the physical principles that ensure a successful removal. Execution of the blow is thus very similar, regardless which kind of biface is worked on. By definition, the typical flakes originate from the strategic operations in the process. Technical subtleties and individual decisions, however, are to be found in the technical variants, this means, in the steps in between. It is a restriction of the possible statements to exclude all other flakes of the production process. Additionally, skill is not an ability which, once acquired, is effortlessly and consistently available. Raw material constraints, daily form of the knapper and simply bad luck can restrict the performance of skilled knappers to mediocre levels and blur the separation (Finlay 2008).

For the Scandinavian flint daggers, a division of labour in the production sequences has been proposed (Apel 2001, 42, figs. 2.5, 2.6). If skilled craftspeople and trainees work together on the same object, this will lead to mixed and contradicting signals in the archaeological record, when only sequence specific flakes are analysed. The differences of skill and knowledge of the involved people in the ongoing process can only be identified if the whole sequence is analysed. Furthermore, the assumption of a division of the manufacturing process can only be proven, if we actually can demonstrate that the levels of knowledge and know-how change during the reduction process. An interpretation based on flakes alone, which themselves demand a higher level of skill, has feet of clay. It does not contradict a division of labour, but it certainly does not prove it either. This is why we have to take a closer look at the details in the production process. The question still stands how knowledge was transmitted, how the learning environment was structured and which forces were at play to maintain and develop the craft, and more importantly: how can we approach answers to these questions in the archaeological record? Identifying technical markers and combinations of these markers, which refer back to learning traditions or even individuals, will help us to find answers and expand our knowledge about developing technological systems.

3.1.2 Transmission of knowledge

First ideas about cultural transmission in humanities started to be formulated in the 18th and 19th centuries. Influenced by biological and also philosophical studies, the ideas of non-genetic transmission and long-lasting development of cultural systems were proposed (Dunnell 1980; Schönpflug 2009). Various disciplines contributed through time, but the general idea of the theory persisted: Like genetic evolution, cultural traits are transmitted between generations and subject to different forces, which can influence their form and content (Jordan 2014, chap. 1; Cavalli-Sforza 1986; Schönpflug 2009; Shennan 2011). This feature makes it possible to utilise already existing analyses from evolutionary biology to study human culture.[6] But, cultural transmission is not exactly like genetic evolution. It can be a faster process than genetic evolution, it is not as pre-determined as genes, which means people can choose not to adopt unfavourable traits, and mostly there is no extinction of populations connected to changing traits (Cavalli-Sforza 1986, 850; Richerson and Boyd 2006, 42-44; Jordan 2014, 29). There is likewise no selection for the 'fittest' trait. In cultural transmission, even traits which are clearly maladaptive can survive if the form of transmission favours it (Lemonnier 1993a, 1-2; Henrich 2001; Larson 2010, 71; Jordan 2014, 26-29). Transmission of cultural traits is divided into four types, which refer to the existing biological terms:

- Transmission – passing on information between individuals,
- Mutation – changes to the information, for example, due to copying errors,
- Selection – an individual's choice which elements from the existing pool of cultural variants should be proceeded with, and
- Drift – random changes in transmission, which are not triggered by the above-mentioned types.

As an example of the last type, most often the untimely death of a craftsperson is mentioned, who did not have the possibility to pass on knowledge which is then ultimately lost (Richerson and Boyd 2006, 69; Jordan 2014, 21-22; Lycett 2015, 23).

Transmission is the type that has received the most attention in research, as it is directly connected to social learning between individuals (*e.g.* Cavalli-Sforza and Feldman 1981; Boyd and Richerson 1988; Henrich 2001; Eerkens and Lipo 2005; 2007; Schillinger *et al.* 2014; 2015; 2016). Beside vertical transmission from (biological) parents to children, other forms of transmission have gained more attention, such as oblique transmission, which is the transmission from an older generation to a new one without involving biological relatives, and horizontal transmission which is learning from peers from one's own generation. All forms have influence on the information which is transmitted. Likewise, the mode of transmission influences the process. The transmitted information

6 For critique against evolutionary and Darwinian approaches, see *e.g.* Frieman (2021, chap. 2).

is thought to be more stable in a many-to-one teaching environment, while in a one-to-many situation the information can spread much faster, if it is accepted (Cavalli-Sforza 1986, 851-852; Schönpflug 2009; Jordan 2014, 23). Beside this, additional forces – biases – contribute to the development of cultural traits, as they structure the decision process and by this also determine which traits are passed on and which are dropped or modified. These biases are also the source for maladaptive and disadvantageous traits that prevail (Richerson and Boyd 2006, 69; Shennan 2011, 1071; Jordan 2014, 26-29). The different biases can be sorted into two categories – content or context bias – depending on which sphere they affect (Henrich and McElreath 2003; Shennan 2011, 1071; Lycett 2015). While content biases relate to the object in question, like the form and function, context-based biases are involved with the individuals engaged in the transmission.

Social learning is perceived the mechanism for cultural change and can be summarised as a process in which information is transmitted from one individual to another (Shennan 2011; Lycett 2015). As the transmission of knowledge always involves at least two persons, loss of information cannot be prevented, in the sense of translating errors. Verbalising or visualising knowledge is not always straightforward, as often parts are included, which the person possessing the knowledge cannot fully comprehend or explain – Pelegrin's (1990, 118; 2000) distinction in *connaissance* and *savoir faire* depicts this problem quite nicely. Another factor is the receiving person, who has to understand the verbal or visual instruction and still form an own understanding of the received knowledge, not always with the result that the transmitter had in mind. Repetition can minimise the effect, but not prevent the loss completely. This is a cause for variation, which in turn is the driving force behind cultural evolution (Boyd and Richerson 2000, 54; Lycett 2015, 23; Schillinger *et al.* 2016, 24; Tostevin 2019b, 318). It has to be kept in mind that social learning is a general term which envelopes different mechanisms for transmission of information between individuals. Learning can happen by at least four mechanisms: stimulus enhancement, emulation, imitation and teaching. Teaching is the only one, which requires the active involvement of the transmitter but not necessarily through verbal instructions (Lycett 2015, 23; Schillinger *et al.* 2016, 24). Stimulus enhancement describes a process, where no direct teaching or copying of behaviours is happening, but where exposure to certain behaviours enhances the adoption in favour of others (Lycett 2015, 22). Emulation and imitation describe deliberate choices of copying behaviour of others. The former is the copying of the outcome, like striving to achieve the same form of a vessel or flint tool, without exactly replicating the production process. The latter describes cases where the process is replicated down to the form of the finished object (Lycett 2015, 23). Each mechanism has effects on the transmission of knowledge and likewise on the transmission process. Further, it is never or very rarely just one of the mechanisms at play during the transmission of information. Most often, a combination of mechanisms will act simultaneously. Similarly, social learning will not always be the only mechanism. Individual learning, often also termed trial-and-error or asocial learning, can be part of the same process, where people practice acquired knowledge on their own (Lycett 2015).

Through social learning, culture develops in a connected sequence, which can be described, analysed and compared. No idea arises out of nothing, innovations and change are always based on already existing knowledge. Ideas and behaviours introduced from outside sources need to be compatible to the existing knowledge in order to be adopted (Leroi-Gourhan 1980; Audouze 2002, 286;

Eerkens and Lipo 2005). Understanding these evolutionary lines can help us to determine by comparison, whether cultural traits are analogous or converging (Eerkens and Lipo 2007, 243; Lycett 2015, 25), that is, if they are adapted from known sources or if they are chance developments looking alike. As described above, the *chaîne opératoire* offers a powerful basis for the analysis of cultural evolution and transmission. By looking at the individual technical sequences in the chain of cultural evolution, the *chaîne opératoire* helps us to recognise changes and breaks in the existing knowledge and aids the detection of development through time and regions (Leroi-Gourhan 1980; Lemonnier 1992; Audouze 2002).

Flint technology, and bifacial production explicitly, is a craft that is highly complex and needs time and experience to be mastered (Callahan 2000; Apel 2001; Geribàs *et al.* 2010; Morgan *et al.* 2015), not to mention the oral instructions to learn what to do. While 'simple' knapping of flakes and blades can be mastered in a relatively short time and by close observation – but will be much easier and faster learnt with explanations – bifacial production depends to a higher degree on verbal assistance in capturing the goals, problems and solutions during reduction, especially for novel learners with little knowledge about knapping (Bamforth and Finlay 2008, 8; Morgan *et al.* 2015; Tostevin 2019a, 344-345). Technical analysis can help to determine how the learning environment was structured and how rigid the framework of production was maintained. Recurring and repeating patterns of technical choices hint at strict traditions, which quite likely were transmitted verbally and can vary geographically (Bar-Yosef and Van Peer 2009, 116). Such patterns would also be an indicator for strong conservative forces at play during the transmission and a stronger dependence on teaching and imitation (Cavalli-Sforza 1986). If no such patterns arise from the data, then the production process was probably in itself not as important, as the form and emulation could be a stronger mechanism in transmission, where asocial individual learning could also have played a bigger part. Conservative forces can exert pressure in different intensities on an emulative learning situation. The way to manufacture the artefact may not have been that important, but still the form, function and/or aesthetics could have been very strictly regulated. This would allow for change and innovations in the production process but not in the general form of the artefact.

The transmission, as well as the maintenance and development of a technology, is said to be closely connected to the population and the degree of contact and communication between actors (Henrich 2004; Powell *et al.* 2009; Berg-Hansen 2018, 67-68). While small-scale societies need frequent and close contact to maintain technology systems and keep the technological variability low, larger societies generate a higher variability due to smaller (needed) communication networks (contrary: *e.g.* Read 2006; Collard *et al.* 2013b). Following the thought of closely guarded knowledge and secluded production areas, the bifacial technology system in Scandinavia would have either needed close and frequent contacts to other production sites, just to be able to maintain the degree of knowledge, or a higher density of craftspeople who are privy to the knowledge. The first version would imply a high standardisation of the technical choices across the entire area. The second version would be more prone to regional differences in the technical choices, but also to a loss of skill and knowledge if the population of craftspeople became too small or failed to transmit knowledge in time. Other factors, such as risk for the subsistence and environmental conditions, also play a part for the preservation and development of knowledge (Read 2006; Collard *et al.* 2013b; Collard *et al.* 2013a). Due to this, generalised statements about the transmission of knowledge and technology in societies cannot be made, as transmission always depends on the context and social group in question.

Archaeology as a discipline is particularly suitable to study cultural transmission. With its comprehensive and cross-temporal data sets, archaeology can make important contributions to investigations on cultural change and technological developments based on the material culture. Besides the changes in cultural norms and customs through the analysis of form and symbolism of and on artefacts, technical developments of societies can also be studied through the analysis and comparison of the manufacturing processes, to name just a few examples.

As in technological research (see Subchapter 3.1.1), studies concerning cultural transmission theory and the production of bifaces often focus on the variation in form to identify changing technological traditions and learning environments (*e.g.* O'Brien *et al.* 2014; Schillinger *et al.* 2014; 2015; 2016; Goodale *et al.* 2015; Lycett and von Cramon-Taubadel 2015). Especially in the case of bifacial tools, this is a major limitation for the statement of technological development. Not only can the shape and size of the artefact depend greatly on the available raw material, but the skill and daily performance of craftspeople can also lead to variations (see Fig. 5). Even skilled individuals usually do not manage to produce an exact copy of their own work, so a certain variation is always to be expected (cf. Finlay 2008; Stenak 2022a). In addition, re-sharpening can have a massive influence on the form. This, of course, makes it difficult to say at what point a deviation in metric measurements represents a break in the typological series and a change in the technological tradition. Another disadvantage of focusing on the aesthetic and/or metric features of a finished artefact is that it ignores the production process. The finished artefact only reflects the last steps in production, but reveals little about the work that preceded it. Thus, no precise statement can be made about the different steps and the existing knowledge about production.

If we want to find out more about the development of technological knowledge in complex methods, such as bifacial production, we cannot solely focus on the end products. The whole production process needs to be described and analysed in detail in order to identify differences. We also need these descriptions to draw conclusions about the transmission of knowledge. Only if we understand how knowledge has changed, step by step, can we draw conclusions about how it was transmitted and which factors influenced the development. To do this, researchers need to put more emphasis on analysing the seemingly infinite mass of knapping products that are part of the manufacturing process. The intended products are undoubtedly often beautiful to look at, and in themselves provide a great deal of information about the skill and dexterity of the craftspeople, as well as the aesthetic ideas of the given society (Stenak 2022a, 57). But the wealth of information about the craft tradition lies in the rather unnoticed flakes that are necessary in order to achieve the final product in the first place. Here, hidden in a flood of information, is also the knowledge about changing traditions. We just have to find and recognise the right patterns.

That is what this project will attempt to do. Through the detailed analysis of the manufacturing processes and decisions of different craftspeople, patterns and structures within the technical process are to be worked out with the goal to not only distinguish between individual approaches but also to identify possible external influences. This is only viable if the different procedures within the *chaîne opératoire* of the entire manufacturing process can be recognised and compared. A detailed analysis of the knapping products is therefore important and the means of choice.

3.2 Method

3.2.1 Experiments in Archaeology

Although experiments have a long standing in archaeology, the debate about what experiments are, can prove and how they have to be conducted is still controversially discussed (*e.g.* Johnson 1978; Carr and Bradbury 2010; Petersson and Narmo 2011; Eren *et al.* 2016; Paarderkooper 2019). Definitions of experiments vary between authors and approaches, but the common thread is the notion of a pre-planned and observed action to test a hypothesis or a question (*e.g.* Ascher 1961; Malina 1983; Skibo 1992; Reynolds 1999; Kelterborn 2001; Mathieu 2002; Nami 2010; Bell 2014). A seemingly unbridgeable gap of the classification, whether an experiment is treated as valuable for research, lies in the execution. On one end of the spectrum, there is the strictly controlled scientific experiment (*e.g.* Malina 1983; Kelterborn 1990; Lüning 1991; Reynolds 1999; Nami 2010). On the other end of the spectrum, the uncontrolled experiment is found, often also termed field, experiential or contextual experiment (*e.g.* Skibo 1992, chap. 2; Rasmussen 2001; 2007; Hansen 2008; Petersson and Narmo 2011).

The controlled experiment has its roots in the positivist research tradition, which assumes that general laws of phenomena can be uncovered and applied to similar situations. This conviction was strongly represented in archaeological research in the 1960s and 1970s. Researchers of that time believed decidedly that archaeology needed a reorientation of its goals following the example of natural sciences. Theory and methods adopted and developed were not a rigid framework, but followed a school of thought, which has been summarised as processual or new archaeology. The general thought maintained that, by testing hypotheses, deductions about behaviours in the past could be drawn and formulated into generalised laws structuring past processes, which then could be used to study cultural evolution independent of the chronological setting (*e.g.* Shanks 1992; Lammers-Keijseres 2005; Sabloff 2005; Apel and Knutsson 2006; Johnson 2008; Johnson 2020; Nami 2010; Schenck 2015; Webmoor 2015). Best practice standards were derived from natural sciences, which meant that experiments not only had to be controlled but must also deliver measurable and repeatable results (Kelterborn 1990; 2005; Reynolds 1999). Ideally, in an experiment all variables are under control, while just one, which is thought to be the cause for variation, is changed during repeated tests (Amick *et al.* 1989; Skibo 1992; Rasmussen 2001; Mathieu 2002; Nami 2010; Beck 2011).

In case of flint technology studies, the underlying assumption is that flint always fractures following the same physical laws, regardless of who knaps the flint or when in time it is done. The laws of fracture mechanics can be demonstrated experimentally and applied to the interpretation of flakes from every chronological setting and make it possible to infer how the material was treated during production. This shows a central point in positivist research: the concept of objective truth, which can be found by creating knowledge. But scientifically, there is no such thing as a true 'truth', as hypotheses cannot be verified. They stand only as possibly true as long as they have not been falsified and replaced by new hypotheses (Popper 1935; Malina 1983; Outram 2008; Schenck 2015). Another problem, similar to the non-existence of an objective truth, is the equifinality. There is not only one possible way to reach a certain outcome. The verification of a feasible way is no evidence that it has unequivocally been this way (Ascher 1961; Bonnichsen 1974; Malina 1983; Carrell 1992; Shott 1994; Mathieu 2002; Hurcombe 2005; Clarkson and Shipton 2015). Regardless of the degree of control exerted on an experiment, the result is always only a possible explanation, which offers analogies for the interpretation of archaeological settings. Experiments provide the opportunity to reject unlikely and impractical hypotheses and can open up new possible ways for interpretation, but they can never stand alone. Every result derived from experiments has to be applied to the archaeological record and assessed. The reason to undertake experiments is to gain new knowledge about the past and not to verify the hypothesis of the researcher (Kelterborn 1990; Dibble 1998; Franklin 2005; Rasmussen 2007; Carr and Bradbury 2010; Beck 2011; Petersson and Narmo 2011; Busuttil 2013; Schenck 2015). Experiments are best thought of as a hermeneutic circle, where the archaeological record is the starting point. Thoughts, ideas and questions arise from the record, which can be tested in experiments. The results have to be compared with the original data and new knowledge is created from this, either in favour of the hypothesis tested or against the hypothesis. In both cases, new knowledge has been created and is a starting point for further research (Linderholm and Gustafsson 1991; Baert 2005; Beck 2011).

One of the main points of critique regarding controlled experiments is the total neglect of human involvement in processes (*e.g.* Johansson 1983; Reynolds 1999; Petersson and Narmo 2011). While they can offer deep insight into properties and laws of phenomena, they often fail to explain 'real life' actions. Outside of the laboratory environment, a lot of variables act on and influence processes, not all of them are controllable or even reconstructable from the archaeological record. In addition, humans do not always act strictly logically. Processes can be influenced by rather illogical actions, seen from the perspective of a 21st century researcher (Andraschko and Schmidt 1991; Inizan *et al.* 1999; Mathieu 2002; Outram 2008; Nami 2010; Schenck 2011; 2015; Bell 2014). Another point of interest is that the experiments are still conducted by humans, and thus their influence cannot be prevented, completely independent of whether it is recognised or not (Baert 2005; Beck 2011; Schenck 2011; 2015). Furthermore, the strictly controlled experiments and the laboratory environment can add or remove variables, which were not present or important in the 'real life' situation and thus lead to misinterpretations (Eren *et al.* 2016). This is where the supporters of uncontrolled experiments see their strength. In addition to the fact that past people did not live in laboratory environments and exerted strict control on variables during their life, the human factor is and has an undeniable influence on processes. Moreover, not all variables, which influenced a phenomenon, can be deducted from the archaeological record. Aside from the already mentioned 'illogical' actions or choices made by humans, archaeological features seldom tell anything about weather conditions, the time of the day or year and other influencing factors. Even if such factors were deducible, they are normally not reconstructable or controllable in a laboratory. Controlled experiments are an essential part of understanding how variables react to one another, but to reconstruct contexts between phenomena and humans, a more abstract level has to be analysed (Mathieu 2002; Petersson and Narmo 2011; Schenck 2015).

The aim of uncontrolled experiments is not the identification and isolation of variables, but the generation of possible answers, inspirations and new perspectives for still incomprehensible phenomena. The focus lies on the formation of analogies to interpret and deepen knowledge about the past. To be applicable to the archaeological record, experiments have to be based on and compared and assessed with the archaeological evidence. Often, it is not so much a hypothesis, but a question that starts an experiment. The process of experimenting to find a solution to this question can help to formulate hypotheses, which in turn can be tested again (Amick *et al.* 1989; Carrell 1992; Skibo 1992; Inizan *et al.* 1999; Mathieu and Meyer 2002; Franklin 2005; Rasmussen 2007; Beck 2011; Schenck 2011; Clarkson and Shipton 2015). While controlled experiments are often very theoretic and build mathematical models, uncontrolled experiments offer the possibility to experience phenomena in action and gain a better understanding of the processes. By this, they can also build the bridge between the theoretical knowledge and the archaeological record (Ascher 1961; Saraydar and Shimada 1973; Eren *et al.* 2016; Currie 2022). Again, it is a simulation of how the researcher thinks a phenomenon happened and can help to determine the validity of this idea. However, it is not possible to reconstruct all the knowledge and steps included in the formation process and thus it is also not possible to truly replicate a phenomenon (Coles 1983; Carrell 1992; Outram 2008; Clarkson and Shipton 2015; Schenck 2015).

Like controlled experiments, uncontrolled experiments are based on the notion that cultural behaviour is structured and follows underlying rules. Furthermore, objects which are alike are perceived as having similar functions, which allows them to be grouped together (Ascher 1961). They seldomly offer a simple yes or no answer, unlike controlled experiments. More often, the results are unexpected and open up more questions. The biggest point of critique is that they cannot be repeated in a scientific manner, meaning that the repetition of the experiment will not lead to the same results (Skibo 1992; Rasmussen 2001; 2007; Mathieu 2002; Beck 2011). This should not be treated as a fault, as the past phenomena had to deal with the same 'problem'. An action would never have happened exactly the same way twice. Consequently, the archaeological record will not be identical due to the various influencing factors which could not be controlled (Mathieu 2002; Bell 2014). Embracing the unexpected in the experimental approaches can thus offer explanations for variations in the record and prevent (typological) classifications where none were present.

As uncontrolled experiments are not restricted to the collection of measurable data, but can include a variety of documented information, including descriptions and observations of the researcher's emotions, they are often treated as non-scientific and experiential in nature, which, from a positivist perspective, renders the results irrelevant (Kelterborn 1990; 2005; Reynolds 1999; Lammers-Keijseres 2005; Beck 2011; Petersson and Narmo 2011). But, as mentioned above: how much relevance do measurable and repeatable results have, if they cannot be applied and compared to the 'real life' specimen? Even if it may seem so, there is also no strict divide between controlled and uncontrolled experiments. The degree of control needed and applied to an experiment is better regarded as a spectrum, and can be chosen to fit the experimental setup as well as the intended outcome (Andraschko and Schmidt 1991; Mathieu 2002; Paardekooper 2011; Busuttil 2013). In some cases, a gradual progression of control has been proposed as ideal for archaeological experimentation, although both directions have been suggested: from starting with controlled experiments and applying the results to uncontrolled experiments, as well as starting with uncontrolled experiments to narrow down possibilities and ending with controlled experiments (*e.g.* Skibo 1992; Lammers-Keijseres 2005). In general, the starting point should be defined based on the knowledge already in existence on the topic and the question asked to the material, likewise the intended result has to be considered when planning the approach (*e.g.* Richter 1991).

Criticism of experimental, especially contextual approaches, has been manifold. Some limitations, which cannot be completely dismissed, but are sometimes ignored include: differences in mental structures between modern and prehistoric humans, different environmental conditions, ethic and moral barriers past and present, missing knowledge and experience of the researcher, circular reasoning, ignorance or missing publication of experiments, and missing logistic and financial means (Andraschko and Schmidt 1991; Forrest 2008; Hansen 2008; Paardekooper 2008; Reich and Linder 2014). Most of them can be prevented by following some rules of best practice, which have been assembled by different researchers with varying details and restrictions (Ascher 1961; Kelterborn 1990; Richter 1991; Inizan *et al.* 1999; Outram *et al.* 2005; Outram 2008; Bradley *et al.* 2009; Carr and Bradbury 2010; Busuttil 2013; Clarkson and Shipton 2015; Schenck 2015). Points which should be applied to all kind of experiments are:

- a clear and relevant question for the research
- detailed descriptions of the used materials and methods
- use of authentic and relevant materials and tools
- the researcher should possess the necessary skills to conduct the experiment or has to rely on personnel with such skills
- professional planning and execution
- testing of several possible scenarios
- comparison to the archaeological record
- publication of results

While some points are self-explanatory and apply to every form of scientific work, other points need some explanation. The first point seems very straight forward, but also includes familiarity with experimental research so far. A question that is already answered is not relevant and does not have to be pursued again if there is no doubt about the results. Prior research should always be considered and included into the formation of the experiments, which helps to clear out possible errors in the setup and prevent failures of the experiment (Andraschko and Schmidt 1991).

The use of authentic and relevant materials and tools can be complicated. In some cases, it is not possible to get hold of authentic raw materials. Thus, the used material for experimentation should have properties as close to the original as possible. The used tools should correspond to tools which were accessible to the past craftspeople. It is valid to use modern equivalents or even strictly modern tools, the latter only when it does not affect the outcome of an experiment (Carrell 1992). If it is not known what kind of tools have been used or what properties they had, experimentation can help to determine this.

Point six, the testing of several possible scenarios, should be elaborated on a bit more. The problem of equifinality was mentioned above. A way to cut down on the possible equally likely scenarios for a certain outcome is the re-testing of hypotheses with different means and courses of action. This is not only a way to show that the researcher is well aware of the problem and not only concerned with underlining their own opinion but it further helps to reinforce the results and statements obtained. While showing that there are several other ways to solve the problem, it can also show the slight dissimilarities between the ways and strengthen the results (Ascher 1961; Hurcombe 2008; Clarkson and Shipton 2015).

Comparisons and re-assessment according to the archaeological record should be state of the art, but are sadly often forgotten. This undermines the significance of experiments, as they cannot stand for themselves. The reason to do experiments should not be conducting experiments, but to gain knowledge about past phenomena. By not comparing results with the archaeological record, the experiment has only shown that it works, but not whether it is a possible solution to the question (Amick *et al.* 1989; Franklin 2005; Beck 2011; Clarkson and Shipton 2015). Likewise, the publication of the experiments and their results should be mandatory, but is often dismissed, especially when the results were negative. This is a serious problem, as unpublished failed attempts cannot prevent others from falling into the same trap. In the worst case, the same unsuccessful experiment is repeated over and over again, which is an unnecessary waste of money, time and resources (Kelterborn 1990; Andraschko and Schmidt 1991; Richter 1991; Carrell 1992; Outram *et al.* 2005; Forrest 2008; Beck 2011; Schenck 2015). Experiments are a method and a research tool above all else and have to be treated and applied accordingly (*e.g.* Ascher 1961; Malina 1983; Amick *et al.* 1989; Reynolds 1999; Olausson 2010; Petersson and Narmo 2011; Hansen 2014; Clarkson and Shipton 2015; Schenck 2015).

As has been mentioned, there are varying classifications and graduations of experiments made by various authors. For this study, the classification of J. Mathieu (2002) is discussed and used: Experiments can be divided and scaled by their scope and aims. Most often, the divide concerns the scope of replication. The simplest form is the replication of objects and increases gradually through replication of behaviour, processes and entire systems. The last point is very hard to achieve and most often not approached through experiments directly but through ethnographic and ethnoarchaeological studies (Mathieu 2002; Paardekooper 2008). The boundaries of the categories are mostly fluid and an experiment can seldom be assigned to only one category. The experiment can even be meant to cover more than one of the categories summarised below.

A replication of objects can happen on different scales. Visual, functional and full replicas are possible and the needed degree depends on the research aim. For visual replicas, only the form is relevant. Replicas should mimic the original pieces, but can be produced with deviating methods and techniques than the original, although the use of authentic or very similar material is necessary. Functional replicas are in a way a subcategory of the visual replicas. The functional aspects of the tool have to be replicated, which often implies that the form (the visual aspect) is replicated, too. A replication of the production process is still not necessary for the most part. All aspects, the visual, the functional and the technical, have to be met, if a full replica is intended. It has to be kept in mind that a replica in the truest sense can never be achieved, due to the mentioned restrictions in the identification of the production process above.

The replication of behaviour includes simulation of activities and techniques. Often functional or full replicas are included in the experiments, which can be categorised as functional, comparative or phenomenological. Functional experiments are applied to test hypotheses about uses and functions of tools, which is why at least the functional aspects of a replicated object involved in the process have to be met. Comparative experiments are carried out to compare two or more actions or behaviours with the aim of achieving a better understanding why certain choices were made. Materials as well as objects and techniques are the aspects compared in this kind of experiment, which means that the replicas involved in the process have to cover the aspects in question. Phenomenological experiments are concerned with the replication of sensory perception and emotions and need full replications as well.

Replications of processes cover experiments, which have a more complex or long-term approach. Mathieu (2002) divides these experiments in formation and technological processes as well as simulations. Formation processes are concerned with the question about how and what factors influence the remains and the state of the archaeological recovery (*e.g.* Yorston *et al.* 1990). With technological processes, the replication of building and production processes is meant. In contrast to all other experiments, actual objects are not directly involved in simulation studies. Summarised under this term are computer-based modelling approaches.

The experiments in this study are good examples of the difficult division into the defined categories. Superficially, the replication of the bifacial tools seems to be easily assigned to the full replication of objects. But the replication of the tools was not the main goal of the experiments. Questions referring to the replication were concerned with differences in the production process, which would define them as replications of technological processes, while personal preferences and knowledge transmission in craft production brings in an aspect of the replication of systems. As it was not possible to study 'authentic' prehistoric flint knappers in action, modern craftsmen were observed to form analogies, which can guide the interpretation of archaeological settings.

The personal approach to raw material during production is also the strongest support for not conducting controlled experiments. The aim of this study is not to test which attributes influence each other and in which way, but to gain insight into the decision process and technical choices during production and how they can be manifested on flakes. This cannot be revealed if a craftsperson does not have a choice during the work process, but has to follow strict instructions. Likewise, constant measurements of, for example, striking angles, positions of arms, tools or the artefact in production or force and velocity of the strike can be very distracting and disrupt the work flow. Too much involvement of the researcher into the production to get measurements or ascertain control on different variables will actually nullify the personal approach by the craftsperson. This is why the only partially controlled aspect in this study is the raw material[7]. Every knapper was presented with raw material from the same source, being an authentic choice for the artefact types and chronological period. Everything else was up to the choice of the knappers: knapping tools and implementation (within an authentic range, using steal hammers would not have been an appropriate choice, whereas using copper pressure flakers, on the other hand, is appropriate), gestures, positions, even the choice which nodule to use, to progress or abandon. The least possible disturbance on the part of the researcher was maintained

7 Partially because the quality of raw material is not uniform. Each nodule had a different quality, some rather poor, though it was attempted to obtain nodules with a rather good quality. Another point, which speaks in favour of uncontrolled experiments when accessing technical choices, is that controlled experiments mostly resort to custom-made 'nodules' of glass or ceramics (*e.g.* Cotterell *et al.* 1985; Dibble 1997; Dibble and Rezek 2009; Khreisheh *et al.* 2013; Dogandžić *et al.* 2020; Van Peer 2021), which mimic the ideal raw material and ensure that no flaws hinder the process. Natural raw material will seldom have this quality and a lot of technical and personal choices are connected to the flaws in the material and the ability to cope with these problems.

during the experiments, restricted to writing, making photographs or videos and occasionally asking questions to clarify what was going on.

Most points of best practice in experimental setups are met by the study, only two points could not be included. First, the test for several possible scenarios was not applied. As the study was not concerned with the reconstruction of the 'one and only' way of producing bifacial tools in the Late Neolithic and the Early Bronze Age, relying on the existing and assessed path was deemed sufficient. The aim of the study is to detect individual choices and preferences in technological systems, which is covered, as all knappers are influenced in their work by the present 'tradition'. There is a big 'but' in this statement. The results cannot be applied directly to archaeological settings, as the background and social traditions are totally different from prehistoric conditions. This starts with modern knappers, who are often self-taught quite late in their life. While prehistoric children grew up with flint knapping and learned the basics very young, modern knappers usually start as early adults or later with no prior knowledge. Another big difference is that modern knappers are not restricted by technological traditions in the same way as prehistoric people. While modern knappers follow modern traditions and perceptions of how knapping was conducted, or chose to not mimic prehistoric knapping but use modern, often easier options, there are no (social) restrictions or boundaries of learning or adapting techniques. Thus, modern knappers are not restricted in their repertoire of technologies and methods and are often able to replicate tools, techniques and methods from a wide chronological range (Olausson 1998; 2008; Eren *et al.* 2016). This means that the possibility of choice is much broader for a modern knapper than was the case for a prehistoric knapper.

Secondly, the last and crucial point of best practice is concerned: comparisons with the archaeological record. Comparing the results of the experiments with the conditions of the archaeological material makes it possible to evaluate how valid the results are and if the analogy can be applied. If the correspondence is poor, the experiment has to be restructured, based on the not fitting parts. Unfortunately, no archaeological material could be included in this study, so the results lack a final validation of possibility. Due to this, this study has to be treated more as an initial test and pilot study if an identification of individual flint knappers from knapping products is possible at all. The application of the results to the archaeological record and a possible restructuring and repetition of experiments would be the next step in research, which regrettably cannot be done in this project.

3.2.2 The recording system

Before a discussion of the recording system used in the study starts, a short summary of knapping techniques and some definitions of terms shall be given. A detailed description of attributes and how they connect to knapping techniques is given in the sections about the attributes, but for a better understanding, the general distinction of included knapping techniques is concisely clarified. Furthermore, a short introduction on the used terminology of flakes and attributes is given. Some terms are additionally displayed in figures 2 and 3. The study follows the French terminology.

Besides technology and technique, another concept is important and constitutes a kind of intermediate in flint knapping technology, the method (Fig. 1). A method describes a sequence of interrelated actions, which lead to the produc-

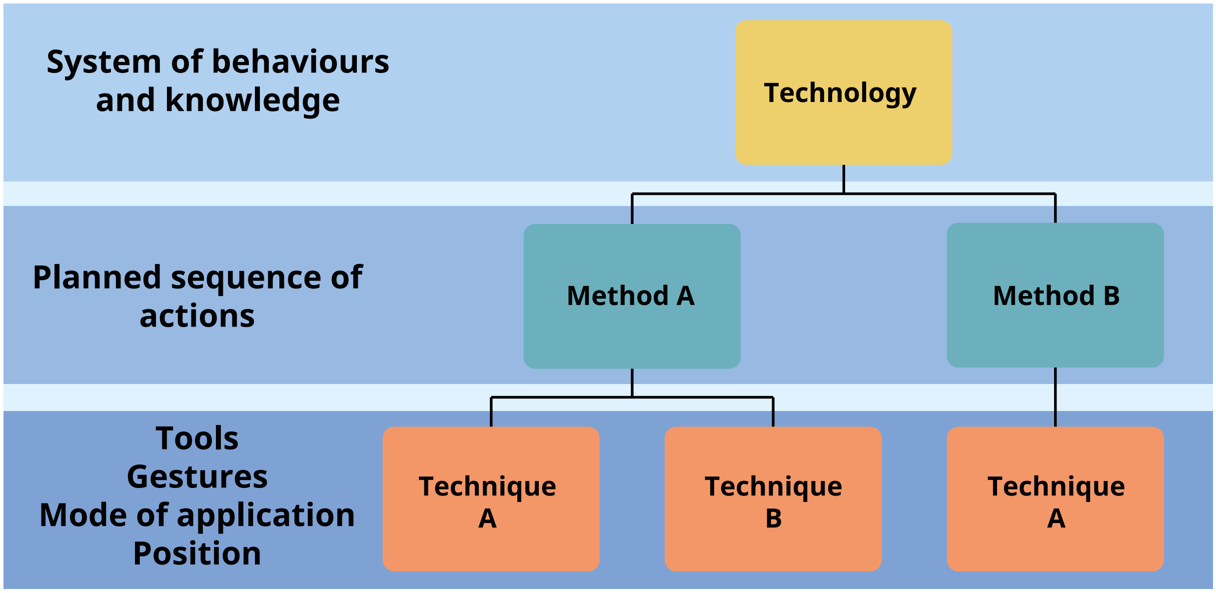


Figure 1. Exemplary and simplified hierarchy and a short explanation of terminology.

tion of predetermined products (Inizan *et al.* 1999, 30). Knapping technologies can encompass several methods, which can include various techniques. The term has been used very restrictive. Accepted methods are summarised in Inizan *et al.* (1999), among them the bifacial shaping method. Quite often, the distinctions in terminology are not drawn or the definition is chosen otherwise, so that bifacial technology is referred to (*e.g.* Bamforth 2003; Hofman 2003; Forsberg 2010). As the French terminology is followed, the bifacial (shaping) method is used and treated as a part of the Scandinavian flint knapping technology in the Late Neolithic and the Early Bronze Age.

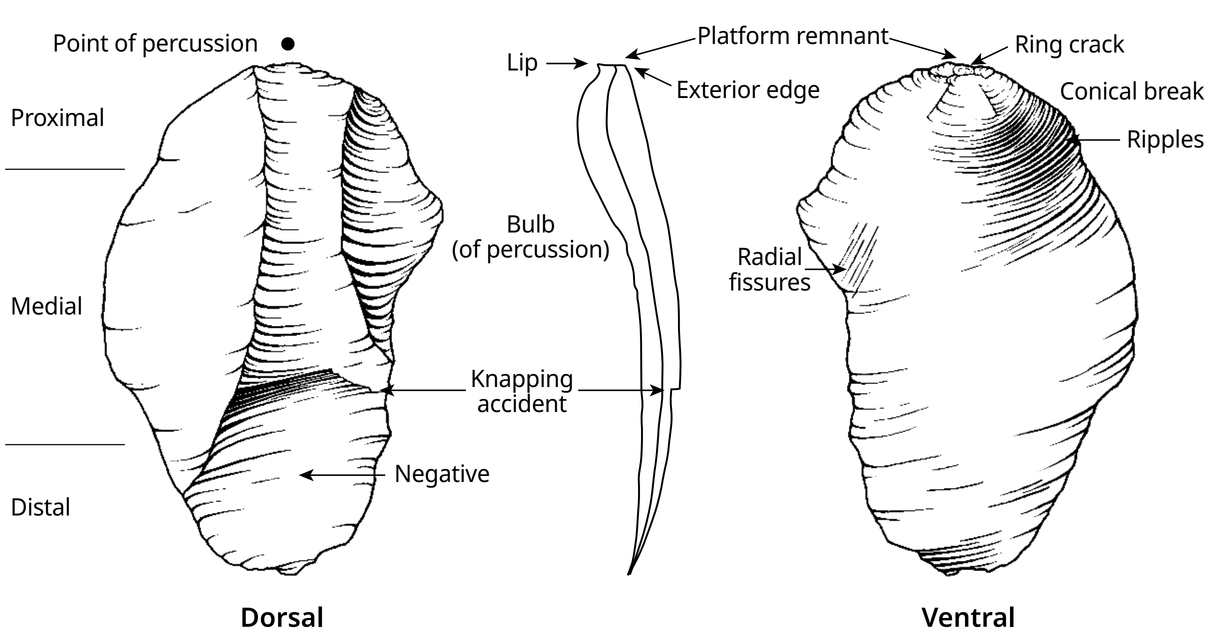
Shaping is defined as a sequence of operations to manufacture a single artefact to a desired form (Inizan *et al.* 1999, 43), while flaking (in French research termed *debitage*) refers to the action of fracturing with the intention of producing blanks for further use (Inizan *et al.* 1999, 59). Knapping is a general term, covering any action with the intention to fracture raw material, this includes shaping but also retouching and flaking. This definition also has implications for the nomenclature of the products. The general term would be knapping product, which is used for every flake detached in a knapping process. If the flake is identified to be a blank, the name changes to *debitage* or, in English, a flaking product. Only flakes, which have been clearly identified as being produced without pre-planned purpose beyond the need to be removed to achieve the goal, are true knapping waste products. It is a rather vague category, as every flake has the potential to be used as a blank (Inizan *et al.* 1999, 32). This becomes quite a problem in bifacial production in Scandinavia. On first glance, it seems obvious that the flakes produced during the manufacturing process are waste flakes in the truest sense of the word. No other reason than the shaping of the artefact is the aim of removing the flakes. But flakes from bifacial reduction are highly suitable for further processing and have often been used as blanks for other tools and projectile points, which would change the term to *debitage* or flaking products. As not always and not all the suitable flakes were in fact selected and processed, knapping waste products would probably still be the more appropriate term. It is certainly the case in this study, as no intention for further tool production has been present in the production process. It shall be noted that if the knappers would have been given the opportunity, they would have selected suitable flakes. This would have better reflected the spectrum of flakes, which could be expected in archaeological contexts, but would have created gaps in the analysis of the production process. In general, knapping products is used throughout the study as it is the shorter term and includes the potential of the flakes to be used as blanks.

The first distinction in knapping techniques is between direct and indirect application. Meaning, if the knapping tool was applied directly to the nodule in work or if an intermediate piece was used between nodule and percussor. Direct knapping techniques are the oldest known and presumably direct flaking with a hard hammerstone is the earliest of them all (*e.g.* Inizan *et al.* 1999, 30; Semaw 2000). Classically, direct percussion is separated in hard percussion with a stone and soft percussion with organic implements such as antler or wood (*e.g.* Tixier 1982; Inizan *et al.* 1999; Pelegrin 2000; Floss and Weber 2013). A third technique has been proposed, which can be identified on basis of the attributes; direct percussion with a soft stone, for example, sandstone (Inizan *et al.* 1999, 30; Pelegrin 2000; Floss and Weber 2013).

The distinction between hard and soft percussion does not only concern the materials but also fracture mechanics, which are expressed in the diverging attributes (cf. Fig. 3 and Fig. 4). Direct hard percussion results in the characteristic conchoidal fracture and is usually expressed by a rather pronounced bulb and the absence of lip formation (Cotterell *et al.* 1985; Cotterell and Kamminga 1987; Hayden and Hutchings 1989; Floss 2013; Damlien 2015; Van Peer 2021). Other classic attributes are ring cracks, which can be accompanied by a Hertzian cone and éraillure scars. Often, big platform remnants as well as pronounced ripples and fissures are mentioned (Madsen 1986; Hayden and Hutchings 1989, 241; Pelegrin 2000; Floss 2013; Floss and Weber 2013; Damlien 2015; Van Peer 2021, 20-21).

Knapping with soft, organic percussors results in a bending fracture (Fig. 4). In contrast to hammerstones, organic mallets are applied tangential to the edge, which results in a more tearing strike, initiating a bending of the raw material (Cotterell and Kamminga 1987; Floss 2013). The fracture starts a little distance behind the point of contact, which results in the formation of lips, while the bulb is absent or

Figure 2. Example flake to display some of the attributes recorded for the analysis (Illustration: K. Winter, UFG Kiel).



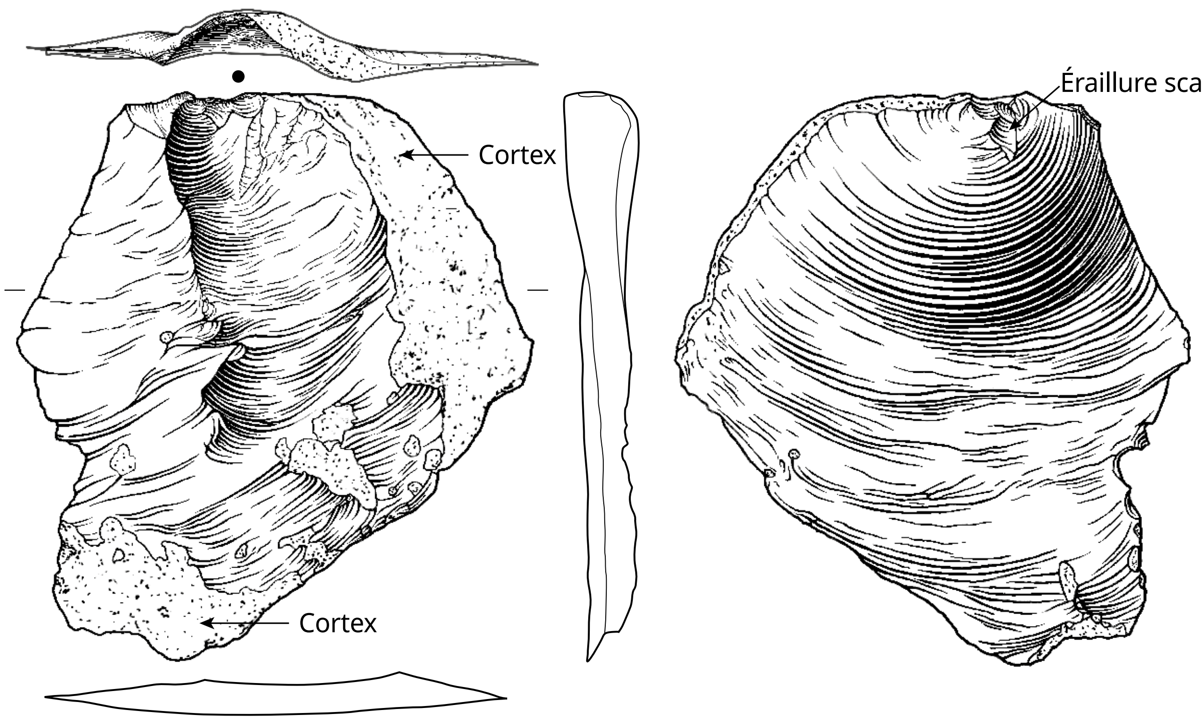


Figure 3. Exemplary generic flake removed in hard direct percussion (Illustration: K. Winter, UFG Kiel).

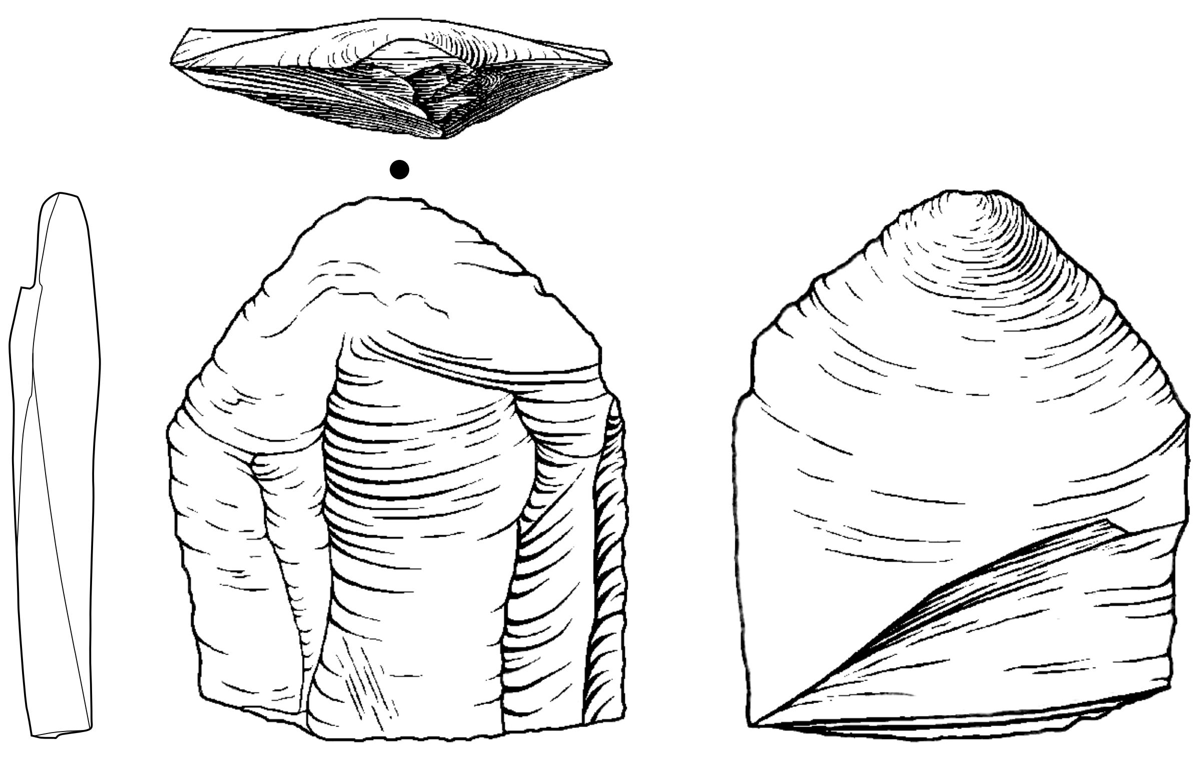


Figure 4. Exemplary generic flake removed in soft direct percussion (Illustration: K. Winter, UFG Kiel).

rather weak. Due to the soft material, the area of contact between mallet and nodule is quite large and no ring cracks or Hertzian cones can form (Cotterell and Kamminga 1987; Floss 2013; Floss and Weber 2013; Magnani *et al.* 2014; Damlien 2015). Platform remnants tend to be smaller than remnants from conchoidal fractures, even though the fracture initiates behind the point of impact. This is related to the fact that the blow is struck behind the edge of the platform when knapping with stone hammers, while with organic mallets the strike is dealt transversely to the edge (Hayden and Hutchings 1989; Pelegrin 2000; Damlien 2015).

The last direct technique covers the application of soft stones. Two varieties have been identified: application like a hard stone and application more in line with organic mallets. While the first type leaves attributes basically not distinguishable from hard percussion, the latter type has similarities with organic percussion. It is associated with lip formation, diffuse bulbs and often shattered platform remnants (Pelegrin 2000; Magnani *et al.* 2014; Damlien 2015). Ring cracks can be present and likewise small Hertzian cones also in combination with lips. Ripples on the first few centimetres of the ventral side as well as *esquillement du bulbe* have also been identified (Pelegrin 2000; Floss and Weber 2013).

A technique that is applied in a direct manner, but counted as a separate technique, is pressure. During pressure flaking, a device with a pointed tip is set directly on the edge and pressure is applied until the flake detaches. This can happen by both conchoidal or bending fracture. Like direct percussion, pressure flaking can be split into a hard and a soft variety. The former is done by using copper tipped pressure flakers, while the latter uses tips of antler, wood or bone (Cotterell and Kamminga 1987; Inizan *et al.* 1999). In addition, it does not necessary imply the involvement of a special made device, such as the Ishi-stick, an antler tine with a pointed tip can suffice. In general, platform remnants tend to be rather small and plain, barely exceeding the area of contact with the tip. The harder the tip, the smaller the remnant can be and the more likely that a conchoidal fracture results (Cotterell and Kamminga 1987; Pelegrin 1994; Damlien 2015). The bulb is often pronounced but very short and rather high on the ventral face (Damlien 2015). When copper tipped pressure flakers are used, the formation of ring cracks is possible (Pelegrin 1994; Méry *et al.* 2007).

Indirect technique describes a knapping technique, which includes the use of an intermediate piece, positioned on the edge where the flake is wished to be removed, on which the blow is then dealt. Like pressure technique, the control is higher as in free percussion, as the exact spot for removal can be chosen, but the force delivered is higher than achieved by pressure. Intermediate pieces are denoted as punches and are usually made from antler or copper, but other materials are possible (Inizan *et al.* 1999). Flakes from indirect percussion often have pronounced lips and, in combination, quite diffuse and long stretched bulbs. While ripples are mostly absent, éraillure scars can be present (Damlien 2015). Depending on the material of the punch, ring cracks can be formed. The size of the platform is, like with pressure flaking, also dependent on the size of the punch tip surface. J. Pelegrin (2003, 68) notes that concave and big platform remnants can only be formed by indirect technique, as pressure would not allow for the formation of big remnants and direct percussion would fail on concave surfaces.

Research on indirect technique is rather scarce, especially from the 'scientific' American side, which could be due to the difficulty to construct devices, mimicking the technique and keeping the variables under control. Another explanation could be the relative novelty of the technique, developing during the Postglacial in Europe (Sørensen 2006a; 2012; Inizan 2012; David and Sørensen 2016), which reduces the interest and applicability for studies and results.

Each technological study starts with the decision about which information base will be used for the analysis. Early on it was decided to use an attribute-based data set for this study. In attribute studies, a given number of attributes, here knapping characteristics and metric values of the flakes, are recorded for later analysis. Attribute studies have the advantage of generating information in high resolution while being extremely flexible. The recording system can be tailored to fit the given research question and still offers the possibility to explore different questions later on (Steffen *et al.* 1998). A disadvantage is the time-consuming and labour-intensive recording (Ahler 1989, 86-87; Aldenderfer 1998, 99). Even in a simple present-absent recording, each piece has to be examined and evaluated for the given number of attributes. This requires familiarity with the knapping process and resulting markers and most often a true objective evaluation and classification, whereby different people are asked to make statements that agree with one another, is hard to achieve.

In the following, a brief summary of the chosen attributes and the reason for the choices will be given. It is emphasised that a single attribute is not meaningful on its own. Only in combination with other attributes and in frequent occurrence can we draw a tendency for applied techniques.

For this study, a system with 32 attributes was assembled (Table 3), which is meant to give insight into the choice of techniques in use during the production of the bifaces.[8] The system was designed as a living database in the beginning, meaning that attributes, or shape and markedness of the same, could be added or deleted as the recording went ahead. Part of the analysis was to infer which attribute combinations are the most significant. For this reason, the number of recorded attributes was held relatively high. One component of the analytical part is an evaluation of the benefits as well as an assessment of the included attributes. The system was additionally meant to be used in recording archaeological inventories, which would have included different types of artefacts apart from waste flakes. Due to the Covid-19 pandemic, the recording of archaeological inventories had to be removed from the project. As a result, some categories of the recording have become obsolete but were not deleted from the sheet, for example, the basic form or the type of artefact. The coding for types of artefacts was simply not used and will not be discussed in detail. Beside technical statements, some of the attributes were chosen with the intention to attempt a rough division of production stages of the flakes. This would help to identify changing modes of production during the preparation of artefacts and between the knappers' mental organisation of production steps.

For the sake of a comprehensive description of the technological procedure, all flakes with proximal preservation with a minimum length of 0.5 cm were recorded, regardless of their completeness. If known, flakes from the final pressure retouch were included, even if they measured less than 0.5 cm in length. These

8 The system was based on the *Flintartefaktaufnahme* (Version 1.2), which has been developed by the sub-projects B1 "Pioneers of the North: Transitions and Transformations in Northern Europe Evidenced by High-Resolution Data Sets" and B2 "Transitions of Specialized Foragers" of the "CRC 1266 – Scales of Transformation – Human-Environmental Interaction in Prehistoric and Archaic Societies", Kiel University. For the analysis of bifacial technology and to answer the questions of this thesis, some categories of the original system were dropped or extended and new categories were added. The *Flintartefaktaufnahme* (Version 1.2) was chosen, as I had prior experience with it (see Hinrichs 2020) and it offered an easy adaption.

Abbr.	Definition	Code	Characteristics
GF	Basic form	1	Flake
		2	Blade
		3	Core
		4	Shatter
		5	Nodule
		6	Indefinite
TH	Thermal alteration	0	No
		1	Yes
		2	Indefinite
ACN	Proportion of the natural surface	0	None
		1	1/4
		2	1/2
		3	3/4
		4	Complete
		5	Indefinite
KF	Proportion of the interior cleft of ACN	0	None
		1	1/4
		2	1/2
		3	3/4
		4	Complete
		5	Indefinite
GE	Preservation of the basic form	0	Incomplete
		1	Complete
		2	Proximal
		3	Medial
		4	Distal
DIE	Distal characteristics	0	Not preserved
		1	Pointed
		2	Broad
		3	Hinge fracture
		4	Step fracture
		5	*Outrepassé*
		6	Indefinite
GW	Lengthwise curvature	0	Not preserved
		1	Straight
		2	Curved
ABNA	Number of negatives		Num. Value

Table 3 (continued over the following pages). Legend of the recording system.

Abbr.	Definition	Code	Characteristics
ABNR	Direction of negatives	0	None
		1	Same
		2	Opposite
		3	Bidirectional
		4	Oblique
		5	Same and oblique
		6	Against and oblique
		7	Bidirectional and oblique
		8	More not same or against
		9	Indefinite
SFPD	Preparation of edge	0	None
		1	Abrasion
		2	Fine
		3	Fine + Abrasion
		4	Strong
		5	Strong + Abrasion
		6	Not preserved
SFRP	Preparation of striking surface	0	Not preserved
		1	None
		2	Faceted
SFRF	Shape of platform remnant	0	Not preserved
		1	Ridge
		2	Oval
		3	Circular
		4	Shattered
		5	Other
		6	Roof-shaped
		7	Collapsed
SFRB	Width of the platform		Num. Value
SFRD	Thickness of the platform		Num. Value
ABW	Exterior edge angle		Num. Value
SA	Ring crack	0	None
		1	Present
		2	Present with conical break
		3	Not preserved
SAD	Ø Ring crack		Num. Value
SPP	Distance from the edge of the point of percussion		Num. Value

Abbr.	Definition	Code	Characteristics
BU	Bulb	0	None
		1	Normal
		2	Strong
		3	Double
		4	Not preserved
BUA	Bulb scars	0	None
		1	Éraillure scar
		2	Esquillement du bulbe
		3	Split Fracture
		4	Not preserved
		5	Éraillure scar + Split fracture
		6	Esquillement du bulbe + Split fracture
BUW	Ripples on the bulb	0	None
		1	Present
		2	Not preserved
		3	Indistinguishable
RAS	Characteristics of radial fissures	0	None
		1	Weak
		2	Strong
		3	Not preserved
		4	Weak + Strong
SL	Lip formation	0	None
		1	Weak
		2	Normal
		3	Lateral
		4	Not preserved
		5	Strong
SUD	Knapping accidents on the surface	0	None
		1	Hinge fracture
		2	Multiple hinge fractures
		3	Step fracture
		4	Multiple step fractures
		5	Hinge and step fractures
		6	Lipped Flakes
ARTA	Type of artefact	000	Shatter
		010	Flake
		012	Blade-like flake
		600	Biface

Abbr.	Definition	Code	Characteristics
AL	Length		Num. Value
AB	Width		Num. Value
AD	Thickness		Num. Value
AG	Weight		Num. Value
CT	Visible copper trace	0	No
		1	Yes
DG	Dorsal Grinding	0	No
		1	Yes
EG	Extent Grinding	1	1/4
		2	1/2
		3	3/4
		4	Entirely

decisions added time to the work of recording, but removed a bias from the later analysis. Smaller flakes are more numerous in the production process regardless of the stage of production. Drawing samples from the inventories would have added more significance to the smaller flakes. Sampling for size classes (see here Subchapter 5.3) could have helped to clear this bias, but would have excluded a lot of information about the technical approach as small flakes are common in all stages and techniques. A diffuse mix would have been the result of this sampling (Ahler 1989, 87). Another problem with sampling for size classes would have been the low number of artefacts per class, especially in the upper size classes, which left it nearly impossible to get a statistically significant sample from the classes without recording all the artefacts anyhow.

The first five categories offer a basic description of the recorded artefacts. The **basic form** became obsolete in the progress of the work, as no archaeological inventories were recorded and the finished bifaces were not included. Thus, solely flakes were recorded in the end. Some pieces of shatter or bigger parts of the nodule remained on rare occasions. Shatter was not included in the final analysis, as the pieces do not hold any significant technological information, beside the testimony of faults in the raw material. In the course of recording, the strategy changed and solely artefacts with conservation of the proximal part were recorded, which naturally excluded all shatter.

Thermal alteration was also mostly included for the archaeological inventories and would have described the preservation of the pieces. Actual heat treatment of the material for a better workability has not been observed in archaeological contexts in Scandinavia (Olausson and Larsson 1982; Inizan *et al.* 1999, 23-24; Weiner 2013). However, with the Type IC Dagger by Greg Nunn, a heat-treated artefact is included in the study. This is due to the different raw material (Texas flint in contrast to Scandinavian flint), which would not allow the execution of parallel flaking without heat treatment. None of the used flint nodules from Hillerslev were heat treated and also none of the knappers included in the study felt the necessity to use it in the production.

As mentioned above, the **proportion of the natural surface** and the **interior cleft thereof** were included for the sake of a rough division of the knapping products by production stages. The average proportion of covered surface was recorded, spanning in four steps from no cortex left to entirely covered. If a surface ranged between two categories, the higher portion of coverage was chosen (Andrefsky 2005, 105-106). Surfaces with areas where it could not be determined whether a natural surface was present were recorded as indefinite. In general, the more cortex left on the surface, the earlier the removal happened (Amick *et al.* 1988, 28; Bradbury and Carr 1995, 101-102; Apel 2001, 137). Cortex-bearing flakes can appear up until quite late in production, depending on the workflow of the knapper and the restraints of the material. High percentages of cortex cover are a good indicator for early stages, but it should not be used as a general mean for division into production stages (Magne and Pokotylo 1981, 36; Bradbury and Carr 1995, 106; Andrefsky 2005, 116-118). The proportion of interior cleft provides the opportunity to determine if and how big a proportion of the natural surface is cortex. No interior cleft means the entire proportion of natural surface (if present) is cortex, which in turn informs about a more or less early removal in the production process. In contrast, a high proportion of interior cleft suggests a later removal, when inner faults of the nodule were encountered. Furthermore, it offers insight into the quality of the raw material and the difficulties the knappers faced during work. Interior clefts can also be found as natural surface on nodules and can give insights to origin and source of the raw material. The 'simple' coding for the statistical analysis falls a bit short here, as it does not distinguish between clefts as natural surface or interior faults.

The last entry to the basic description is the **preservation of the basic form**. Especially in archaeological inventories, this is nice information to have in order to determine how fragmented an inventory is. With the choice to not include archaeological inventories and exclude all flakes without proximal preservation, it became obsolete. The choice of recording only flakes with proximal preservation is a choice for a biased sampling. It was made to save time during recording and still get the highest possible amount of technological information. If random samples had been taken from the inventories, a bigger portion would have been flakes without any information about the knapping procedure. The time and labour invested in the recording would have been disproportional to the gain of information, as flakes without the technical information of the proximal part would have been excluded from the analysis regardless.

Starting with the **characteristics of the distal part**, information about the production process is brought into focus. The distal part can hold a lot of information not only about the production process but also about the skill of the knapper. For the analysis, a distinction was drawn between pointed and broad endings, hinge and step fractures as well as *outrepassés* (also called overshot) and indefinite and not preserved parts. The distinction between pointed and broad endings was chosen with the identification of thinning flakes in archaeological inventories in mind. Thinning flakes are a quite distinctive type of flake of bifacial production and often used as an indicator to determine if production of bifaces took place at a given site (Whittaker 1994, 185-186). They are aimed for after the first few stages of production (cf. Subchapter 4.1) when form giving and thinning of the artefact is pursued. As the name suggests, thinning flakes are meant to remove material from the body of the artefact (thin down the nodule) but not at the loss of width. This means they have to be quite broad and far reaching, but narrow at the platform (Newcomer 1971; Yerkes and Kardulias 1993; Whittaker 1994, chap. 8). A broader ending is thus preferred in contrast to blade production, where the termination is ideally narrow and pointed.

Hinge-, step fractures and *outrepassés* are generally unwanted terminations and indicate failed execution of the blow. Recurring and numerous failed terminations are an indication for missing skill and/or knowledge (Shelley 1990, 191; Inizan *et al.* 1999, 36). Thereby, termination failures can be used as an indicator for the number of involved knappers at a site and convey a sense of the learning environment. In most cases, hinge and step fractures occur when not enough or too much force is used for the blow, but they can also indicate the wrong choice of angle (Cochrane 2003, 14). All these errors are more likely to happen when inexperienced knappers are involved (Dibble and Whittaker 1981, 287; Cotterell and Kamminga 1987, 700; Shelley 1990, 191; Waldorf 1993, 50; Whittaker 1994, 106-109, 163-165; Callahan 2016, 32; Hein and Lund 2017, 116). Step fractures can also be induced by material restraints. When a nodule has a less homogeneous quality or internal cracks, the force of the blow cannot progress evenly. It will stop short and the flake will end abruptly (Floss 2013, 126). Hinge fractures are often triggered by too flat working faces, when the force has no guiding ridge. In such cases, it will dissipate and turn back to the surface untimely before the fracture has reached the intended extent (Cotterell and Kamminga 1987, 701; Odell 2004, 57-58). These terminations can hinder following removals and may lead to an artefact being discarded before it is finished. In general, it is more interesting how the knapper reacted to the failures (Dibble and Whittaker 1981, 287). Skilled knappers make mistakes as well, but the reaction and actions dealing with these accidents are fundamentally different. This is partly recorded in the knapping accidents later on. *Outrepassés* are a slightly special type of failure, because they can be used deliberately to correct mistakes or material issues but require a high amount of control of the knapping process and skill to be used effectively (Dibble and Whittaker 1981, 287; Cotterell and Kamminga 1987, 701; Inizan *et al.* 1999, 149-151; Aubry *et al.* 2008, 57-59; Bamforth and Finlay 2008, 5). Corrections with this method always entail sacrificing material and, in case of bifaces, this concerns a part of the edge, which by itself can lead to a loss of an entire artefact. Most often, it is too risky to try to correct a biface with an *outrepassé* and it is more likely the result of choosing the wrong angle and force for the removal (Dibble and Whittaker 1981, 287; Waldorf 1993, 51; Whittaker 1994, 193; Callahan 2000, 108; Aubry *et al.* 2008, 57-59; Dibble and Rezek 2009, 1950; Hein and Lund 2017, 116).

Indefinite is used as a characteristic when it is not identifiable how the flake terminated. This can be the case when it is not clear if the ending is a step fracture or a break. Not preserved is the case when the distal part of the flake is not preserved due to breakage of the piece.

Lengthwise curvature of the flakes is recorded as not preserved if too little is left of the flake to allow for a statement. Otherwise, it is categorised as curved or straight. The initial thought behind including this characteristic was its benefit for the interpretation of archaeological inventories. Namely, for a distinction between bifacial and axe production flakes, the curvature can provide hints about the type of production. Flakes from bifaces are more prone to curvature than flakes from axes due to the outline of the pieces being respectively lenticular or square (Arnold 1981b, 53 fig. 48; Apel 2001, 151). If the artefact is known beyond doubt to be a biface, the curvature of flakes can give hints about the stage of production. Early thinning flakes are curved more often than late thinning flakes

(Apel 2001, 137; Callahan 2016, 26). To some extent, the curvature can hint at the technique in use. Soft hammers can produce flakes with a greater curvature than hard hammers (Hayden and Hutchings 1989, 245; Andrefsky 2005, 109).

The **number of negatives** left by prior removals was added for the sake of a rough division of the inventories by stages. Generally, flakes from early stages carry less negatives than flakes from later stages (Magne and Pokotylo 1981, 36; Amick *et al.* 1988, 29; Stafford 1998, 346; 2003, 1541; Apel 2001, 155). The number can also be influenced by other factors. Distinguishing the stage of production based on flake scar count alone is not advisable. In general, the bigger a flake is, the greater possibility for an increased flake scar count (Andrefsky 2005, 106-109). The **orientation of the negatives** is determined in relation to the direction of the removal and provides indications about the stage and position of the removal (Arnold 1981b, 53 fig. 48; Callahan 2016, 26). If a large flake carries bidirectional negatives, the chance is high it was removed in an earlier stage of thinning, while a small flake with bidirectional negatives quite possibly was removed from the point or base of the artefact.

Preparation of the exterior edge of the platform remnant is a quite essential part of biface production and has to be executed with care. For example, contrary to blade production, the blows during bifacial production have to be dealt directly on the edge of the artefact. Both, too much or not enough preparation, can lead to failures. If the edge is not prepared and overhangs are left before the strike, the platform will most likely collapse and no or just a small flake will be detached. In contrast, if the platform is too stout, the force necessary to remove the flake will be high and, in most cases, the knapping implement will slide off the edge without detaching a flake (Waldorf 1993, 56; Whittaker 1994, 185-187; Callahan 2000, 34, tab. 11; Apel 2001, 37; Magnani *et al.* 2014, 42). The extent and kind of preparation can further give insight into the stage of production as well as the utilised knapping implements and personal preferences of application (Hayden and Hutchings 1989, 240; Pelegrin 2000; Apel 2001, 130-132; Stafford 2003, 1541; Sørensen 2006b, 27-28).

The most common and simplest preparation is abrasion. This can be done with an abrader, a smaller fine-grained stone, or a hammerstone, and leaves a characteristic smooth edge. Abrasion is especially needed when knapping with organic materials, so that the sharp edges of the artefact do not bite into the billet and damage the surface. Organic billets have a bigger zone of contact than hammerstones and so a wider part of the edge needs to be prepared evenly. This is more easily achieved by abrasion (Whittaker 1994, 102-104, 145; Pelegrin 2000).

Another method for removing overhangs and to strengthen the platform is dorsal reduction, also called trimming (Whittaker 1994, 101). It can also be used to correct the edge angle, as it shifts the edge back and thus opens the angle between the platform and the surface (Sørensen 2006b, 27-28). Trimming can be executed in a fine and subtle way, removing minuscule flakes, or in a strong and distinct way with comparatively larger flakes, often ending in hinge or step fractures and a noticeable pushing back of the edge. Both gradations of trimming are obtained by tapping along the edge with the knapping implement, regardless of material. Combinations of trimming and abrasion are not uncommon.

No preparation of the edge at all was encountered more often than expected, considering that bifacial reduction is most often done in direct soft technique. The preparation or lack of preparation can also be an indicator for the stage and which kind of work is being done. While working on the rough out stage of a biface, major concern lies with establishing the working edge of the artefact. The strikes are mostly dealt slightly behind the edge, so preparation of the edge becomes futile (Apel 2001, 130). In contrast, when the attention shifts from the edge to the outline of the artefact, more strikes are dealt to the edge and preparation becomes necessary (Apel 2001, 131). Not preserved preparations concern pieces with shattered or collapsed platform remnants (see below).

Similar to the preparation of the edge, the **preparation of the striking surface** is necessary to remove irregularities and can be used to adjust the angle between the platform and the surface (Whittaker 1994, 101, 199; Cochrane 2003, 14). It can also be used to create elevations, which isolate the point of impact and help to guide the progression of force through the material. Like the edge, the striking surface is more likely to be prepared in later stages of manufacture (Apel 2001, 137, 152; Stafford 2003, 346; Arnold 2013, 925-927). In most cases, unprepared platform remnants are made up of platforms with single facets left from negatives of prior removals. Truly unprepared remnants are solely found on the first few decortication flakes. Thus, unprepared remnants denote the lack of further work invested rather than no work put in at all. Often, it is hard to determine if the platform was faceted deliberately or a suitable spot was chosen for the removal. The combination with the form of the platform remnant can help to determine how much work was invested in the preparations and to identify different approaches between knappers.

Some studies suggest the possibility of dividing flakes into production stages by means of the number of negatives on the platform remnant (cf. Apel 2001, 130-137; Stafford 2003, 1541). As the need for the preparation of the platform is not directly linked or exclusive to the stage of production, it was highly doubted that the choice of number of facets would help to determine more than the basic distinction between investing or not investing time. This has already been covered with the observation if facets are present or not. The extent of preparation and thereby the number of facets is more likely influenced by the need of the raw material and skill of the knapper to preserve the circumferential edge. Indeed, in early stages, less faceting of the remnants is expected, while later removals will show more facets, as the negatives from earlier removals will also be smaller and in close proximity. Another problem would have been to decide which facets to count. All facets or just those, which have been made as a true preparation of the surface. Moreover, how should they be distinguished from each other? During the recording, some flakes showed very small removals along the edge, barely a millimetre in length, like a string of pearls. The best guess so far is that they originate from the occasional scrapping with the side of a copper tip along the edge. Should these negatives then count as facets for preparation or would they have to be included as preparation of the edge? Based on these reasons and questions, the information gain by including the count of facets was not deemed very expressive (cf. Andrefsky 2005, 92) and was therefore not included in this study.

The **shape of the platform remnant** was subdivided into seven categories, which can help to determine the knapping implement in use (Inizan *et al.* 1999, 134-136). As mentioned before, direct soft percussion with organic billets is the main technique in use during biface production. Typical remnants tend to be rather small and oval. During the hard direct technique, the knapping implement connects further behind the edge, which leads to generally larger remnants. The shape is more prone to diverge from oval forms, as more material is removed. A lot of factors not connected to the technique can influence the shape of the platform remnant. Important for this thesis was the division between techniques, meaning that forms, which did not contribute to identify knapping techniques, were summarised as other. Ridge-like and circular platforms were included to determine the use of direct soft percussion with a soft stone (Pelegrin 2000, 77-80; Damlien 2015, 124, 127). Small punctiform and oval remnants can be found when pressure technique was used (Damlien 2015, 127). The harder the material of the applied pressure flaker, the smaller the remnant tends to be. The roof-shaped remnant was integrated into the system during the recording (see also Chapter 4). In addition to providing insight into technical choices, it tells more about the care and work invested into the production as well as the mental template of the knapper. In general, roof-shaped (or dihedral) remnants are more commonly found if organic percussors (Pelegrin 2000, 78-80) or copper tipped pressure flakers are used (Inizan *et al.* 1994, 253; Pelegrin 1994, 529; Méry *et al.* 2007, 1107), as a hard hammerstone would simply shatter the roof. With an organic billet caution is advised, as the ridge would abrade and ultimately destroy the billet if the ridge is too pronounced and bites into the softer material. Something similar would happen with organic pressure flakers, which need smooth platforms.

The last three cases are not preserved remnants. Either the remnant shatters, if the force and material in use is too hard, or the strike is dealt too close to an (un-) prepared edge (Hayden and Hutchings 1989, 240, 247; Pelegrin 2000, 75-76, Magnani *et al.* 2014, 42), or it collapses and removes a greater part of the proximal ending (Callahan 2016, 32). Some techniques can also be prone to shatter the remnant in different variations. While the soft stone seems to shatter the remnant, organic billets tend to break them (Damlien 2015, 124). Shattered remnants can give insight into the skill of the knappers involved; inexperienced knappers tend to shatter their remnants more often (Nonaka *et al.* 2010, 163). Lastly, the remnant could have been broken due to different reasons, still leaving the proximal part intact but removing the remnant. An example would be the partial removal of the remnant due to an *esquillement du bulbe*, which hinders the identification of the original shape of the remnant. These were categorised as not preserved.

Almost more significant than the form are the **measurements** of the remnants. The width is measured from one lateral edge to the other, whereas the thickness is measured from the ventral to the dorsal edge of the remnant. The flake is oriented along the axis of the blow, so the area measured equals the area while still attached to the biface. Both measurements are given in millimetres (mm) and taken at the widest, respectively thickest part of the remnant, giving the maximum measure. Most studies measure the thickness (depth) from the point of percussion to the exterior edge (*e.g.* Dibble and Rezek 2009; Magnani *et al.* 2014). These studies have taken place under controlled conditions, where the point of impact was known and mostly recognisable due to hard hammer percussion. This is not the case in this study and, in addition, soft stone and organic percussion often leave no mark on the remnant. As soft techniques initialise a tearing fracture, the split will start further behind the point of impact. Due to this, the maximum measurements were chosen for this study (cf. Amick *et al.* 1988). Other, more precise methods to calculate the platform area exist, but are mostly concerned with the prediction of flake size and shape from the size and morphology of the platform remnant (*e.g.* Clarkson and Hiscock 2011; Muller and Clarkson 2016; Archer *et al.* 2018). As this was not the goal of the thesis, the simple width and thickness measurements were deemed sufficient.

Depending on the technique in use, the point of contact will lie on different parts of the nodule and not only affect the form of the remnant, but also the width and thickness. Hard hammer percussion needs a stable and rather flat surface, so mostly the blow will be delivered behind the edge in contrast to percussion with an organic billet (Pelegrin 2000; Magnani *et al.* 2014, 38). The latter is executed in a more tearing way and mostly affects the edge, which needs to be tough so it does not shatter. The break starts some way behind the point of impact leaving rather large remnants but commonly smaller than with hard hammer percussion (Hayden and Hutchings 1989, 241; Damlien 2015). The soft stone can leave similar attributes as the organic billet, but as it is still harder than antler or wood, the point of impact is smaller. The remnants left are, again, possibly smaller compared to organic percussion (Pelegrin 2000; Damlien 2015). The smallest remnants will be produced by indirect and pressure technique. As the punch/pressure flaker is set on the exact spot where the removal is meant to happen, often exactly on the edge, the remnant will generally not be bigger than the contact point. Meaning, the sharper and narrower the point of the punch or flaker, the smaller the remnant will be. The dimensions of the platform remnant can thus help to determine the technique in use, as well as give a slight indication of the production stage of the pieces (Whittaker 1994, 185-186; Apel 2000, 130-131, 137; Andrefsky 2005, 90; Damlien 2015). Hard hammer percussion is, for example, often more common in early stages. The removals tend to be bigger and mostly have bigger platform remnants. This example shows that the thickness of the platform corresponds to some extent to the measurements of the detached flake (Dibble and Pelcin 1995; Dibble and Rezek 2009; Nonaka *et al.* 2010; Clarkson and Hiscock 2011; Archer *et al.* 2018) and can be used as an indicator for its position within the production sequence.

The **exterior edge angle** is measured between the surface of the platform remnant and the dorsal side of the flake. In general, measuring the angle is often complicated. Curvature of the flake as well as an uneven surface of the remnant can make it challenging to detect the right intersecting lines. The result is a variety of possible angles, which can be measured not just by varying researchers but also by the same researcher successively (Andrefsky 2005, 91-93; see also Cochrane 2003). Despite these problems, the exterior edge angle was still considered a possibly significant attribute for individual and technical differences and was included in the analysis. To get the maximum dependability for the measurements, the flakes were always oriented in the same way when measuring the width and thickness of the remnant. For the sake of simplicity, it was recorded in degrees in steps of five degrees (Cochrane 2003, 19). In some cases, the morphology of the remnant resulted in different degrees. If it was not possible to determine the exact point of contact of the blow, the average of the measurements was recorded. For ridge-like platform remnants, no angle was measured, as the rounded surface left no chance to apply the goniometer correctly. Or more exactly: it could not be determined when the goniometer would rest on the correct flat surface of the platform.

Besides being a factor determining the length of a flake (Dibble and Whittaker 1981, 289; Dibble 1997, 157; Nonaka *et al.* 2010, 163), the angle is also dependent on the choice of technique (Inizan *et al.* 1999, 129). While the ideal angle for removing a flake lies around 70°, more obtuse or sharp angles are possible. Direct percussion with an antler billet works best between 60-80° and gets more difficult the more obtuse the angle becomes (Pelegrin 2000, 76-77). With the hard hammer, angles between 60-90° can be worked, while the soft hammer works best between 75-80° (Pelegrin 2000, 75-80). Indirect and pressure technique allow for much more obtuse angles. Ideal are angles between 80-90°, but 75-100° are possible. In exceptional cases, more than 100° have been observed (Méry *et al.* 2007, 1106; Dibble and Rezek 2009, 1952; Pelegrin 2012, 487). Generally, the longer the product is intended to be, the more acute the angle has to be (Nonaka *et al.* 2010, 163). However, the more obtuse an angle is, the more accuracy is needed to successfully remove a flake (Speth 1981, 19; Cochrane 2003, 14). Most experimental studies are carried out on cores or core-like forms with the aim of producing flakes or blades (cf. Cotterell and Kamminga 1987; Dibble and Rezek 2009; Pelegrin 2012). Bifacial production does not aim for the same goals, the opposite is the case. The waste is composed of the detached flakes, while the "nodule" yields the intended product with occasional exceptions of suitable flakes for tool production of projectile points. As the method is different, the technical details are bound to deviate. But as the physical principles behind the formation of flakes stay the same, differences between the applied techniques should still be detectable. Furthermore, like the thickness and width of the platform, the angle can be directly controlled by the (experienced) knapper and thus provides insight into the technological system and the behaviour of the knapper (Dibble 1997, 156; Cochrane 2003, 14; Andrefsky 2005, 90; Nonaka *et al.* 2010, 161).

Ring cracks usually appear while working with a hard hammer and a higher amount of force is dealt during the strike. It is usually not formed when applying organic billets, as it needs a restricted point of impact (Madsen 1986, 21; Hayden and Hutchings 1989, 240, 243; Damlien 2015, 124). The smaller the point of impact, the harder the applied material. Ring cracks are often just a few millimetres in diameter and they are smallest when copper tipped pressure flakers were utilised (Pelegrin 1994, 592, 594; 2000, 75-76; Méry *et al.* 2007, 1107). A distinction could probably be drawn between the application of a hard and a soft stone used in a hard way by including conical breaks (Damlien 2015, 124). Ring cracks can help determine which technique and material were applied. This is not solely related to the differentiation between hard hammer percussion and pressure technique with copper, but it is also useful to distinguish the sequences between the knappers. According to Callahan (2016), an indicator for skilled knappers is the long application of the hard stone, as it is harder to control and leaves less room for mistakes than the antler billet. In contrast, the choice between stone and antler can also indicate personal preferences (cf. Chapter 4) or problem-solving strategies.

The **diameter of the ring crack** is measured in millimetres at the widest point and helps to determine which material was used for the removal. Similarly, the **distance from the edge of the point of percussion** can help to detect which technique was used. It is also given in millimetres, if a visible point was present.

Another indicator for technical choices, which should not be overrated, is the **bulb**. The markedness of the bulb has often been connected to the applied technique. But a lot of other factors besides hardness of material and delivered force influence the presence and shape of the bulb. It should not be used as a sole indicator for technical reconstruction, as is true for all attributes (Cotterell and Kamminga 1987, 586-587; Hayden and Hutchings 1989, 241, 243; Pelegrin 2000, 75). Generally, it is stated that the more pronounced the bulb is, the harder the knapping implement and the stronger the used force (Madsen 1986, 21; Floss 2013, 119-120; Damlien 2015, 124, 126). The high amount of subjectivity in classifying the markedness of bulbs is a problem. This is not just a question of the presence and absence of an attribute, but a distinction between forms. When is a bulb truly strong? As no convincing classification could be found in the existing literature and just one person was involved in the recording process, the decision was drawn on a subjective level. The distinction between not present, normal and strong was drawn based on the author's experience and the common markedness in the inventory. If a bulb was surprisingly more marked as expected by the size of the flake, it was classified as strong.

Most work in the analysed inventories was done with organic percussors, so the bulbs are not expected to be strongly marked. A shape and markedness, which was not recorded but occasionally encountered, were rather small, yet quite marked bulbs. This can be connected to copper pressure flaking (Waldorf 1993, 6). Not all flakes with visible copper traces had this kind of marked bulb, which still is in accordance with Waldorf (1993). He states that the markedness of the bulb is connected to the sharpness of the tip; when the tip wears off, the attributes lose markedness.

A double bulb says something about the aim, preparation and maintenance of the knapper and their materials. Double bulbs occur when the fracture was initiated at the same time from two points of impact. This can hint at a less good preparation of the platform, which left too much material in elevated places, so the percussor connected at two points. It could also indicate that the prepared spot was not hit or not hit precisely enough. Lastly, if the platform was prepared properly and the strike was dealt correctly, it would hint at less care for the maintenance of the applied tools. Flint is a truly hard material, which wears the knapping devices down. They have to be maintained quite like the exterior edge of the nodule during reduction. If the surface of the knapping implements becomes too level or the material ripped, the area of connection will become too big or the blow cannot be delivered continuously across the area. This can lead to different failures, like no detachment or loss of the percussor due to breakage, as well as to multiple places of fracture initialisation and double bulbs.

Scarring of the bulb can come in different guises and expressiveness. Éraillure or bulbar scars are connected to the fracture mechanics and mostly regarded as an indicator for direct hard technique, although they are also commonly found on flakes from direct soft technique (Madsen 1986, 21; Hayden and Hutchings 1989, 241, 243; Odell 2004, 55; Floss 2013, 120-121; Damlien 2015, 124). The raw material also has an effect on the formation. Éraillure scars are more common in fine grained materials than in coarse ones (Damlien 2015, 126-127). *Esquillement du bulbes,* in contrast, are connected to the application of soft stones. It is distinguishable from the éraillure scar by its characteristics: the former starts directly at the interior edge of the platform remnant and follows the direction of force, while the éraillure scar originates slightly below the interior edge of the platform remnant and runs oblique to the direction of force (Pelegrin 2000, 78-80; Floss 2013, 120-121; Floss and Weber 2013, 134). Another scarring is the split fracture, which is not exactly a scar on and of the bulb but a removal of material from the bulb. The platform remnant literally splits and removes a part of the proximal end of the flake. In some cases, the flake is split across the entire length, which is called a *siret* break. This is more likely to happen with direct hard technique and is also linked to the quality of the raw material in addition to being an indicator for missing skill (Inizan *et al.* 1999, 34, 156). *Siret* breaks were so scarce in the inventory that no category was included for them. Just in a few cases, éraillure scars or *esquillement du bulbe* occurred together with split fractures. Not preserved was noted when the proximal part was not preserved and became obsolete, as the recording changed to include only flakes with preservation of the proximal part.

Ripples were only recorded when present directly below the interior edge, that is, on the first maximum centimetre of the bulb. The formation of ripples on the bulb is characteristic for soft stone application and is probably connected to the slight shattering of the stone's surface during contact (Pelegrin 2000, 78-80; Floss and Weber 2013, 134). This attribute was recorded as present, absent, not preserved or indistinguishable, if, for example, material constraints did not allow to determine if ripples were present or not.

Like the éraillure scar, **fissures** or **lances** are a product of the fracture mechanic which can hint at the technique and force in use (Hayden and Hutchings 1989, 241, 243; Floss 2013, 122). In general, fissures, especially strong ones, are connected to hard hammer percussion, but Hayden and Hutchings (1989, 241, 243) could not detect a significant difference between hard and organic percussion, although they mention fissures to be slightly less often during reduction with the antler billet (see also Damlien 2015, 126). The fissures can also help to determine the point of fracture initiation. Like ripples, they point back to the point of application of force (Inizan *et al.* 1999, 142; Floss 2013, 122). Fissures were recorded in the gradation of their markedness: none, weak, strong or both weak and strong. Lastly, not preserved was recorded when the preservation of the flake did not allow to determine if fissures were present or not.

Lip formation is an attribute, which is often said to be strongly linked to the technique in use. Lips do not form during a conchoidal fracture, but are rather a product of a bending fracture, which connects this attribute to direct technique with organic billet and soft stone as well as indirect and pressure technique with organic punches and pressure flakers (Hayden and Hutchings 1989, 247; Bradbury and Carr 1995, 101, 105; Inizan *et al.* 1999, 144; Pelegrin 2000; Floss 2013, 119; Floss and Weber 2013, 134; Magnani *et al.* 2014, 39-40; Damlien 2015). Lip formation during hard hammer percussion is possible but scarce. As a rule of thumb, it will be more likely the softer the material used for the removal (Magnani *et al.* 2014, 40). In addition, the exterior angle has influence on the lip formation; more acute angles are more prone to exhibit flakes with lips (Pelegrin 2000, 76-77; Magnani *et al.* 2014, 40). Even though the lip alone offers little evidence for the applied technique, it can provide hints and, in combination with other attributes, show tendencies. A slight tendency in markedness of the lip depending on the technique has been detected. A soft stone tends to leave more diffuse lips than organic billets or indirect technique (Damlien 2015, 124-126). In this study, lips were recorded as not present, weak, normal, strong or lateral. The latter describes lips, which are restricted to the outer parts of the interior edge, being slightly off the mid-point of the platform remnant. While none or lateral lips are quite easy to detect and differentiate, the division into weak, normal and strong is a bit more difficult. Again, a more or less subjective solution was chosen. A lip was recorded as weak, when it was slightly perceptible while trailing with a finger nail across the bulb and interior edge, but not or just barely visible in profile. Strong lips were present, when a distinctive overhang could be seen in profile, which did not need further tactile proof. All cases in between were recorded as normal lips. Not preserved was chosen, when shattering of the platform or other scarring of the bulb did not allow a determination of the presence of a lip.

A last technical attribute that was recorded is represented by **knapping accidents** on the dorsal surface of the flakes. Hinge and step fractures in single, multiple or mixed cases were recorded. Besides giving information about the amount of failed terminations, which can be compared to the distal characteristics of the flakes, it provides insight into the problem-solving strategy. As already mentioned, beginners have a higher tendency to fail terminations, which often leads to rejection of the piece due to successive failures. Skilled knappers are not beyond mistakes, but are able to correct them and continue working. Accidents were only recorded if they were an obstacle for further removals. An accident, which does not affect the dorsal surface, but is quite distinctive for bifacial reduction, was added here: lipped flakes (Inizan *et al.* 1999, 36). It is a characteristic accident for soft stone percussion. The strike removes a larger part of the edge than planned and the flake shows a characteristic large platform remnant with an extremely diffuse bulb.

The biggest restriction of existing categories was made in the **type of artefact**. As just experimental inventories were included, solely four categories remained: shatter, flake, blade-like flake and generally bifacial pieces. Shatter became an obsolete category after deciding to exclude all flakes without proximal preservation. The differentiation in flake and blade-like flake was made to assess the quality of flaking. As mentioned above, bifacial flakes, especially in thinning stages, are required to remove a broad part of the surface. Blade-like flakes would thus not be desirable and show either a personal preference or imperfect execution of removals. Bifacial pieces were kept as a category due to the blind test of E. Callahan, which included bigger parts from the core which were detached in an early stage of production. They are bifacially worked, but not true bifaces. As such spontaneous and unplanned removals could also have been included in the inventories of the other knappers, the category was not excluded.

Measurements of the flakes were included in a more general sense. It is useful to record length, width, thickness and weight of a flake. These measurements can give hints about the technique in use and the stage of production; hard hammer flakes tend to be much bigger and thus heavier than flakes from organic percussion or pressure flaking, and hard hammer flakes tend to be more common in early stages. But a true division into stages by size or weight is not possible, as it is also influenced by the size of the nodule (Magne and Pokotylo 1981, 40; Stahle and Dunn 1982; Amick *et al.* 1988, 29; Patterson 1990; Andrefsky 2005, 98-102). For this thesis, the maximum extents of width, length and thickness, while aligned to the axis of the blow, were recorded in millimetres (mm) for all fully preserved pieces. The weight is given in grams (g) and every piece recorded was weighed, regardless if whole or broken. The last three categories were included to identify specialised techniques.

Visible copper traces were recorded to see whether combinations in attributes could give better indications about which flakes were removed with metal tools and to evaluate when metal was used and where to expect the traces in archaeological inventories. Copper traces were either recorded as present or absent and observed with the naked eye or a magnifying glass.

Grinding and the extent of grinding was included to analyse whether grinding was indeed a part of the production process and how fast the grinding was removed from the surface through the successive removals. Grinding was recorded as present or absent and the extent in quarters ranging from none to entirely grinded, similar to the recording of cortex coverage.

3.2.3 Implementation of statistics in the analysis

Statistics has a long tradition in archaeology. While basically no one would argue about the implementation of seriation, typology or ^{14}C-dating in archaeological research, the situation is rather different for the use of descriptive and multivariate statistics in reasoning, despite the fact that the archaeological record is to a great extent made up of quantitative data, like counts and frequencies of artefacts, types of traits and decorations, shapes, forms and measurements, all said to include information about human behaviour (Mauss 1973; Leroi-Gourhan 1980; Madsen 1988a; Lemonnier 1992, chap. 4; Drennan 2008; Barceló *et al.* 2015; Read 2015, 100).

With the rise of processual approaches, great appreciation was given to statistical methods, specifically, in hypothesis testing, although neither the theoretical nor the methodological approaches are connected to one another and have been applied in different contexts too (Shennan 1988, 4-5). Processual archaeology wanted to describe human behaviour and culture in a scientific way as the natural sciences carried out research; by looking for general laws, describing human behaviour throughout time. Statistics was not only seen as a 'true' scientific and objective way, but also started to advance into a powerful and accessible tool during the 1960s and 1970s due to the progress and accessibility of computer systems. Increasingly sophisticated methods were developed and could be applied to the complex and often messy archaeological data sets. Frequently, the statistical methods were applied uncritically and even in wrong ways, which diminished the acceptance and spiked critique, especially in post-processual contexts (Cowgill 1977; 2015; Shennan 1988; Aldenderfer 2005; Barceló *et al.* 2015; Baxter 2015a; Djindjian 2015; Niccolucci *et al.* 2015). Research interest shifted from generalisations and laws towards more dynamic and situated characterisations of behaviour, mostly rejecting statistical methods in favour of descriptions and analogies. There is still a growing field of statistical research in archaeology, notably concerned with modelling in the latest years, but there seems to be a rather strict divide between supporters and opponents of statistical approaches (Clark and Stafford 1982; Shennan 1988, 4-5; Cowgill 2015). This divide can also be seen in technological research, where the geographical aspect of the divide becomes apparent, corresponding to the theoretical divide between more 'scientific', processual approaches in North America and the responding critical orientation of post-processual approaches in Europe (Watson 2008b; Schenck 2015, 31; Johnson 2020, 23). The American research is still often tied to statistical methods, which has already been shown in the experimental research on knapping characteristics (*e.g.* Speth 1972; 1974; Dibble and Whittaker 1981; Dibble and Rezek 2009; Magnani *et al.* 2014), while European and especially French research is often more empirically based (*e.g.* Lemonnier 1993b; Inizan and Pelegrin 2002; Pelegrin 2003; Méry *et al.* 2007; Aubry *et al.* 2008; Soressi and Geneste 2011), although overlaps in the approaches do exist (*e.g.* Apel 2001; Stout 2002; Darmark 2010; Bradley 2013; Scerri *et al.* 2016).

The position taken in this thesis is that neither qualitative nor quantitative research is the only and right way to pursue archaeological questions. Both approaches have their problems and merits, but neither approach excludes the other. Quite contrary, including both and looking at the data from various perspectives can help to answer the questions in a more thorough way and on a more solid basis of reasoning (Shennan 1988; Barceló *et al.* 2015; Niccolucci *et al.* 2015; Read 2015; Carlson 2017). Statistical analysis is a tool, which helps to reduce information and structure data in a summarising manner, to simplify the interpretation. This is true for simple descriptive statistics, as well as for complex multivariate methods (Clark and Stafford 1982; Aldenderfer 1998; Carlson 2018; Siegmund 2020). In complex data sets, like the one assembled for this thesis, where a multitude of variables are included, simple bivariate analysis is not sufficient. Looking at single variables and their relationships to others is the first step in the analysis and an important one, in order not to overlook patterns and to get an impression of the structure of the data. But the analysis of multiple variables by uni- or bivariate methods is simply too cumbersome. Luckily, multivariate methods and an increasingly easy implementation using software packages solve a lot of problems (Clark and Stafford 1982; Tabachnick and Fidell 2007; Baxter 2015a; Cowgill 2015; Carlson 2018).

There are still some problems with statistical analysis, which should be kept in mind. Most prominently, there is no truth to be found in statistical results. The possible outcome of a method relies very much on the data chosen for the analysis. With different variables, algorithms or methods, other results are possible, which would be equally likely from a statistical point of view. For this reason, among others, introductory texts often admonish us to try other approaches, combinations and algorithms suitable for the data, before deciding which analysis to use. The seemingly objective method is thus not only influenced by the available data, but also by the subjective choice of the researcher, deciding which result makes most sense (Madsen 1988a; Read 1989a; 2015; Aldenderfer 2005; Krzanowski 2014; Baxter 2015a; Cowgill 2015; Carlson 2018). Moreover, the data obtained by archaeologists is in very rare circumstances truly statistically valid, since there is simply no way to recover a true sample of the original population for various reasons, including conditions of preservation and recovery, as well as sampling biases (Madsen 1988a, 9-10; Aldenderfer 2005, 526; Drennan 2008, 2096-2097; Gelfand 2014). Another problem is the human mind, which is very good at detecting (visual) patterns, even if none exist (Clark and Stafford 1982, 109; Everitt *et al.* 2011, 15). Statistics is thus not a means to an end, but a tool, which can help to determine how valid patterns are, although it cannot help to determine if the patterns are true. Decisions about significant combinations of variables and interpretations of arising patterns cannot be based solely on statistical analyses, as they mostly need a statement about significant variables beforehand. This means that non-statistical methods have to be included, to get an impression of how the variables relate to one another and possibly could structure the data, which then in turn can be explored by statistical means (Madsen 1988a, 11; Read 2015). This is precisely why the two-fold way was chosen here. The starting point of the analysis involves documentation, observations as well as experimental research on knapping, which gives an impression of which markers to focus on and where the personal differences between knappers could lie (see Chapter 4). Results from this comparison will be used to guide the statistical analysis to see if the expected patterns are present in the data, or how they deviate from the expected results (see Chapter 5). The aim is not only to get detailed descriptions of the *chaîne opératoire* of bifacial production and the personal production schemes of the knappers but also a more objective impression of how and which variables and factors express the differences. Furthermore, the statistical analysis can help to recover patterns, which were not perceived or only noticed subconsciously without being able to clearly state what the difference is.

In the following, a short summary of the included statistical methods is provided. As it is not the aim of this study to make an assessment of the different methods or their applicability to archaeological data, no in-depth discussion of the mathematical background will be given. There are sufficient introductory texts which explain the backgrounds and application options in varying degrees (*e.g.* Shennan 1988; Baxter 2003; Drennan 2009; Greenacre 2014; 2017; Baxter 2015a; 2015b; Carlson 2017; Handl and Kuhlenkasper 2017; 2018, Wollschläger 2020). The analysis in Chapter 5 has mostly relied on Carlson (2017), which includes lines of code and package recommendations for implementation in R. Choices regarding methods and techniques during the analyses are stated in more detail during the discussion in the chapter.

In a way, the data set in this study is rather limited, compared to archaeological assemblages. It solely includes flakes from complete production processes of two tool types by three knappers. Another preform by a fourth knapper is included in the data set, but is not analysed in detail, as it was mainly used as a test for the suitability of the recording system (see Subchapter 5.1). As the aim is not to describe the inventories and differences in flake shapes and compare them to other inventories, the descriptive part of the statistical analysis is rather concise. Beside some description about the raw material and produced tools (Subchapter 5.1 and Subchapter 5.2), the descriptive part is mainly used to assess the question, if flakes can be attributed to production stages based on their measurements (Subchapter 5.3). Subchapter 5.4 does include some descriptive summaries to assess the technical variations between the knappers, and continues to analyse single variables in detail before settling on the comparison of the multiple variables, mostly through multivariate statistics. Included are principal component (PCA), correspondence (CA) and cluster analysis, and the analysis of variance (ANOVA). The multivariate methods are used in an explorative way during the analysis; they are included to look for structuring patterns in the data and not to predict how artefacts should or could look like in order to be included in categories. The advantage of descriptive approaches – which multivariate methods are a part of – compared to inductive approaches is that the mathematical theory behind the methods does not have prior assumptions about the data (Madsen 1988a, 10; van der Heijden *et al.* 1989, 250).

Analysis of variance (ANOVA) is not in itself a multivariate method, although it can be applied to multivariate data, subsequently termed multivariate analysis of variance (MANOVA) (*e.g.* Tabachnick and Fidell 2007, chap. 7; Krzanowski 2014, 5; Pillai 2014). It is mostly treated as part of simple and descriptive statistics and used in the context of hypothesis testing. In archaeological contexts, it is often of interest to know if samples originate from separate populations. This can be done by different tests, depending on the structure of the data. In the present thesis, metric data is used, so differences in means tests were chosen (Carlson 2017, 171). As the term implies, differences in the mean of the samples are used to evaluate the probability of them belonging to the same population. A problem occurs, when more than two samples are compared. It is possible to chain t-tests together and test the null hypothesis for each pair of samples, but this leads to the multiple comparison problem. With rising numbers of samples to be compared, the probability to reject the null hypothesis rises too, although it is true (also termed Type I error) (Argyrous 1997, 228; VanPool and Leonard 2011, 149; Carlson 2017, 180). This is an unfortunate connection, which cannot be solved easily without choosing another way of testing. In this respect, ANOVA is the more reasonable and robust choice, which is also more easily calculated. It compares the within group sum of squares of the mean with the between group sum of squares of the mean and measures the deviation of observations from the grand mean. Overlapping groups will have very similar means to the grand mean, while separate groups should differ (Argyrous 1997, 288; Drennan 2008, 2100; VanPool and Leonard 2011, 153; Carlson 2017, 178-179). There are two ways of applying ANOVA, which do not differ in the calculation but only in the interpretation of the results. The first is termed 'fixed effects ANOVA' and the second 'random effects ANOVA'. The names indicate with which premises the results have to be considered. In fixed effects, the variables in consideration are kept fixed, while the variable of difference is changed. The result shows the impact of the variation and explains the differences in the means (VanPool and Leonard 2011, 154). In random effects ANOVA, no control is or can be exerted on the variables. The source of variation is unknown or out of control, which is the case in most archaeological inventories. The results of the analysis will thus be a prediction if differences are present in the samples and a starting point for other analyses with the aim to identify the factors which cause the variation (VanPool and Leonard 2011, 154, 168). In this way, ANOVA was applied for this thesis. Despite working with experimental data, no control was exerted on the different variables, the aim was to see if – and if possible which – variables show differences, which then could be analysed in more detail through other means.

While one to three variables can still be analysed and compared rather easily by simple statistical methods and, *e.g.* scatterplots, data sets which include more variables need multivariate methods to be interpretable (Chibnik 1985; Krzanowski 2014; Johnson and Wichern 2015). The aim of principal component as well as other multivariate methods is the reduction of displayed data without losing the bulk information. For PCA, this implies a reduction of dimensions. Technically, as many dimensions as variables are present in a given data set. PCA reduces the number of dimensions by finding linear combinations between variables, the so-called principal components, which still express the maximum variance in the data (Shennan 1988, 245-270; Joliffe and Morgan 1992; Jolliffe 2014; Baxter 2003, chap. 7; 2015a, chap. 3; Drennan 2009, chap. 24; Carlson 2017, chap. 12; 2018; Wollschläger 2020, 517-523). It is one of the oldest methods, dating back to the beginning of the 20th century, but the complex calculations made it basically impracticable prior to the invention of computers. The development of software packages has contributed greatly to its implementation in the last few decades (Jolliffe 2002, chap. 1.2; 2014; Everitt and Hothorn 2011, 3; Krzanowski 2014, 3-4). The results obtained from a PCA can be visualised by a biplot, which can help to identify patterns and groups inherent in the data (Jolliffe 2002, chap. 5; 2014; Carlson 2018). The term biplot does not refer to the graphical display of two dimensions, but designates the function of the plot, displaying rows and columns in the same graphic (Carlson 2017, 271; Greenacre 2017, 100). Still dealing with multidimensional data, the interpretation of the biplot is not always straight forward. Rotation of the principal components can help in clarifying groupings, but also has drawbacks. One is that a number of ways to rotate the components exist, which all have influence on the results (Jolliffe 2002, hap. 11; Baxter 2003, 80-83; 2015b, 259-263; Carlson 2017, 268). Rotation has not been used in the analysis, so a discussion is omitted. As a PCA in itself does not make predictions about patterns or groupings in the data, it is often used as a first step to get an overview before further methods are applied, such as cluster analysis (Jolliffe 2014). Some downsides of PCA are that it needs sufficient normally distributed data and it is only easily applied to metric variables. In addition, it is also sensitive to outliers and scale-dependent, which implies that the data has to be examined and, if necessary, standardised before analysis (Madsen 1988a, 13; Baxter 2003, 73-75; 2015a, 65; Drennan 2009, 301; Everitt and Hothorn 2011, 66).

A mathematically similar approach, often termed as an extension of PCA, is correspondence analysis (CA). Like PCA, a reduction of dimensions is calculated to have a better graphical representation of tabular data sets (Baxter 2003, chap. 11; 2015a, 100; Bølviken *et al.* 1982; Madsen 1988a, 14; van der Heijden *et al.* 1989; Greenacre 2014; 2017). The origin of the method lies in the 1930s and it was developed for two-way contingency tables, but is not restricted to them. Originally, it had little impact, but was re-discovered and re-named several times (Hirschfeld 1935; Bølviken *et al.* 1982; van der Heijden *et al.* 1989, 250; Baxter and Cool 2010, 212; Legendre and Legendre 2012, 464-465; Baxter 2015a, 101). The term correspondence analysis persisted in the end and is derived from the French *analyse factorielle des correspondances*, where it received great attention in research (Djindjian 1989; 2015; van der Heijden *et al.* 1989, 249). Due to various reasons, above all the language barrier, CA was not applied regularly outside of France for a long time, especially in Britain and the United States. Beginning publications in English, mostly by Scandinavian researchers, changed the circumstance and CA developed to one of the most implemented analysis methods in archaeology, especially used in seriation and dating contexts (Bølviken *et al.* 1982; Madsen 1988b; van der Heijden *et al.* 1989, 250; Zimmermann 1997; Baxter 2003; 2015a).

In contrast to PCA, CA can show the relationship between variables and observations alike in one plot. While PCA is restricted to the relation between variables and thus an R-mode technique, CA can analyse the connection between the observations as well, making it an R- and Q-mode technique (Bølviken *et al.* 1982; Madsen 1988a, 14; van der Heijden *et al.* 1989, 251; Baxter 2015a, chaps. 5 and 6). It works best with categorial data of any kind and needs positive numbers (Baxter 2003, 144; 2015a, 100; Madsen 1988a, 10; Greenacre 2017, 15). Like PCA, it is sensitive to outliers, which can cover the interesting patterns of the analysis, whereby examination and standardisation of the data before and during analysis may be necessary (Bølviken *et al.* 1982, 56; Baxter and Cool 2010, 220-225; Baxter 2015a, 113).

Both methods are often used in an explorative fashion to detect groups or clusters in the data (Everitt *et al.* 2011, chap. 2; Read 1989b, 159; Cowgill 2015, 7; Carlson 2017, chaps. 12 and 13; 2018, 3-4). Another explorative method often used in combination is cluster analysis. Like PCA and CA, the theoretical and mathematical development of this method gathers momentum in the 1930s, but it has an even longer tradition especially in biology and ecology, where it has contributed to taxonomy and classification (Shennan 1988, chap. 12; Read 1989a, 24; Everitt *et al.* 2011, 4; Krzanowski 2014; Djindjian 2015; Lowrimore and Manton 2016). Cluster analysis is not just one method, but rather a generic term for a whole series of methods and techniques, which have a subdivision of data in common based on similarities or dissimilarities. The goal is to find groupings, which are internally as homogeneous as possible, while being as distinct as possible from other groups (Shennan 1988, 195-196; Read 1989a, 44; Jolliffe 2002, 210; Baxter 2003, 90; 2011, chap. 1; Everitt and Hothorn 2011, 165; Legendre and Legendre 2012, chap. 8; 2015a, chap. 7, Mucha *et al.* 2015; Lowrimore and Manton 2016; Carlson 2018, 4). On a basic level, cluster analysis can be divided into two approaches: partitioning and hierarchical. While hierarchical methods do not need prior decisions about the number of clusters, partitioning methods, like k-means clustering, require a choice. Another divide can be drawn between agglomerative and divisive methods. The former starts out using each individual observation as single cluster and merging pairs together until only one big cluster is left. The latter does the process in reverse, starting with one single cluster of all observations and dividing it up until single units are left (Everitt *et al.* 2011, chap. 4; Baxter 2003, chap. 8; Shennan 1988, 197; Krzanowski 2014, 7; Mucha *et al.* 2015, 192; Carlson 2018, 4). In addition to choosing the method of clustering, further choices have to be made concerning clustering techniques and (dis)similarity measures, which are used to assign or remove an object to or from a cluster. Each choice has influence on the outcome of the analysis (Aldenderfer 1982; Read 1989a, 45; Drennan 2009, chap. 25; Borcard *et al.* 2011, chap. 4; Legendre and Legendre 2012, 340; Krzanowski 2014, 7; Baxter 2015a, 140, 158). Data with a strong structure will show quite similar results, while weak or unstructured data can show quite opposing results. Similarly, the choice of variables to be included in the analysis has an influence on the result. This means that excluding or adding variables can form new and different clusters (Read 2015, 115). Deciding on the 'right' method, techniques and variables is up to the researcher, and as no fixed rules exist, it often comes down to a decision which result makes the most sense, a circumstance that has been used as critique against cluster analysis, as it is rather subjective which quite easily renders the implementation of cluster analysis useless. Picking the 'right' techniques or results has the potential to end in circular reasoning, as humans tend to decide in favour of results, which meet their expectations. Thus, allegedly known facts are reproduced and underpinned, but no new or opposing knowledge is generated, and so the analysis is pointless (Read 1989a, 45). Another related problem concerning all clustering methods is that it will produce clusters even if no natural segmentation of the data set is present (Shennan 1988, 197; Read 1989a; 1989b, 45; Everitt *et al.* 2011, 8-9; Baxter 2015a, 154, 160; Carlson 2018, 4). Beside generating unwanted clusters, it can also fail to detect clusters in the data (Christenson and Read 1977; Read 1989a, 45). Still, the method has strong merits, and the best practice advice is to try out all methods and techniques, which make sense for the class of data in question, and relate the results to each other. Discussing the diverging results cannot only help in deciding which clustering is the most appropriate, but can also reveal influencing variables, which had not been perceived in the beginning. It has to be kept in mind that no result will mirror some form of general 'truth'. There is simply no way to prove the existence of generated clusters (Aldenderfer 1982; Read 1989a, 45; Everitt *et al.* 2011, 4; Baxter 2015a, chap. 7). Assessing the strength of clusters can help to determine how reasonable the grouping is, as can the repetition of patterns. If diverging techniques show similar results, the chance is higher to have detected a pattern inherent in the data (Shennan 1988, 198; Legendre and Legendre 2012, 341; Cowgill 2015, 7; Carlson 2018, 4). Finally, the sense or meaning of the clusters can be used as a measure of reason. Every analysis is conducted to explain some kind of question to a set of data. If meaningful results are generated, this strengthens the results, too (Aldenderfer 1982, 61; Drennan 2009, 316).

Classically, cluster analysis is done in strict ways, meaning that the assignment to a cluster cannot be reversed and it is not possible for an observation to be in more than one cluster (Everitt *et al.* 2011, 71; Baxter 2015a, 147). This does not always reflect real situations and in the last years, fuzzy clustering methods have gained popularity (Ragin 2008; Borcard *et al.* 2011, 59-60; Everitt *et al.* 2011, 242-249; Legendre and Legendre 2012, 348; Manton and Lowrimore 2015). In fuzzy clustering, observations can be present in different clusters, based on their degree of membership. Fuzzy clustering was not used in this analysis, as the data was not suitable offhand and thus will not be discussed in greater detail. It could offer a better way to analyse differences in knapping techniques, since the attributes as discussed above (see Subchapter 3.2.2), overlap and mostly form a continuum instead of being exclusive. A solution for the data here could have been to calculate a degree of membership to a knapping technique based on the markedness of attributes with a range from 0-1, with 0 denoting no membership in the technique group and 1 full membership. Another solution, also based on the attributes, could have been to scale the techniques from 0-1, with direct hard percussion on one side of the scale and direct organic percussion on the other, and to assign a value to each flake, based on which signature the attributes show. The former would allow for the membership in more than one group, but it would necessitate the calculation of a value for each of the techniques examined for every flake. The latter would classify the flake directly, but would be more complicated to implement, because: is direct soft stone percussion exactly in the middle of the spectrum between hard and organic direct percussion? And what about indirect percussion and pressure technique? Trying both ways and comparing the results would have been very interesting, but unfortunately, like so many ideas developed during the project, there simply was no time to pursue it.

Hierarchical clustering was deemed the most suitable approach for the data and the intended results. It does not require prior decisions about the number of present clusters and thus gives a more 'natural' division. Still, the decision about how many clusters should be used as the results and for interpretations has to be made in the end (Drennan 2009, 316). Results of hierarchical clustering can be visualised in dendrograms, which help to identify patterns (Shennan 1988, 197; Baxter 2003, 90). One method to decide on the number of clusters is to look at the length of the stems. The longer the stems, the more dissimilar the connected objects (Lowrimore and Manton 2016, 5). Often, an arbitrary height of the dendrogram is chosen for the cut and the number of clusters is decided on based on the number of stems cut at the height. If the clusters are very nested, this can be an unsatisfactory method, which can result in some quite large and a lot of very small clusters. A more dynamic approach has been developed in recent years, where the dendrogram is cut on different heights for the varying clusters. Still a decision about how many clusters there are is needed in order to decide on where to cut (Everitt *et al.* 2011, 95). A calculation of scree plots can help in the decision process. It plots the increasing total within sum of squares against a decreasing number of clusters. An ideal number of clusters is then indicated by a jump in the total within sum of squares (Carlson 2017, chap. 15). Scree plots are also a means to decide how many principal components or dimensions are sufficient for PCA and CA (Baxter 2003, 80; 2015a, 59-61; Tabachnick and Fidell 2007, 644; Everitt and Hothorn 2011, 71-72; Carlson 2017, chaps. 12 and 13). Here, the eigenvalues are plotted against the number of components and often show a rather steep decline, hence the name (D'Agostino Sr and Russell 2014). The rule of thumb is to look for a part of the curve, where the decline more or less abruptly changes directions, often called the elbow of the plot. In the end, all this can help to decide how many clusters are included in the final interpretation, but the decision is still to be made on the part of the researcher, who decides what makes most sense.

The theoretical background of hierarchical clustering is concerned with finding hierarchical structures inside of data sets, determining which objects rank above others. This aspect has been a point of critique in archaeology, since archaeological data very rarely reflects hierarchies. The method is often implemented without further concern for the background, which is also criticised. Although it can be applied to non-hierarchical data, it should still be kept in mind that the apparent hierarchy does not have to be present (Everitt *et al.* 2011, 73; Baxter 2015a, 148, 157). While it is not presumed that the attributes in this study have a form of hierarchy, the ultimate goal of the analysis could have a hierarchy. The aim is to identify personal approaches to the manufacturing process also in hope of recognising a transmission of knowledge. This transmission could be expressed in a hierarchical structure, with the 'inventor' or initial teacher as a starting point and subsequent branching due to variations by pupils. As these variations will be expressed in the attributes, the structure of the dendrogram could actually refer back to a hierarchy of transmission.

A last point, which will be discussed briefly, is a common denominator for multivariate methods discussed here. Distance is a central theme in all of them, needed to express the variation in the data and to visualise the distributions of points or clusters (Drennan 2009, chap. 22; Carlson 2017, 296-303). In PCA, when working with metric data, this is generally the Euclidean distance (Baxter 2015a, chap. 4). Correspondence analysis normally uses the Chi^2-distance (Bølviken *et al.* 1982, 42; Baxter 2003, 144; 2015a, 110-112; Greenacre 2017), while cluster analysis can use a variety of distances (Everitt *et al.* 2011, chap. 3; Baxter 2015a, 156-157; D'Agostino Sr *et al.* 2017). Applying a distance calculation to data is a choice with effects on the results for all of the methods. Likewise, the data sets limits to the choice of distance measures (Everitt *et al.* 2011, 68-69; Lowrimore and Manton 2016, 4). For example, Euclidean distances cannot be applied directly to rank data (Drennan 2009, 301). The researcher either has to choose a method for the calculation of distances suitable for the data or the data has to be transformed before application. In some cases, standardisation of the data prior to analysis can also be necessary and can be done in different ways.

A further discussion of all the techniques will not be given here. The choices made during the analyses are explained more closely during the calculation in Chapter 5. For further information regarding techniques and differences between them, reference is made once more to the introductory texts, such as: Shennan (1988, chap. 12); Drennan (2009, chap. 25), Carlson (2017, chap. 15), Baxter (2003, chap. 8), Baxter (2015a, chap. 7), Everitt *et al.* (2011), Legendre and Legendre (2012, chap. 8) and Mucha *et al.* (2015).

Chapter 4: Production sequences in action

In this chapter, detailed descriptions of the production sequences for each knapper involved in the study will be provided. As a starting point, an ideal sequence was created from available literature on bifacial production and the work of each knapper was organised according to this sequence. This was mainly done to have a basis for comparison not only between the individual knappers but also to the ideal sequence. As will be discussed below, this organisation into a more or less fixed sequence is not always a good or true picture of a knapper's production mode. It has to be kept in mind that the sequence is a rather generic construct, which is used here as a frame of reference and by no means has to picture the actual manufacture of an artefact.

Beside the production sequence, tools and modes of application will be discussed and differences between knappers are highlighted. Likewise, the sequence was not split for artefact type in production, but if present, diverging approaches between artefact types are discussed in the stage of production when they occur. The differences observed are not only a result in themselves, but are further used to guide the statistical analysis in Chapter 5.

4.1 Ideal production sequence

Despite being visually and functionally quite different, bifacially worked sickles and daggers differ less in complexity of production as one might think at first glance. As a rule of thumb, the demand of skill to produce a biface increases with the size of

Idealised Sequence	Rough out	Primary preform	Secondary preform	Final preform	Pressure flaking	Final pressure retouch
Hammerstone	x	x	x			
Antler billet	+	x	x	x		
Indirect percussion	+	+	+	x	+	
Abrader		x	x	x	x	
Antler pressure flaker			x	x	x	x
Copper pressure flaker			x	x	x	x

Table 4. Utilised knapping tools per stage for an ideal production sequence. + denotes tools which may be used, but only in very few instances. If not stated otherwise, indirect percussion always means the application of an antler punch and a wooden baton.

the biface, regardless of the form (Apel 2008, 102). This does not primarily depend on the length of the artefact, but is largely determined by the width-thickness ratio. The hardest part in bifacial reduction is producing a thin piece without losing too much width (Apel 2008, 147). If this production step is not mastered properly, products will tend to be quite narrow, rather thick and mostly also shorter.

The overarching production sequence of daggers and sickles consists mostly of the same steps as well as used techniques. Differences start during the last steps of production. In general, sickles are not ground or do receive pressure flaking of the surface at the end (Eriksen 2000, 284), although it has to be kept in mind that likewise not every dagger goes through the stage of grinding. Traces of grinding have been observed on every type of dagger, but the full grinding of the faces as a technical necessary step is restricted to types with parallel pressure flaking of the blade (Lomborg 1973, 29-31). It is still up to debate if copper was used during the production of daggers (*e.g.* Barrowclough 2004; Strand Tanner 2015; Stenak 2022b), but it is more or less excluded for the production of sickles during the Bronze Age. However, studies on sickles have been scant and they focus more on use than on manufacture (*e.g.* Steensberg 1943; van Gijn 2010; Eriksen 2018).

As the production sequences of both artefact types have a lot in common, an ideal sequence will be described as a reference for the individual procedures. This ideal sequence will be rather concise concerning daggers and fairly detailed for sickles in some points. It has to be kept in mind that the separation of production into stages can be a bit arbitrary. It is often hard to determine transitions between the stages and it is strongly influenced by the working mode of the knapper. The more structured the knapper likes to think and work, the more prominent the stages will be. However, in general, the stages III-V form a rather continuous work flow. A definite point of transition between the preform stages is therefore often hard to draw. Nonetheless, it is at least attempted to assign the different preform stages (primary, secondary, final) to the knappers' sequences as far as possible. This will primarily be done to get a more detailed and comparable account of preferred techniques used during the stages as well as differences, not just in between the stages, but most importantly in between the individual knappers.

The stages of bifacial production are defined based on E. Callahan's (2000; 2016) and G. Nunn's (2005) work. A short overview of knapping implements per stage for an ideal production sequence is given in Table 4.

Stage I – Acquiring raw material

At this stage, no further tools but the senses of the knapper are needed. In addition, some knowledge has to be present prior to the collection of the raw materials (Apel 2001, 36; Callahan 2016, 2-4). The knapper should know which kind of material is necessary in light of the knowledge about the properties of raw materials, which dimensions the raw material should have, as well as which quality is needed for successful reduction. Moreover, maybe the most important knowledge is how to acquire the needed raw material, *i.e.*, where the outcrops are located, how does one get there and, most importantly, how does one decide if the quality is good enough. While choosing the right proportions is easily done by looking at the nodule, choosing the right quality is somewhat harder. Sound is a good indicator here. By cautiously tapping the piece with a hammerstone one can hear if a nodule contains significant faults. High quality flint will ring with a clear, crystalline sound (Inizan *et al.* 1999, 23). All this implies that this stage needs a certain level of knowledge and know-how, as the knapper has to already envision the final product in the raw nodule and consider if the form and quality fit the intended outcome (Pelegrin 1990, 118; Stafford 2003, 1540-1541; Apel 2008, 102). Besides obtaining the nodules to produce an object, the flint knapper also needs to have the right tools to knap the flint. Having the needed tools and knowing how to implement them also includes knowledge how to maintain the tools, so that the flaking does not deteriorate.

A technique not used on Scandinavian flint is intentional thermal alteration, also called heat treatment, which can improve the knapping qualities of flint (*e.g.* Purdy and Brooks 1971; Bleed and Meier 1980; Inizan *et al.* 1999, 23-24). This is due to the fact that Scandinavia has an abundance of good quality flint outcrops and it is easy enough to obtain suitable nodules (Olausson and Larsson 1982; Stafford 2003, 1541).

Stage II – Rough out

The aim of this stage is to remove the cortex of the nodule and give it a first, really rough shape. Furthermore, it is important to create the edge circumscribing the centre of the piece (Callahan 2000, 67; 2016, 15-21; Apel 2001, 36). To accomplish this, not much practical know-how is needed. Quick mastering of this stage is no obstacle if one is familiar with the basic principles of flint knapping and one has a teacher who is available (Apel 2000, 147; 2008, 102). Direct hard percussion is the usual choice of technique for this stage, but the work can also be done in soft percussion. On rare occasions, indirect percussion with punch and mallet can be applied if, *e.g.*, tough inclusions thwart the removal of a flake (Callahan 2016, 17; Eriksen 2018, 308).

Stage III – Primary preform

In this stage, a further rough form-giving is intended, as well as first attempts at a thinning of the piece. Both are directed at obtaining a lenticular cross section and getting a centred edge (Apel 2001, 36; 2008, 103; Stafford 2003, 1541; Callahan 2016, 24-33; Eriksen 2018, 308). The preform stages involve most of the available tools. They are also the most complex steps in the production of bifaces, though not necessarily the most difficult to perform (Callahan 2016, 26, 28-29; Eriksen 2018, 308-311). In this stage, knowledge comes into play significantly. Practical know-how and motor control will not lead to a successful outcome if the knowledge about what to do when and where is missing (Callahan 2016, 32). Tools that are most typically used in this stage include abraders, hammerstones and antler billets, which means direct hard and soft percussion as used techniques. Again, indirect technique can be necessary but is not often applied (Callahan 2016, 33).

Stage IV – Secondary preform

The form-giving of the artefact is continued as well as further and more extensive thinning. The aim in this stage is the production of big, far-reaching thinning flakes. Ultimately, the faces of the piece in progress should be roughly level without greater concavities or humps, but a lenticular cross section should still be maintained. The most difficult task during this stage is to thin down the artefact without losing to much width (Apel 2001, 36; 2008, 103; Callahan 2016, 41-49). In contrast to the primary preform, here practical know-how becomes more important than the knowledge of what to do (Apel 2008, 103-104; Callahan 2016, 46-48). Indispensable for the removal of thinning flakes is the proper preparation of the edge, as the blows will be delivered directly on to it. In order to prevent shattering of the edge, it has to be strengthened. But too much preparation can be equally obstructive, as the energy needed to release the flake increases (Apel 2008, 103; Eriksen 2018, 311). The only way to learn the proper measure is by practical experience, which can be easily achieved by some and remain a complete mystery for others. Having not to struggle through the process alone, but to receive help and explanations quickens the process of understanding and mastering (Apel 2000, 147; Callahan 2016, 43). Depending on the toughness of the raw material and intended removals, soft hammerstones, antler billets and abraders are again used during this stage. Beyond the occasional use of the punch, pressure flaking with antler or copper is more likely to be included in this stage. In combination with the abrader, the pressure flaker is used for fine trimming of the edge and platform preparation (Nunn 2006, 95; Callahan 2016, 44-45).

Stage V – Final preform

As can be concluded from the name, this stage is dedicated to final workings on the preform. This mainly concerns the outline and thickness of the piece. Symmetric, more or less parallel edges (depending on the artefact in production) are intended, as well as a thin blade. Any remaining ridges are meant to be eliminated in this stage, so the surfaces of the artefact become as level as possible. It is said to be the most difficult stage, as any mistake is likely to ruin the piece (Apel 2000, 149; Callahan 2016, 57). In this stage, know-how, skill and knowledge are needed, as well as the ability to think three-dimensionally (Callahan 2016, 63). Basically, this is the last stage expected to be found in sickle production, with the exception of a final pressure retouch, which can be conducted but is not absolutely necessary.

Again, billets, pressure flakers and abraders are in use. While pressure flaking continues to be used for preparation of platforms and to attain the outline, indirect percussion can be in use quite extensively. Signs of pressure flaking are often missing due to this reworking of the margins with a billet or a punch (Nunn 2006, 96; Callahan 2016, 64).

In principle, the dagger or sickle is functional and finished with the end of stage V. All further work is more or less purely aesthetic and contributes to the prestige of the object and maker or owner (Nunn 2006, 96; Callahan 2016, 107). If this is not the case, a final pressure retouch can be done to sharpen the edges of the finished piece.

Stage VI – Ground preform

In contrast to the previous stages, no extensive knowledge or know-how is needed. Almost every person should be able to grind an artefact in the correct way after a few instructions (Nunn 2006; Callahan 2016, 86). Although it is fairly easily done, this stage is the most time-consuming step (Stafford 2003, 1542; Nunn 2006, 96). No knapping takes place in this stage. The tools in use are limited to grinding stones and presumably some kind of device to have a better grip on the artefact. A stone to peck up the surface of the grinding stone can come in handy (Nunn 2005; Callahan 2016, 88). The aim of this stage is to create a regular and smooth surface without ridges or concavities to disturb the propagation of the flakes in the next stage. Normally, dagger handles were not ground. The focus was concentrated on the blade part, where parallel-flaking was executed. To perform this, it is important that the angles between the edge and the face are not identical on either side of the piece. During grinding, it thus has to be kept in mind from which edge the pressure flakes will be detached later. On this edge, the angle between the edge and the face has to be sharper, while on the opposite edge, the flakes need a steeper decline to have enough momentum to travel all the way across. This means a more obtuse angle between the edge and the face on this side and thus a not perfectly lenticular cross section of the piece as the summit has to be slightly off from the middle (pers. com. A. Benke 2021). Grinding is a necessary stage for bifaces which are to receive parallel pressure flaking. This concerns daggers of type IC and type IV C-E (Lomborg 1973, 29-31; Stafford 2003, 1546; Callahan 2016, 84). Consequently, this means that not all daggers have been ground and up to date no grinding traces on sickles have been found.

Following Lomborg (1973, 29-31), minor grinding on the blade of daggers can be found on all types. Mostly, this grinding is executed only on a small part of the blade and is thus distinguishable from the full ground preform. The most likely explanation for this kind of grinding is that failed terminations or tough areas on the material could not be removed by flaking and were eliminated by grinding the piece. Problematic areas on the surface can also be present on bifacial sickles and will limit the usability of the piece so, in theory, nothing argues against partial grinding of sickles except for the investment of time and labour. Grinding is a rather tedious and strenuous task, so it could be argued no one would apply it to a mere harvesting implement just to facilitate working with it. In contrast, the invested time in grinding would make harvesting easier, which also is no light task, and could thus be worth the effort. Probably the most likely explanation for no grinding traces on sickles so far is the low production time and the abundance of suitable raw material. A skilled flint knapper can manufacture a sickle in a couple of hours and, unlike the daggers, there are fewer demands on the raw material. So, if a piece did not work out due to a failed termination or problems in the material itself, it was probably easier just to start on a new one, than to invest time in rescuing the unsuccessful attempt (Nunn 2006, 94).

From the point of view of work, not much is to say about this stage. The biface has to be ground on a grinding stone, until the surface is smooth and ideally free of negatives (Callahan 2016, 86). This is also the reason, why the faces have to be cleared of material humps and concavities before grinding. The more even the surface, the less work has to be done here. As a rule of thumb, it is easier to grind down elevated areas, as it is to smoothen out indentations (Nunn 2006, 94). But attention has to be given not to grind facets into the surface, which will hinder the propagation of flakes later (Nunn 2006, 99). Grinding can also be used as a fail-safe step. Instead of risking breakage of the piece, the knapper can decide not to remove flakes, but leave the material to be removed by grinding. This lengthens the time of grinding, but reduces the risk of failure. P. Wiking and A. Benke both stated that they rather grind longer than to risk breakage of the biface.

Prior to grinding, the edge has to be dulled, to prevent undue chipping. This chipping cannot be impeded entirely, but can ruin the edge if not well-tended. When the edges start to get sharpened by grinding, the dulling has to be repeated. It can help to change to a finer grained grinding stone for the last bit of work in order to save the edge from chipping (Nunn 2006, 98-100).

As this stage just concerns daggers and leaves no waste material, which could be recorded, this stage will not be discussed in further detail during the individual sequences. No grinding was executed on the experimental sickles.

Stage VII – Pressure flaking

Just as not every type of dagger was ground, likewise not every dagger received a pressure flaking finish. Most types were percussion finished like sickles. Thus, like grinding, this is a step in the manufacturing process that is not mandatory.

The aim of this stage is the establishment of a nice uniform surface by parallel flaking, which can be done in full- or half-parallel-retouch. While the flakes extend from edge to edge during the former (hence edge-to-edge pressure flaking in anglophone research), the latter is executed from both margins so that the flakes meet each other either at the midline of the blade or shifted to one margin (Lomborg 1973, 29; Stafford 2003; Nunn 2006). Archaeologically, there are cases where one side of the blade is executed in full- and the other in half-retouch. This has typically been interpreted as pieces with a 'show side' and a less carefully worked back side (Lomborg 1973, 29). It shall be noted here that a more mundane explanation should be taken into consideration. During the 2021 experimental setting in Schleswig, A. Benke wanted to deliver a nice edge-to-edge pressure flaked surface but due to various reasons the first few flakes broke halfway. A. Benke then settled for a half retouch and started to come into trouble on the second face. By then, he had had time to establish a work flow and, now working on the less problematic side, his pressure flakes started to extend farther than the midline of the piece. For personal aesthetic reasons, A. Benke continued to work a half-retouch but could have manufactured a dagger with two different faces without problems. If he had decided to do an edge-to-edge pressure on the second side, this would have been treated as the 'show side'. The point to be made here is that there is more to consider than just the showing-off of knappers when describing the surface treatment of prestigious daggers. Aims can and have to change due to material and/or for personal reasons during the production of the pieces and knappers can decide not to show-off and settle for the allegedly not so prestigious or skilled work due to aesthetic reasons, as A. Benke did. Likewise, a half-parallel retouch does not mirror missing skill or intention by the knapper. On some days, things just do not work out as planned. This is true today as well as back in prehistory.

Great care has to be taken with the edges in this stage, as the platform is essential for the success of flake removal (Stafford 2003, 1542-1543; Nunn 2006, 101). Here again, a lot of knowledge and know-how are needed to successfully master the stage, as well as some physical strength (Nunn 2006, 84; Callahan 2016, 104). Typically, the dagger handle will neither be ground nor parallel-flaked (Nunn 2006, 100).

This stage is done mainly in pressure technique, so the needed tools encompass different pressure flakers. These can be either antler tines or handles with antler tips. Pressure flakers with copper tips have probably been in use too, although no archaeological evidence has been found so far. It is still open to debate if it is possible to detect copper traces left on the surface of archaeological artefacts during production of the piece and thus verify the use of copper tipped flakers (cf. Barrowclough 2004; Strand Tanner 2015). On experimental artefacts, these traces can easily be seen and appear often where failures happened, as the copper tip slipped and scratched across the surface (Strand Tanner 2015). More often, traces are left on the platforms of the removed flakes as small circular dots.

Experimental studies verify the assumption that copper tipped pressure flakers were already in use during the Late Neolithic. It is thus presumed that the stitched seams on the Type IV dagger handles cannot be done without copper tips (Stafford 1998, 342; Callahan 2016, 121) or would at least have been very hard work, which could be avoided with the implementation of copper which was known in Scandinavia at this time (Callahan 2016, 108). Likewise, parallel flaking would have cost less strength and simultaneously would have been much more regular, when using a copper tipped pressure flaker (Stafford 2003, 1544). In contrast, experimental studies on Neolithic axe production suggest that the seams on dagger handles have a much longer tradition and can be done in punch technique (Hansen and Madsen 1983; Frieman 2012b, 443-444). This is also presumed by Callahan and Apel (Callahan 2016, 107): to create stitched seams along the handle, a ridge is needed. This preliminary seam has to be punched if no usable ridge is present or was not already done in prior steps. This can be made by arranging removals from both sides of the handle, so that the flakes do not overlap but leave a ridge.

A. Benke agrees with E. Callahan and G. Nunn that the stitching on the handle seams of the Type IV daggers cannot be done without copper tips (pers. com. 2021). He argues that some of the stitchings are so fine so that no antler tip could ever be this pointed and still apply enough force without breaking. On the contrary, he is not sure if the same applies for edge-to-edge parallel flaking. From a technical point of view, he is convinced it should be possible to achieve edge-to-edge pressure flakes with antler, although not with pointed tips. He believes it could be possible with spatula-like pressure flakers made of antler that are oriented vertically to the edge. He plans to try this, but he has refrained from doing it so far, as he feels he needs more control of the parallel flaking process in general, yet.

Stage VIII – Final retouch

The aim of this stage is to finish the outline of the piece, to remove overhangs as well as last grinding traces if still present, and to give the piece an even and sharp edge (Apel 2000, 146; Stafford 2003, 1543; Nunn 2006; Eriksen 2018, 313). On some sickles, the cutting edge was worked to a saw-like shape. Again, the only technique in use is pressure flaking. Finishing this stage, the dagger or sickle simply had to be hafted and put to use. As many re-sharpened archaeological specimens witness, the final retouch is far from being the last stage in the life course of bifacial artefacts. Not in every case has re-sharpening been done by the same person or even a person with the same level of skill (Lomborg 1973, 21-22; Eriksen 2018, 315). As none of the experimental inventories include used and re-sharpened artefacts, this is as far as the analysis will go.

4.2 Individual working procedures

Differences in applied techniques by individual knappers can easily be overlooked. Part of this is due to the fact that the use of different techniques can yield nearly indistinguishable results (Pelegrin 2000; 2006). In contrast, it is also possible to reach totally different results with the same technique, which is not just a result between two different knappers but can also be the case if just one person is involved. This hampers the recognition of differences in the analysis of technical and technological differences. When is a difference truly caused by use of a different knapping instrument? And how can we explain differences caused by divergent applications of the same material? Is it really a difference between individuals or more likely a different approach by the same knapper? Which variations do we have to look for? Is it even possible to distinguish the two types of differences from each other?

Experimental studies offer a unique possibility to answer these questions. As a result of the complete recording of the working sequences, personal choices of knapping implements as well as approaches to the material are captured and can be used to clarify the observed variations; or the lack thereof. Furthermore, by comparing the knappers' approaches and techniques prior to the analysis of the data, we get a deeper insight into which variations should be observable and partly also which differences should cause different outcomes. By this, it is possible to emphasise variables and narrow down the possibly significant combination of differences for a closer study, which is done here by statistical analysis.

No knapping sequence will ever be exactly the same as another, as no two artefacts will ever be the exact copy of each other. This is in the nature of flint as a material, as no two nodules can ever be exactly the same. Not only the knapper has to be aware of this during the manufacturing of an artefact but also the researcher during the analysis. From a scientific point of view, the production of an object cannot be repeated and the results are thus always different and not fully comparable. The knapping process is more like a dialogue as the knapper constantly has to adapt to the given material constraints. Beside unknown and often unwanted inclusions inside the nodule, simple mistakes can force the knapper to change plans or render the piece unfit for further use at worst. Further factors, independent from the raw material, have an influence on the process. Available light, temperature, shelter from wind and rain, disrupting noises, persons, animals or smells, sudden distracting thoughts, time (pressure) or lack of sleep, food and drink are just some examples of what can influence the performance of

Type	Nodule	Year	Worker	Place
Dagger IC	---	2021	A. Benke	Schleswig
Sickle	---	2018	A. Benke	Schleswig
Dagger IC	---	2005	G. Nunn	---
Sickle	26	2006	G. Nunn	Moesgaard
Sickle	33	2007	G. Nunn	Lejre
Sickle	7	2006	P. Wiking	Lejre
Sickle	32	2007	P. Wiking	Lejre

Table 5. Inventories recorded for the analysis.

a knapper and determine the success or failure of a project. Discovering as well as replicating all of these factors is impossible. There is no way to cover all variables and factors leading to a certain outcome, so we have to focus on the parts, which can be rediscovered, and keep in mind that a lot of information is hidden but still responsible for some of the variation we see.

This means that there is not just one sequence to consider and record for analysis. But, like in mostly everything people do, every knapper has a preference

Figure 5. Finished artefacts of the flake inventories included in the analysis as far as available. Bottom to top: A. Benke 2021 and 2018, G. Nunn 2006, P. Wiking 2006, G. Nunn 2007, P. Wiking 2007 (Photo: A. Heitman, UFG Kiel).

for certain techniques, tools, gestures or work sequences. These preferences can be brought to light and compared by compiling ideal production sequences for each analysed knapper. With these differences, it is easier to look for specific differences in the recorded flakes. Are the differences that we would expect from the production sequences visible on the recorded artefacts? Are there other differences which have not been predicted? And, most importantly: are the preferences of individual knappers strong enough to leave fingerprints in the inventories or is the forced adaption to the material enough to disguise individual lines of thought?

This thesis includes flaking products from five sickles and two daggers made by G. Nunn, A. Benke and P. Wiking (Table 5 and Fig. 5). G. Nunn and P. Wiking participated in experimental workshops at the Lejre Forsøgscenter in July 2006 and August 2007. G. Nunn kindly performed knappings in an additional experimental study a few weeks after the first Lejre workshop at the Moesgaard Museum in 2006, where the sickle inventory included in this thesis was made. Extensive documentation of the knapping events was done in written form, supplemented by photographs. Additionally, video documentation from 2007 exists, showing the production of a sickle by G. Nunn and a part of the production process by P. Wiking. In addition to the sickles, a type IC dagger made by G. Nunn was included in the analysis. Documentation of this was done by video recording (Nunn 2005). A. Benke participated in two experimental setups in July 2018 and 2021, when he manufactured a sickle and a dagger, respectively. Both setups were documented in written form and with photographs by the author among others. P. Wiking participated in an additional knapping session from June to July 2022, manufacturing a range of sickles and daggers, the latter left in a finished preform state or more in line with the Type IB percussion finished daggers (Lomborg 1973, 38), as no grinding and edge-to-edge flaking were done. Documentation was carried out according to the prior experiments although no inventory was included in the final analysis. The main goal of this last knapping session was to gain a personal impression and obtain experience of P. Wikings work, as he was the only knapper who had been analysed by photos and a very short video so far.

None of the flint knappers invited to the experimental sessions had prior experience with Bronze Age flint sickles from Denmark (cf. Eriksen 2018, 340). They were all provided with a template consisting of an archaeological artefact or a very close replica as well as a detailed description of the observed *chaîne opératoire* based on archaeological specimens. They were then asked to manufacture a replica as close as possible to the artefact. For G. Nunn, it was also his first time working with Scandinavian flint. Every knapper was allowed to use his personal toolkit to exclude influence on the knapping process caused by unfamiliar or unfitting tools. There were no further restrictions concerning positions, gestures or the implementation of tools, so each knapper could perform the task the way he preferred. The collection of flakes was done at the end, after an object was finished, except for the replication of the dagger in 2021, when the knapping products were collected during breaks in the production.

4.2.1 Greg Nunn

G. Nunn started flint knapping in 1986 and has since had a number of teachers. The most well-known teacher outside of the U.S. is probably E. Callahan, with whom he began studying edge-to-edge pressure flaking in 1991. This has become his speciality, but beside bifacial artefacts, he is also very skilled in blade production

(Nunn 2016; 2021). Since then, he has himself become the teacher of several other knappers, including P. Wiking.

The working kit used by G. Nunn differs according to the types of artefact he is manufacturing but also between the pieces he is working on. Here, I will present the overall choice of knapping devices and a short description of utilisation.

Hammerstones

Greg Nunn prefers to have a variety of different stones at hand, which he applies based on subjective choice. This choice is based on his notion if the stone is fit to accomplish the task he has set out to perform. Often, this is decided upon more due to the form of the stone rather than due to hardness or weight. Generally, G. Nunn seems to prefer softer sandstones. Direct percussion with stone is part of nearly the complete production process of a biface. Solely pressure flaking and final pressure retouch stages do not include any kind of direct percussion.

Antler billets

During bifacial reduction, G. Nunn uses a light and a heavy elk antler billet. The North American elk is not a moose, but a wapiti, and is closely related to European red deer. Thus, his elk antler billet is not comparable to a Scandinavian elk antler. Deer is significantly harder than elk, as the compact bone surrounding the spongier inner cancellous bone is thicker.

The choice to use the antler billet and which one to use is dependent on the situation and conditions of the material he is working on. The lighter billet is used more often in the later stages of production, when more care has to be spent on the applied force to prevent breakage of the piece. Billets are used throughout the production process except during decortication and the first rough out of the artefact.

Ishi-stick/Copper pressure flaker

Flaking with the Ishi-stick or copper tipped pressure flaker is applied surprisingly early. Already while working on the preform stages, G. Nunn applies the devices to prepare and adjust the edge. Depending on the force he needs and the outcome he intends, he chooses either the Ishi-stick or the shorter pressure flaker. Both implements are primary working devices during the pressure flaking and the final pressure retouch stages. The latter is most often done with the pressure flaker alone.

Other

Besides the already mentioned knapping instruments, other implements can be in use. One of them is an abrader, mostly a smaller sand stone. Quite frequently, abrasion is done directly with the hammerstone in use or even with the copper pressure flaker. Indirect percussion can be part of the production sequence, though more often during the production of daggers than during the manufacture of sickles. G. Nunn uses an elk antler tine as a punch and a baton of hard wood. Additionally, he likes to use a branch to secure the nodule against slipping down between the legs. The placement on a surface gives a form of anvil effect during knapping. This has the benefit that less force is needed for the blows and the piece is less likely to change position so more control of the location of the blow is achieved.

Individual production sequence

For an overview of the used tools per sequence, see Table 6 and Table 7.

Stage I – Acquiring raw material

During the experiments in Denmark, G. Nunn was presented with previously collected nodules from Hillerslev. He could then choose which nodule to work on. The included type IC dagger is made of Texas flint from Edwards Plateau.

Table 6 (top). Utilised knapping instruments per stage for dagger production sequences by G. Nunn. + indicates probable use without proof through documentation.

Table 7 (bottom). Utilised knapping instruments per stage for sickle production sequences by G. Nunn.

Stage II – Rough out

As mentioned above, G. Nunn prefers to use more soft sandstones and has a variety at hand from which he can choose, depending on the situation and purpose of the strike. Force during the strike is applied as it seems necessary, which can leave a wide array of characteristics in the knapping attributes. The nodule itself is

IC Dagger	Rough out	Primary preform	Secondary preform	Final preform	Pressure flaking	Final pressure retouch
Hard stone						
Soft stone	x	x	+	x		
Heavy antler billet		x	x			
Light antler billet			x			
Indirect percussion	x					
Abrader		x	x	x	x	x
Ishi-stick with copper		x	x		x	
Copper pressure flaker				x	x	x

Lejre 2007	Rough out	Primary preform	Secondary preform	Final preform	Pressure flaking	Final pressure retouch
Soft stone	x	x	x	x		
Heavy antler billet		x				
Light antler billet			x	x		
Abrader		x	x	x		x
Ishi-stick with copper				x		
Copper pressure flaker			x	x		x

often turned around and evaluated for the best possible next removal. The mental template of the finished product has to be kept in mind constantly and sometimes also adjusted according to material demands.

In contrast to the production of a sickle, G. Nunn prefers the use of indirect percussion during dagger production at the end of this stage. He does this to straighten the edge for the next stage and chooses the indirect technique, owing to the greater control it permits. Here he works the faces of the blank successively.

Stage III – Primary preform

In this stage, the abrader is quite frequently in use. To strengthen the margins and to reduce the ridges, the edge is constantly worked and the ridges on the faces of the piece are also occasionally worked. During the first phases of this stage, hammerstones are primarily in use. Work is done with more purpose here than in stage II, as forming and thinning of the piece is the aim, the latter though to a minor extent, as too early removals across the faces can lead to hinge and step fractures. Thinning flakes in this stage are generally done with a heavier stone and with more force behind the blow.

There is one typical move set for G. Nunn which is rarely used by the other knappers. For this, G. Nunn positions the piece standing on his thigh and strikes perpendicularly to the edge with a smaller stone. He uses this gesture to clear out concavities along the edge. In contrast, the relocation of the edge is done while supporting the piece lengthwise on the thigh and then 'tapping' the stone along the edge. Quite likely, it will not be possible to distinguish these knapping gestures in the knapping products. More likely, this would appear in spatial distributions of knapping areas, as the upright standing of the piece allows the flakes to fly farther away. However, an excavation would have to be very careful to recover these flakes, which are generally rather small.

Occasionally, the Ishi-stick with a copper tip is used in order to mainly straighten the edge and get it back onto the right plane. This is done by slight pressure on or by scraping the tip across the edge. During sickle production, the Ishi-stick is seldom in use. More often, the shorter pressure flaker is used and this even in later stages, although the transition is harder to draw here.

As the work progresses, the heavy antler billet starts to be applied. G. Nunn switches from stone to antler, as he changes the focus from form and edge to thinning. His impression is that he has more control over the blows with the antler billet (Nunn 2005). The flakes are now farther apart and more regularly spaced, while the strikes become more and more purposeful. This includes the preparation of isolated platforms to gain more control of the removal. With isolated platforms, the abrasion is applied below the edge, more on the face. Turning of the biface happens less often now, as work begins to focus on one face for a few strikes, before attention is shifted to another area.

Finishing this stage, the dagger made from Texas flint was heat treated, as the material is to tough to execute edge-to-edge flaking.

Stage IV – Secondary preform

A major focus has to be given to the edge in this stage. The success of the removal depends to a great extent on the careful preparation of the platforms. To prepare the edge and set off the platforms during dagger production, G. Nunn uses the Ishi-stick. He works with the copper-tipped pressure flaker on sickles. In some cases, problematic areas on the faces are also cleared by pressure flaking.

Abrasion is again mainly focused below the edge and onto the face. Often, the faces of the biface are somewhat grinded with the abrader, to reduce the ridges. The blows themselves are first dealt, when an isolated platform is satisfactory. The larger part of the flakes is removed by direct organic percussion with a heavy antler billet, but also light antler billets are used in this stage. Firstly, this is done to prevent the piece from breaking, as the lighter billet delivers less force to the material. Secondly, the lighter billet can be wielded with a higher velocity, which allows faster strikes.

A hammerstone is far less often used than in the previous stages. Direct hard percussion is often implemented when problems appear due to tough material or failed terminations. Again, G. Nunn assumes to gain more control over the strike, but this time by changing to the hammerstone (Nunn 2005).

Stage V – Final preform

The removal of flakes gets constantly slower and more deliberate. The aim is to finish the form of the piece as well as to get the faces as even as possible. Major work is again done on the margins. The edge receives lighter abrasion, while the faces are strongly abraded where the ridges meet. This is done to get more control over the extent of the intended flake.

The copper-tipped pressure flaker is used to work on the platforms. Beside removing overhangs with small pressure flakes, the tip is also used to scratch along the edge while preparing the platforms. The platforms are again prepared individually for every strike.

A soft hammerstone and a light antler billet are used, while problematic and tough areas are removed with the copper-tipped pressure flaker. This also helps to preserve the outline of the biface. Surprisingly, the Ishi-stick is sometimes in use while working on sickles.

Stage VI – Ground preform

To prevent damage to the joints, G. Nunn uses a device to grind the daggers. This is a construction of wood, on which the dagger is glued with beeswax. Especially for the type IC dagger this makes sense. Archaeological artefacts show that the grinding was done mostly in longitudinal direction (Nunn 2005; 2006, 109-113). If done without some kind of protection, this would lead to at least scraped fingers pretty fast. In contrast, the type IV daggers were ground almost perpendicularly to the midline and could be held at the handle (Callahan 2016, 83-102, fig. 6.6 and 6.7).

Even during the grinding, G. Nunn likes to arrange the work into stages. For his chapter in Apel and Knutsson (2006), he described the stages in detail (Nunn 2006, 98-100). The basic aim of this stage is to get a smooth and even surface without remaining negatives. As mentioned above, G. Nunn uses a sandstone slab to grind daggers.

Stage VII – Pressure flaking

Again, the edge is the most important part for successful removal, as pressure has to be applied directly on the edge. With the abrader, G. Nunn dulls the edge down until he has a ridge of 1-1.5 mm all around the biface. He then starts to remove narrow spaced, parallel running flakes from the tip to the base with a copper tipped pressure flaker. Eventually, the force applied with the pressure flaker is no longer sufficient and he changes to the Ishi-stick. The removal of flakes is done one face after the other.

Stage VIII – Final pressure retouch

This last stage is similar to the grinding stage; not much can be reported. With the pressure flaker, the last overhangs from the parallel flaking are removed, so that the outline and the edge become straightened and sharp. This is mostly done in a more scraping way than with real applied pressure. For the sickles, this stage is a bit more work as the surface is still percussion finished, which leaves more irregularities to modify.

Comparing the sequences

G. Nunn has a rather structured way of production, which is more or less the same regardless of the form of biface he is working on. The only real difference between working on a dagger and working on a sickle seems to be the implementation of indirect percussion. It could not be recorded during the experiments in Lejre. But then again, it is a technique that he rather rarely uses, even in dagger production.

Another difference between the production of a dagger and a sickle lies in the final preform, where sickles are worked with almost every possible knapping implement. However, this can also be due to the fact that just one dagger was recorded, while more sickles were recorded at least by photographs. The chance that some of the nodules exhibit greater problems during reduction was greater and thus more knapping devices could be included in the production sequence during problem solving. Furthermore, the dagger is made from a different material that is more familiar to G. Nunn than the sickles were, which also has influence on the decisions. Another problem is the splitting of stages only by looking at photographs or generally splitting the stages during a continuous workflow. Here, some knapping implements could have been assigned to the wrong stage in the sheet.

Larger differences can be seen in comparison to the ideal sequence. Copper tipped pressure flakers are used earlier than expected, while an antler pressure flaker is almost never in use. Quite surprising is also the use of copper during the production of sickles. As they are percussion finished, it was not expected to see the use of copper so often. We are still missing archaeologically valid evidence for the use of copper during bifacial production. It could be that this choice is influenced by the school of learning. American knappers work a lot with copper-tipped implements and it is often the fastest and easier solution to some problems. G. Nunn is always determined to work as closely to the archaeological record as possible, but still the default to copper pressure flakers could be a move not inherent in prehistoric work logic.

4.2.2 Andreas Benke

A. Benke is often praised as the best German flintknapper (Hein and Lund 2017, 178). His forte is the production of bifaces, in which he has thirty years of experience. Like the other knappers in this analysis, he had no experience with Bronze Age flint sickles from Scandinavia prior to the experimental setup in Schleswig in 2018. He stated that it is harder to work with new types, as no prior mental template is available and the process has to be learnt over the course of working. The same also holds true when switching from the manufacture of one artefact type to another. It takes time to get used to already familiar templates again. This process of familiarisation with the type will quite likely not be visible on the produced artefacts or corresponding waste products, but will have influence on the observed variations of production.

For the manufacturing of the Bronze Age sickle, A. Benke had a template replica sickle made by P. Wiking at hand for comparison, which was reconstructed based on an archaeological specimen. The template for the production of a type IC dagger was, by A. Benke's own statement, G. Nunn's video, which he used to learn how to produce this artefact type. A. Benke then adapted the working procedures and optimised some operations, which he found to be inconvenient for his way of working.

Hammerstone

Unlike G. Nunn, A. Benke used just one stone during both experimental settings. They were not the same, but similar and probably quartzite, which is more in line with a hard stone.

Antler billets

A. Benke used different moose antler billets during the sessions, but only one per session. Both resembled each other. The billets were slightly heavier than the stone, and more in transition between a heavy and a light antler billet. He prefers to work with the billet rather than with the hammerstone.

Ishi-stick/Copper pressure flaker

During the production of the sickle in 2018, only the Ishi-stick was used. During the replication of the dagger, the majority of work was also done with the stick. Solely the retouch of the edges and the final pressure flaking of the faces were done with pressure flakers. Unlike the other knappers, he had two different flakers, one with a rather stout and broad tip and another with a fine and delicate tip. The latter was primarily in use during the parallel pressure flaking of the dagger.

Other

Indirect percussion was used during the production of the dagger but not the sickle. In contrast to the other knappers, different punches were used. First and mostly applied was a copper punch in combination with the same antler billet used for direct percussion. A few strikes were also done with a wooden baton. The baton was also used for a few strikes with an antler punch.

A last piece in the tool kit for the sickle was a pumice stone abrader. During the production of the dagger, abrasion, when done, was mostly performed with the same stone used for percussion or directly with the knapping device in the hand. Before and during the pressure flaking, A. Benke used a fragment of an old grinding disk as an abrader (cf. stage VI below).

Individual working sequence

In comparison to G. Nunn, A. Benke used a rather restricted tool kit. An overview of implements used per stage is given in Table 8 and Table 9.

Schleswig 2021	Rough out	Primary preform	Secondary preform	Final preform	Pressure flaking	Final pressure retouch
Hard stone		x	+			
Heavy antler billet	x	x	x	x		
Indirect percussion:	x	x	x			
with antler punch		x				
with copper punch	x	x	x			
with wooden batton	x	x				
with antler batton		x	x			
Abrader			x		x	
Ishi-stick with copper		x	x	x	x	x
Copper pressure flaker					x	x

Schleswig 2018	Rough out	Primary preform	Secondary preform	Final preform	Pressure flaking	Final pressure retouch
Hard stone	x					
Light antler billet	x	x	x	x		
Abrader	x	x	x	x		x
Ishi-stick with copper			x	x		x

Table 8 (top). Utilised knapping instruments per stage for dagger production sequences by A. Benke. A plus (+) indicates probable use without proof through documentation.

Table 9 (bottom). Utilised knapping instruments per stage for sickle production sequences by A. Benke.

Stage I – Raw Material

A. Benke was also presented with nodules from Hillerslev, which he could choose from. Deliberately, he did not choose the best for the sickle and continued to work on the chosen nodule, despite the later appearance of internal problems. For the dagger, he chose a nodule which best fitted the shape of the aimed product. The favoured piece had a more even surface than some of the others and A. Benke had the feeling it would not have a too thick cortex. However, on this nodule, problems appeared during work, but they did not lead to a rejection of the piece.

Stage II – Rough out

Counter-intuitively, A. Benke dealt a few strikes with the hammerstone and then chose to work with the antler billet during decortication of the sickle. When asked about the change of implement, he stated that he does not see a major difference between the techniques. The same was true for the production of the dagger, which he started directly with the antler billet. In the course of his work, one or two strikes were dealt with the hammerstone, which then was discarded but for occasional abrading of the edges. Quite obviously, he prefers to work with the billet.

The abrader is also in use in this stage, but more during the production of the sickle than the dagger. In contrast to G. Nunn, the abrader is not used on the faces of the biface to level out prior ridges. A. Benke concentrates more on the part he is currently working on and tends not to prepare the complete edge beforehand (except for the preparation before grinding and pressure flaking). A lot of preparation is done with the knapping device in use and thus often performed in a tapping way along the edge. Often the billet is used to scratch along the edges, like it would have been done with an abrader, similar to the scratching with a copper tipped pressure flaker.

During the production of the dagger, copper as a working tool is implemented surprisingly early in the form of a copper punch and the antler billet as a baton. He stated that all the work he had done with the copper punch could also have been done with an antler punch, which he also used a few times, but that the angles had not been ideal to work on and he had had more control using copper than antler. The downside of using a copper punch is that deeper bulb negatives will be left on the piece and the faces have to be levelled out more. The choice of applying the wooden baton or using the antler billet as a baton seems to be linked to how much force A. Benke thinks he needs. The wooden baton is heavier than the antler billet, but it is most often applied with less force. Work continued with a constant switching between direct and indirect percussion.

Similar to G. Nunn, A. Benke used a wooden pedestal for support during indirect percussion in this stage, as the nodule is still quite big and cannot be supported well with his legs alone. The one used here is bigger and stouter than G. Nunn's branch.

He chooses to work with indirect technique, as it is easier to establish an edge with a good angle than it would be with direct percussion and uses it further, when he thinks he needs the extra security to not end up with failed terminations. The work done with indirect percussion is concentrated on the edges and just very few strikes reach farther on to the faces. In some cases, indirect percussion is used to remove failed terminations. For this, the punch is placed on the step left on the face and the blow is dealt parallel to the face.

Stage III – Primary preform

Due to the unfamiliar artefact type in 2018, A. Benke often compared his work to the template sickle. He also stated that he tends to make the artefacts too wide, when not familiar with the form. From the start, thinning was also part of this stage, which leads to correction of the width by working more shorter flakes around the edges. He continued to work with the antler billet to obtain the rough form.

For the dagger, the main goal should also be the outline of the piece. Due to the demands of the chosen nodule, a clear separate working structure according to the stages could not be established. Contrasting to G. Nunn's work, the dagger was not in constant rotation. A. Benke focused more on one side and the edge. This is quite probably due to the problematic chalk-filled indentation, which was deeper than anticipated and hindered the progression of the work that A. Benke had planned. In addition to the antler billet, the Ishi-stick and the copper punch were in frequent use.

As the chalk indentation left little room for mistakes, A. Benke worked very considerately and slowly. Often, he chose not to remove raised parts on the faces as not to chance the work so far. The chalk made the progression of energy through the piece difficult to predict and force applied to the wrong part of the edge could have led to breakage of the piece. Due to this, more heightened areas were already left standing in this stage and were to be dealt with during grinding.

In general, A. Benke seems to work in a more continuous way than G. Nunn. He works in smaller, more interlinking steps, focusing more on problems at hand than persisting on the overall goal. Due to this, it becomes hard to separate stages, as some working steps are done when the opportunity arises. In contrast, A. Benke becomes distracted by problematic zones, as happened with the dagger. The deep chalk-filled indentation on one face hindered the progression of decortication and the establishment of a clear outline. It likewise had consequences for the length of the piece, as the mid-axis of the dagger had to be reoriented and could no longer pass through the longest part of the nodule, a decision with which A. Benke was dissatisfied and only made reluctantly.

Stage IV – Secondary preform

While working on the sickle, forming and thinning were continued and changed in between as deemed necessary or appropriate. The Ishi-stick was applied in this stage and used for the preparation of the edge prior to the strikes as well as adjustment of the edge angle. Direct soft percussion and abrasion of the edges were also applied.

As mentioned above, the work on the dagger was not as structured, which made it hard to separate the stages. At this stage in production, nearly all tools were in use, as seen appropriate. At one point during the work, A. Benke took a mental step back and assessed the work so far. His conclusion here was that he had concentrated too much on the problematic areas and had to start concentrating more on the overarching aim. The outline of the piece started to be worked out more clearly and his handling of the biface changed. The artefact was rotated more during work, as more goals were pursued from different angles. Beyond thinning of the piece and working on the outline, work on the centre plane became more important now. At this point, vibrations through the piece could lead to breakage, so A. Benke worked solely from the tip to the base and supported the dagger with his body.

Stage V – Final preform

In this stage, A. Benke focused on forming both the sickle and the dagger. For the sickle, this meant he had to primarily reduce the width of the piece. Work on the dagger was mainly concerned with finishing the outline and adjusting the edge onto the centre plane as well as removing overhangs along the edge, so that they would not chip during grinding. Most work was done with the Ishi-stick, but the antler billet was also used.

Stage VI – Ground preform

Due to the restricted time available for the production of the dagger, it was refrained from grinding the piece in an authentic and traditional way on sandstone slabs. Instead, A. Benke brought silicium-carbid discs with which he had made good experiences. The discs remove a lot more material than sandstone slabs would do and by this they reduce the time needed for grinding. On the down side, one has to pay more attention to the process, as it is far more likely to remove too much material or start grinding facets into the faces. The grinding of both faces was finished in about four hours and fifteen minutes, split over two days.

To reduce the workload on A. Benke, a student assistant and the author took turns in grinding the dagger, too. Thereby, we also demonstrated that it is not necessary to have prior knowledge or experience to grind an artefact in a satisfactory way. A short introduction about how to handle the piece was sufficient advice. It also helped that A. Benke had a close eye on the work and could intervene before errors were ingrained.

Stage VII – Pressure flaking

As with the previous stage, this one solely concerns the dagger. In the first step, the edge was prepared for the parallel retouch. A. Benke chose to work with the pressure flaker with the delicate tip. While the blade part of the dagger was prepared on the face from which the pressure would be applied, the handle part was prepared in a zigzagging way onto both faces.

Like G. Nunn, A. Benke begins parallel flaking from the tip. The first three to four flakes were removed with the stouter pressure flaker, before switching to the Ishi-stick. The second face was done completely with the Ishi-stick. The removal of overhangs was done with the copper tip, but occasionally he abraded a short stretch of the edge with a broken bit of a silicium-carbid disc. Unlike G. Nunn, he did not abrade the entire edge extensively beforehand and, due to the material of his abrader, he mostly made just one or two strokes along the edge in the area he was currently working on.

As the beginning of the parallel flaking did not work out as expected, A. Benke refrained from working an edge-to-edge parallel retouch and settled for a half parallel retouch. During the flaking, he frequently sharpened the tips of the pressure flakers to keep them pointed.

Stage VIII – Final pressure retouch

Lastly, finishing is again a necessary step on both bifacial artefact types. The cutting edge as well as the back of the sickle has to be straightened and sharpened or, in case of the back, slightly dulled. Most work was again done with the Ishi-stick, but in some cases, especially along the back, the antler billet was applied.

Straightening and sharpening of the edge for the dagger was solely done with the fine tipped pressure flaker. Again, in this stage, the piece was in constant rotation, not just switching work from one face to the other, but also changing the direction of work. Still, A. Benke worked from tip to base on the piece, but the orientation of the artefact in his hand was changed constantly.

Comparing sequences

A. Benke shows a simpler, less complex working structure, not just in contrast to the ideal sequence, but especially in comparison to G. Nunn, which is striking. In no way is A. Benke's work less good or less thoughtful, but it resembles more of an intuitive approach to the material than G. Nunn's approach. While the latter has a quite structured approach, where every stage has a different goal, A. Benke has a more fluent work style.

Quite surprising was the early abandonment of the hammerstone in favour of the antler billet, as well as the early implementation of the copper-tipped Ishi-stick. Especially the first choice should result in different knapping attributes in the inventory, which could be a way to separate A. Benke from other knappers with different approaches. Due to the restricted tool kit, one could argue for a less wide variability of knapping attributes in general. Especially the attributes for hard direct percussion should be less marked in A. Benke's inventories. But, as G. Nunn works with softer stones and A. Benke with a heavy antler billet, the overlap in attributes for soft stone percussion and direct organic percussion could obscure the picture and blur the differences between the two knappers.

4.2.3 Peter Wiking

P. Wiking is a Swedish flint knapper, who has been working with flint since 1997. He has been schooled in blade and axe production by Thorbjørn Petersen and Dan Kärrefors and works mainly with indirect technique. He is self-taught in bifacial production. In addition to observing G. Nunn during the Lejre experiments in 2006, he visited G. Nunn in the United States in between the Lejre setups, where he attended a flint knapping class, which was held by G. Nunn. At the same time, he also spent some days with E. Callahan. A unique situation for the analysis of knowledge transfer arises by including sickles made by P. Wiking and G. Nunn from before and after the visit. If it is possible to detect influences of knowledge transmission in flake assemblages, this would show here. Both P. Wiking and G. Nunn described their interaction during knapping as being more observational. There were no long discussions included, and mostly the exchange of information was done by watching closely what the other knapper was doing. However, a more verbal setting was present during the flint knapping course, during which G. Nunn taught the craft to a variety of knappers, among them P. Wiking. The 'teaching environment' encountered in the situation here is a very visually based one with less focus on verbal transmission. This undermines the assumption that complex lithic technologies need verbal instructions to be transmitted (see Subchapter 3.1.2), but underlines the suggestion by J. Apel (2001) that the knowledge of bifacial dagger production had to be guarded, as close observation would have made it possible to decipher the production steps by everyone with the basic knowledge in flint knapping.

P. Wiking was also presented with flint from Hillerslev and an archaeological sickle, which he was asked to copy at Lejre. In 2022 in Schleswig, the setting was similar but no artefact type was predefined, so a range of sickles and daggers emerged.

Hammerstones

The hammerstones used by P. Wiking are all quite big and heavy in contrast to G. Nunn's and A. Benke's hammerstones. Like G. Nunn, P. Wiking has a wide variety at hand but seems to prefer round heavy stones. Due to the weight of the hammerstones alone, the attributes left by his strikes should look more like direct hard percussion than in the inventories by the other knappers.

Antler billets

P. Wiking also works with a wide variety of moose antler billets. They differ not only in weight but also in form. It seems that he prefers to work with the heavier billets. The smaller, lighter billets are mostly used near the finishing stages for precisely aimed flakes.

Ishi-stick/Copper pressure flaker

Again, and in contrast to both G. Nunn and A. Benke, P. Wiking owns a wider range of copper tipped working instruments. He uses pressure flakers with a handle which are a bit longer than expected. Furthermore, they differ in thickness. These differences will probably not show on the artefacts and more likely differ in handling and grip, which would be used according to the subjective choice of needed features of the knapping implement.

However, the Ishi-stick is shorter than those used by G. Nunn and A. Benke, which would suggest that less energy can be transferred to the stone in work. This could probably be due to the fact that P. Wiking is taller and leaner than the other two. This would change the leverage that he can use and thus he could still apply the same energy with a shorter rod.

In general, he does not like to use copper if he can avoid it. During the experiments in 2022, all work was done with stone or antler. Where the other two knappers default to copper when tough problems hamper the progression of work, P. Wiking mostly leaves the immediate problematic zone and works back towards it to get a better position to remove the problem. He is likewise not fond of the finishing retouch done with copper, because it leaves deeper bulb negatives than antler and by this needs more work to get a straight and sharp edge. This is a real case of personal preference, as A. Benke, for example, also notes that the downside of copper are the deeper bulb negatives, but for him the positive effects of utilising copper for flint production outweighs this negative trait. Perhaps it is also a case of training and experience. As P. Wiking works less with copper, his experience to deal with the deeper negatives are more restricted than those of the other two knappers, who have learnt to work around or even prevent the unwanted deep negatives.

Other

P. Wiking often uses indirect percussion with an antler punch and a wooden mallet. While the punches differ, the mallet stays the same.[9] Indirect technique was mainly applied in 2006. In 2007, the documentation shows that the technique was only included during the production of one sickle to remove a tough inclusion (the second piece from 2007, nodule 32). This absence is probably a bias in the documentation. In 2022, he frequently used indirect technique and from early on in the production process for different reasons. He stated that his excessive use of indirect technique could be due to primarily working with axe and blade production.

During the Lejre experiments, an antler tine pressure flaker was in use. In 2022, all pressure flaking was done with antler. Here it was a very short staff, not longer than his hand, with two antler tip endings. One was pointed on a square base, the other one was more rounded.

Individual working sequence

An overview of applied knapping implements per stage is provided in Table 10 and Table 11.

9 However, he had a new one in 2022 as opposed to 2006.

Stage I – Raw material

Like the other two knappers, P. Wiking had the choice between different nodules of Hillerslev flint. For him, this was also unfamiliar material in 2006. According to his own statement, the material was still unfamiliar in 2022, but in a different way. He knew what to expect from the material, but knew also that he would have difficulties, as it reacts very different than flint from Sweden, which he mostly works with. He said that he has the impression of working with heat treated flint when using material from Hillerslev, as it is much more brittle than his usual material and is more like working with obsidian. Due to this, he chose a nodule of a more doubtful quality and started a warm up piece, which ended up being a bifacial point.

Stage II – Rough out

Similar to A. Benke, P. Wiking already changes from hammerstone to antler billet in this stage. In contrast to the former, he changes back and forth between the implements regularly and continues using stone hammers throughout production just changing the size and weight of the stone in use. Surprisingly, indirect technique is applied by P. Wiking already during the decortication. Nearly every piece was also worked with indirect technique. In 2007, only one sickle could

Table 10 (top). Utilised knapping instruments per stage for sickle production sequences by P. Wiking. A plus (+) indicates probable use without proof through documentation. A star (*) denotes techniques used in 2006 with no proof in 2007.

Table 11 (bottom). Utilised knapping instruments per stage for biface production sequences by P. Wiking in 2022.

Lejre	Rough out	Primary preform	Secondary preform	Final preform	Final pressure retouch
Soft stone	x	x	x	x	
Heavy antler billet	x	x	x		
Light antler billet		x	x	x	
Indirect percussion	*	*	*		
Abrader	+	x	x	x	
Ishi-stick with copper				x	x
Copper pressure flaker				x	x

Schleswig 2022	Rough out	Primary preform	Secondary preform	Final preform
Soft stone	x	x	x	x
Heavy antler billet	x	x	x	
Light antler billet		x	x	x
Indirect percussion	x	x	x	x
Abrader	x	x	x	x
Antler pressure flaker				x

confirm use of the technique by photograph, but just in the picture with the overview of used instruments. No photographic evidence is present for the stage or the time that indirect technique was applied in this case, but the written note by B. V. Eriksen states the cause why it was applied (see above). As the knappers were asked to bring their own equipment and work in their own fashion, the missing evidence for indirect technique in 2007 seems more reasonably to be a bias in the documentation. There is the possibility that the change in applied techniques in 2007 could be the cause of the contact to G. Nunn. This should then be traceable in the inventories and set the one from 2007 apart from the inventory from 2006. There could also be a bias pointing back to the instructions given prior to the knapping sessions. Every knapper was also provided with a production sequence of Bronze Age flint sickles. Furthermore, P. Wiking was not the only one knapping and he had the opportunity to get a closer look at how other knappers worked, who had more experience in bifacial production. This could have influenced P. Wiking to deviate from his working routine and would explain, why so little indirect technique is documented and why copper tipped pressure flaking was frequent. Documentation from 2007 illustrates that P. Wiking starts out with a smaller stone to set the edge and continues then with a heavier stone or an antler billet to work across the faces. The piece is turned around constantly and evaluated for the progression of work (Løvschal 2007). In 2022, the sequence did not change, but he mostly started out with the heaviest stone available and kept using heavy stones far into the production.

Stage III – Primary Preform

As already mentioned, the stages III-IV cannot be easily distinguished from the photographs. Although through the documentation, some of the lines can be followed through. It also became quite clear in 2022 that P. Wiking is a continuous worker, not so much concerned and restricted to stages, which he himself confirmed. While he works on different aims in sections, there is no clear separation between these sections. Like A. Benke, he works on an aim which is achievable at the moment or has highest priority in order to smoothen the process. While A. Benke seems more to follow the possibilities that the material offers, P. Wiking pursues paths which will take him to the final product with the least time invested. This implies that P. Wiking invests more labour into the preparation of strikes than A. Benke. Moreover, P. Wiking seems to follow a broader decision process. During his work, the piece is constantly rotated and evaluated, before he decides on the next step. While A. Benke seems to focus more on tasks at hand, P. Wiking looks from a higher perspective and evaluates the next step in the context of the further development. This has also been stated for the Lejre experiments, where it was noted that he plans more steps ahead of the immediate task (Løvschal 2007). During the production, this decision process can seem a bit hectic, as P. Wiking often seems to change his mind and start preparation anew, reorienting the piece or chosing another hammer, sometimes also changing all of it, before removing the next flake.

The work is continued with heavy antler billets and hammerstones, depending on the quality of the raw material, either the stone or the antler prevails, but predominantly organic direct percussion is implemented. Indirect technique is used mostly for the preservation and adjustment of the edges and to solve problematic areas. Abrasion is done heavily and, in some cases, also across the faces. Primarily, the preparation is restricted to the edges and done with hard hammer percussion. In light tapping movements, material is removed from the edge with the stone, then abraded before the antler billet is applied. Quite often, P. Wiking positions the piece upright on his thigh and conducts knapping perpendicularly to the edge before abrasion, like already seen by G. Nunn. It cannot be said whether P. Wiking did this already in 2006 or whether he copied the procedure from G. Nunn. Often, abrasion is done directly with the hammerstone or antler billet that he is working with.

Stage IV – Secondary Preform

In this stage, mainly the handling of the artefact changes. Instead of turning it up and down constantly, now the focus stays more on one side at a time. If it has not happened earlier, the last areas of remaining cortex have to be removed now and the outline has to be narrowed down. A major focus is again laid on the edge, which is prepared meticulously, so that flakes can be removed, which extend far across the faces. Direct hard and soft technique as well as indirect technique are applied as needed.

Stage V – Final Preform

During this stage in 2006 and 2007, pressure flakers are primarily used and occasionally light antler billets or light hammerstones are applied by P. Wiking. In 2022, pressure technique was solely used for the final retouch.

Stage VIII – Final pressure retouch

During the Lejre experiments, P. Wiking worked with the copper tipped pressure flaker in this stage to centre and sharpen the edge, like the other knappers. As mentioned above, he is not fond of using copper and did not apply it in 2022. But again, this stage was seldom reached during the experiments in Schleswig. Two daggers broke due to inclusions, one had to be left unfinished as an inclusion in the edge prevented further work. One dagger was percussion finished and the edges of the last dagger were retouched as a preparation before grinding. The sickles were the only artefacts in this session to receive a true final pressure retouch, done with an antler pressure flaker.

Comparing sequences

Like A. Benke, P. Wiking also works in a less overarching structured way than G. Nunn and concentrates on smaller steps along the way. In contrast, he seems to think more problem oriented, as he plans ahead for removals that might fail or already thinks about the next best way to continue during the preparation of the removal.

Surprising was the extensive application of indirect technique, which quite likely can be explained by the different backgrounds and specialisations. Indirect technique has been discussed for sickle or dagger production in the Late Neolithic and the Early Bronze Age. Considering P. Wiking's own reflection about using so much indirect technique in comparison to the other knappers, and due to his background in the production of four-sided axes and blades, it should at least be assumed that the knowledge was already present in the Late Neolithic. It could be that this is one of the techniques which was forgotten or discarded quite early, as it is not a strict necessity for bifacial production. By having inventories with the application of this technique, the distribution of attributes can be compared more easily to archaeological inventories and a more reliable statement about the involvement of indirect technique can be provided.

4.3 Observed differences from documentation

While going through the documentation in written, photographed and filmed form, differences in the handling of the artefacts and tools were easily recognisable. It also became quite clear that some differences are negligible for the outcome of attributes but still contribute to the personal signature of the knapper. Four gradations of difference were assigned (see also Hinrichs in prep.).

No differences in the choice of technique is quite self-explanatory. A good example is the final pressure retouch (see Fig. 6). No difference means that not only the same tools were used but also that the handling of the artefact is the same during the work process. This implies that no differences should be detectable on the artefacts and flaking products. The attributes should show the same characteristics between the knappers and the produced artefacts. Variation is nevertheless possible, as knapping characteristics are not exclusive between knapping implements, but can also differ while using the same tool or material (see Subchapter 3.2). In general, the differences should be less pronounced when working with the same technique and tool material. Additionally, the transition between stages can sometimes be hard to draw, depending on the mental template and mode of action chosen by the knapper. Furthermore, requirements of the raw material can prescribe the course of action and obscure transitions between stages. This can make it difficult to decide whether the knappers are truly using the same tools for the same work.

Beside the final pressure retouch, parallel flaking and thinning stages of the biface also tend to be executed in a similar manner (Fig. 7). Here, especially G. Nunn and A. Benke use the same ways of operating, if not always with the same tools, which we will come to later. Generally, most of the stages are worked with antler billets by all three knappers so the basic signature of the attributes should show soft percussion for all craftsmen.

A use of **different techniques** is a more rarely seen occasion (Fig. 8). A. Benke uses stone hammers only when encountering tough spots, but in the majority of cases, he uses pressure technique with copper tips to solve problems. P. Wiking and G. Nunn also use pressure technique to handle problematic zones, but less often than A. Benke, while they work more with the hammerstone. During work steps, which include pressure technique, differences also arise as P. Wiking is not fond of using copper pressure flakers and beyond that he applies pressure technique a lot less often than the other two. Despite this, no major differences are expected to be seen between the knappers, as P. Wiking used copper tipped pressure flakes during the Lejre experiments, from which the recorded inventories stem. A possible difference could be less indication of pressure technique in P. Wikings inventories, keeping in mind that he does not feel comfortable in using the technique.

Another example is the implementation of indirect technique to carve out the edge, remove faults in the material or to correct knapping accidents on the surface. G. Nunn rarely uses indirect technique at all, in contrast to the other two knappers, who nonetheless also differ from another. While A. Benke uses indirect technique when he wants to progress carefully and with more control, P. Wiking simply prefers to use indirect technique. A special difference found on a single occasion is the indirect technique used by P. Wiking for the finishing of the edge.

Figure 6. Example of no differences in work. Left: A. Benke 2021 (Photo: M. Hinrichs); middle: G. Nunn 2005 (Screenshot, cf. Nunn 2005); right: P. Wiking 2006 (Photo: B.V. Eriksen).

Figure 7. Organic direct percussion during decortication. Left: A. Benke 2018 (Photo: M. Hinrichs); right: G. Nunn 2005 (Screenshot, cf. Nunn 2005).

Figure 8. Different techniques during straightening of the edge. Left: P. Wiking 2022, indirect technique (Photo: M. Hinrichs); middle: G. Nunn 2007, direct hard percussion (Photo: M. Løvschal); right: A. Benke 2018, pressure technique (Photo: M. Hinrichs).

Differences should be detectable in the analysis, especially when the production steps can be compared to one another, as there is a higher possibility to leave truly differing attributes when the technique in the steps varies.

Different tools represent more of a subcategory of different techniques, at least in the first case presented here. The knappers use different tool materials during the same stage and/or work, although the general technique stays the same (Fig. 9). The handling of the artefact is also mostly identical. The most striking difference can be seen when comparing A. Benke to the other two knappers. While G. Nunn and P. Wiking start out with direct hard percussion and continue to use the hammerstone throughout production, Andreas Benke rarely touches his hammerstone. His preferred tool is the antler billet, the hammerstone is solely used where difficulties in the raw material arise.

Figure 9. Left: direct percussion with stone by P. Wiking 2022; right: direct organic percussion by A. Benke 2018 (Photos: M. Hinrichs).

Figure 10. Indirect technique by A. Benke 2021 (Photos: M. Hinrichs). Lower right: for comparison, the indirect technique by P. Wiking 2006 (Photo: B.V. Eriksen).

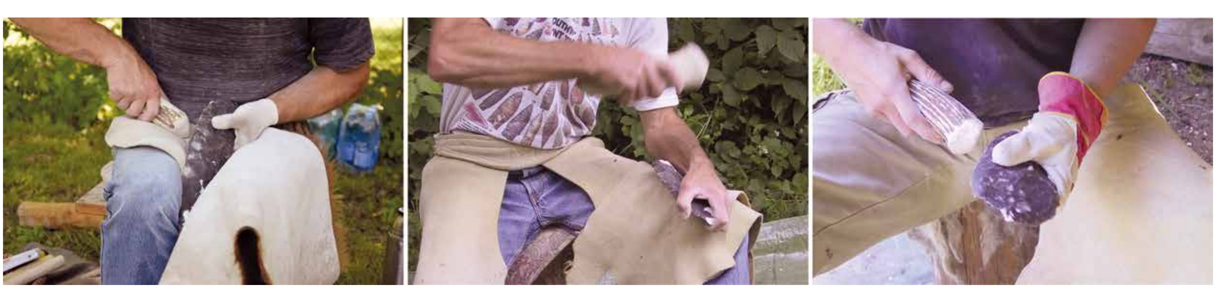


Figure 11. Examples of different holding positions during production. Left: A. Benke 2021 (Photo: M. Hinrichs); middle: G. Nunn 2006 (Photo: B.V. Eriksen); right: P. Wiking 2006 (Photo: B.V. Eriksen).

In addition, indirect technique offers the possibility to choose different intermediate punches, as well as the mallet, to deliver the blow (Fig. 10). A. Benke operates differently than G. Nunn and P. Wiking at least during the production of the dagger. While the latter two stick to antler punches and wooden mallets, A. Benke skips back and forth between antler and copper punches as well as wooden and antler mallets. While the difference between antler and copper punch should be detectable in the attributes, it is not possible to say for sure, if the use of different materials for the mallet leaves traces.

Knapping attributes have a high potential of diverging from one another in this category. If we recall (Subchapter 3.2.2), direct hard percussion tends to leave more marked attributes than direct soft percussion. But the transition is fluid, obscured by the hardness or softness of the chosen material as well as the applied force by the knapper. Indirect percussion is mostly recognised by very small platform remnants, thinner flakes and the harder the material, the smaller the attributes. Experimental evaluation of attributes is often based on blade or simple flake production, which has a totally different aim than biface production (*e.g.* Pelegrin 2000; 2006; Méry *et al.* 2007; Dibble and Rezek 2009; Van Peer 2021; Li *et al.* 2022a). There is no basis for a comparison of flake attributes from direct and indirect percussion based on metrics. Nonetheless, here lies another potential for the recognition of differences between knappers and their individual preference for specific techniques.

In general, keeping the differences that have been compiled so far clear from each other is no easy task and is probably hard to achieve without being able to reconstruct the production sequence. Deciding if only the tool material differed or the technique in general cannot be based on flake attributes alone. Refits would be a major help to identify the differences, since the decision to use one tool or technique is not a general one made by the knapper, but can be a case to case decision.

The last and quite ephemeral difference is **different gestures**. Here, the choice of technique, tool and work is the same but the holding position of the artefact being worked on is different (Fig. 11). The difference is striking between P. Wiking and the other two knappers. While A. Benke and G. Nunn mostly handle the artefacts in a similar way, P. Wiking has a surprisingly loose grip on the artefact. This is most noteworthy as bifaces are prone to break due to shock caused by the blows. This is why, according to G. Nunn and A. Benke, the piece always has to be supported with the body, so that the force of the blow has a way to leave the body of the artefact (see also Hein and Lund 2017, 194; Whittaker 1994, 185; contrary: Waldorf 1993, 37-39). P. Wiking seems to have no problem when knapping sickles or daggers while just supporting them with the hand and states that he has more sense and control of what he is doing by knapping in a rather unsupported way. The further benefit of the free hand technique is the ability to work with more force. Beside this, the force can spread wider across the face and remove bigger flakes, which are still thinner, than comparable flakes removed while supported during the strike. P. Wiking thinks that the notion of needing the support of the leg during reduction is a genuine idea from the American knapping tradition. Furthermore, he has seen E. Callahan and G. Nunn work free-handed, too. During the sickle experiments in Lejre, G. Nunn can be seen to knap while supporting the artefact free-handed. In contrast to P. Wiking, his hold is still firmer. While P. Wiking is working free-handed, he supports his underarm on the leg, which results in a lot of movement of the artefact during the strikes, depending on applied force. G. Nunn, in contrast, supports his wrist on the leg and by this, the artefact is in a seemingly more secure position against movement. Generally, G. Nunn seems also to use less force for the strikes than P. Wiking.

Gestures and handling are a quite promising factor for a distinction of the learning traditions. Unfortunately, it is nearly impossible to reconstruct these steps from the knapping products, although a promising study has been published recently by Li *et al.* (2022b).

4.4 Observed differences on knapping products

Quite early on during the recording of the material, it became obvious that subtle differences are present in the flake inventories, which are not entirely dependent on the choice of the knapping tool. On a subjective basis, it was possible to recognise which knapper's inventory was being recorded. The varying choices were best observed on the platform remnant preparation and form.

This is not an observation which can be made solely on a few pieces, but requires a greater number of artefacts. At this point now, it is also not clear if a 'by sight' recognition of knappers would be possible in the archaeological record. These inventories are fragmentary and mixed, not only due to the preservational conditions but also due to the handling before discard. While the artefact in production was needed, the remaining flakes were not and would have been handled with lesser care. Some pieces might have been brought to further use, but collectively they would have been considered waste and dumped accordingly or left scattered. Generally, the archaeological inventory does not consist of the waste solely made by one person at one time, but is a conglomerate of different workers over time. It is thus hard to determine how many knappers are present in one inventory or even in one waste pit. Often, it is also difficult to decide if the production of a certain tool is present at a site and if it is, which knapping products belong to it and which do not. Again, the mass of flakes can help to unveil recurring patterns, but probably the 'aha-effect' of recognising the knapper straight away will not happen during recording of archaeological knapping products. The greatest chance of recognition would be if some kind of working tradition existed, in which many craftspeople repeatedly worked in the same fashion, leaving strong markers on every production sequence.

It seems likely that the differences on the platform remnants have less to do with the choice of the knapping tool, and considerably more with the mental template and personal ways of operating (see also Driscoll and García-Rojas 2014, 139). As such differences are minor, they are probably obscured in the statistical analysis of the recorded attributes. One of the bigger problems in lithic technology analysis is the fact that varying tools and techniques can leave quite similar attributes and vice versa (see Subchapter 3.2.2). The way of applying a tool during production has great influence on the outcome of attributes. As the recording for the statistical analysis uses categories, which cannot describe all observed differences and are necessarily chosen to be simple, the analysis will miss a lot of subtle differences. Therefore, a twofold way is chosen here. The first step was an evaluation of the observed differences through a thorough description of the individual knapper's production sequence. In the next step, the differences will be used for the statistical analysis to explain emerging patterns and evaluate the reasonability.

One early and easily recognised trademark of G. Nunn is the roof-shaped platform remnant (Fig. 12). During the recording of the sickle by A. Benke, this category was added, as it became obvious that this kind of platform was not acci-

Figure 12. Comparison of typical roof-shaped platform remnants on smaller flakes by A. Benke, P. Wiking and G. Nunn (left to right). More marked remnants were encountered for each knapper, but for the illustration, flakes with more average markedness were chosen (Photo: A. Heitman, UFG Kiel).

dentally created, but was rather a recurring form of preparation (after 756 recorded flakes). In the statistical analysis, the number of roof-shaped platform remnants in A. Benke's sickle inventory is therefore certainly missing a few pieces.

In G. Nunn's inventories, the roof is most often formed by two or more larger facets and has a distinct peak, which makes it easy to hit on spot. In the dagger inventory, the platforms usually have an oval shape but other shapes occurred, too, as depicted in figure 12. Other shapes were encountered more often on flakes from sickle production, but the oval still prevailed. As the prevalent feature of the attribute was chosen for entry during recording, here the roof-shape above the outline of the platform, no total numbers can be compared and no statement of the significance can be made. In contrast to G. Nunn, A. Benke's roof shaped platforms appear almost incidentally. Mostly, they are formed by two facets, but the ridge is so shallow between them that the possibility is higher for him just to have chosen a spot on the edge, where two previous negatives meet. Nonetheless, he hits the ridge precisely in most of the cases. The shape of the platform varies, but a great part does have an oval shape.

In addition, P. Wiking's inventories show a lot of roof-shaped remnants though in lesser markedness, more like A. Benke. The peak is often not as deliberately created and a lot lower than those by G. Nunn. Moreover, the blows do not frequently hit directly on the ridge but slightly off. In many cases, the roof-shape seems more like a coincidence, left by earlier removals or preparations. The outlines of the platforms are more often not oval when compared to those in G. Nunn's inventories, but again, no total number can be provided for this observation. An explanation for the seeming lack of coordination could be the different way of handling the artefact during work. While G. Nunn and A. Benke support the biface during the blows, P. Wiking has a more unsupported grip (see Fig. 11), which also means that the biface has a greater potential for movement during the blows. Supporting the artefact with the hand alone may also reduce the accuracy of the strike, as the hand cannot be held completely still and will also be affected more by the movement of the strike than if the artefact is supported against the thigh. P. Wiking said that he can deliver more precise blows when supporting the artefact solely with the hand, but during the experiments in 2022, it was also seen that he often needs many more tries to remove a flake than the other two. In itself, this can be responsible for the signs of recurring blows.

A lack of signs of abrasion on the flakes was conspicuous for all three knappers. First of all, bifacial production is primarily done in soft direct percussion, which needs sturdy edges (see Subchapter 4.1). Overhangs and other problematic areas have to be dealt with before a successful removal of flakes can happen. This is generally done with abrasion of the working edge, but can also include minor reduction on and below the edge. From the documentation of the experimental sessions, it is known that G. Nunn and P. Wiking applied a great deal of abrasion to the edges. G. Nunn even went so far as to abrade the ridges of former negatives on the faces of the piece in work. Because of this, it was anticipated that a high amount of abrasion would be observed, quite likely on every piece. That this was not the case came quite as a surprise.

Different 'perceived' types of knappers were constructed, based on the observations and documentation. Starting with G. Nunn again, a very structured way of working was encountered. The overall impression delivered by preparation and execution of the removals was strict control. G. Nunn did not take chances and prepared for the strikes accordingly, if needed, by constructing remnants where the exact spot could not be missed. In this, his careful way of working is also apparent. A great deal of thought and care is given into the preparation of the removals, so they happen as planned and no accidents hinder the progression of work.

In contrast, A. Benke appeared to be a more intuitive worker. On the one hand, he invests less time in the preparation of the edge and platforms, on the other hand, he pursues and utilises suitable existing opportunities. P. Wiking seems to be somewhere in between these two types and appears to be more pragmatic in his approach. He prepares the edge and platforms with comparable care like G. Nunn, but his execution differs. Even though a lot of remnants have a roof-like shape, frequently his strike hits the roof slightly off. Likewise, the remnants in P. Wiking's inventory show percussion marks or ring cracks from earlier attempts of removal. This was something rarely seen while recording flakes from G. Nunn or A. Benke. The term 'pragmatic' is considered not because of the attributes and impressions from the knapping products, but because of the observed working mode in 2022. He is a lot faster than the other two, but then again also seemingly more careless about the outcome (see also Table 2). In approximately the same time that A. Benke took to knap the dagger up to the grinding stage, P. Wiking worked on five bifaces, but only three reached a more or less finished stage. Here, the rather pragmatic approach to the material can be recognised, where the non-completion of artefacts is accepted in favour for swiftness during production. This seems to be related to the background of the knappers. While G. Nunn and A. Benke live in areas where good quality flint is not always easy to obtain, P. Wiking has no problem with resupplying. This difference could also be observed quite well in the discussions with A. Benke and P. Wiking. While the former was working on a not so easy nodule, he always referred accidents back to himself and did not want to let faults in the nodule count as an explanation for problems. P. Wiking, in contrast, just grinned at one point and stated ironically that the flint was at fault if something went wrong.

For all three knappers, it was their first encounter with Scandinavian Bronze Age sickles during the sessions. All of them are skilled workers with experience in bifacial production, but working a new type of artefact with nothing more than a template piece can still be challenging. Nonetheless, for every knapper, the first inventory made was chosen. Some of the differences and surprising observations can thus be part of the struggle of adapting one's own working process to the unfamiliar form.

4.5 Conclusion

In this section, it was demonstrated how seemingly equal work is done quite differently, still ending up with similar artefacts. It was also shown how subtle some of the differences are and that it is quite problematic to trace them solely by attribute analysis. This is why researchers still have to lay hands on the material themselves.

The inventories by G. Nunn and P. Wiking should display more attributes of direct hard percussion, at least during the first stages of production. Likewise, the characteristics of indirect technique should differ between the knappers, depending on whether they choose to use it and in which fashion. In total, it should be possible to structure the flakes from G. Nunn's inventories more easily into stages than those from A. Benke and P. Wiking. Both have a more fluent structure of work than G. Nunn. Comparing P. Wiking's and G. Nunn's inventories from 2006 and 2007 will be interesting, as a possible change in working procedure could be found here due to mutual influence.

Chapter 5: Statistical analysis

Within the last chapters, a theoretical discussion and an analysis of observed reduction strategies dominated. The following subchapter is concerned with the statistical and technical analysis of the attributes that are recorded from the knapping products (see Subchapter 3.2.2). Basic descriptive statistics and an analysis of technical patterns will be the starting point to look for variation between the knappers, before moving on to multivariate methods of analysis, to see if and how the observed patterns can be detected and verified. The free software environment R (last used version: 4.3.0 'Already Tomorrow', 2023-04-21) in the desktop application of RStudio (last used version: 2023.06.0.421, 'Mountain Hydrangea') has been used for all writing and computation. Like Chapter 4, this section will be loosely structured following the production sequence when it is possible and reasonable. This means, the first subsections will include some general remarks about the recorded inventories and the work process, before moving on to the analysis of techniques and differences.

5.1 The inventories

In total, eight inventories made by four knappers were recorded (Table 12), which sum up to 12,184 recorded flakes. As most of the inventories were collected and bagged after the artefacts were finished, no clear separation for production sequence could be made during the recording, with exception of the type IC dagger by A. Benke. Another half exception is the dagger of G. Nunn, which

Knapper and artefact	Count
Benke_Dolch_IC	3,330
Benke_Sichel_2018	1,730
Blindtest_Callahan	127
Nunn_Dolch-IC	2,109
Nunn_Sichel-1.26_2006	1,059
Nunn_Sichel-3.33_2007	1,771
Wiking_Sichel-1.7_2006	977
Wiking_Sichel-2.32_2007	1,081
Total	**12,184**

Table 12. Total counts of recorded flakes per knapper and artefact.

was presorted by size for some of the flakes and at least the parallel flaking and finishing pressure retouch was bagged separately from the other knapping products. In contrast to all the other inventories, E. Callahan's dagger preform covers solely the first stage of production and stops at the primary preform. It was mainly used as a test case for the recording system and as a reference to G. Nunn, who was greatly influenced by E. Callahan's work. No in-depth analysis of Callahan's work will be given here, as it was also not discussed in detail in previous chapters. It was not totally excluded from the analysis as it was deemed possible to find comparisons to G. Nunn's inventories and see how incomplete reduction sequences behave in the analysis.

After the recording of every piece of flake of the sickle produced by A. Benke, it was decided that the progress had to be quickened. For this, a sampling strategy was developed. The knapping products were sorted loosely by size (see Subchapter 5.3), and a statistically significant number of pieces were chosen from each size class, favouring pieces with proximal preservation. This was done to obtain the maximum of technical details in relation to the time effort needed for recording. How a flake was detached and which technical operations were included in the production sequence are all comprehensible from attributes concentrated on the proximal part. Thus, for the reconstruction and analysis of technical behaviour during production, there is no part of a flake which is more important (Inizan *et al.* 1999, 90). It became apparent quite early that not enough pieces with proximal preservation were present for a significant sample in the bigger size classes. For the knapping products of the type IC dagger by G. Nunn and the sickle from 2006 by P. Wiking, the number of flakes recorded for each class were either all flakes with proximal preservation or a statistically significant number if enough flakes were present. This meant that every piece in the size classes had to be counted prior to selecting the sample. As this procedure was likewise time-consuming, the counting was dropped for the last four inventories. They were still sorted by size classes, but then all flakes with proximal preservation were recorded (Table 12 and Table 13). It was refrained from taking samples of the entire inventories, as smaller flakes are much more abundant than big flakes and the sampling would have been much too easily biased towards bigger or smaller flakes. Furthermore, the selection would probably have obscured the technical details during work, as just a minor proportion of the production

Knapper and Artefact	Count
Benke_Dolch_IC	3,330
Benke_Sichel_2018	1,471
Blindtest_Callahan	101
Nunn_Dolch-IC	1,978
Nunn_Sichel-1.26_2006	1,059
Nunn_Sichel-3.33_2007	1,771
Wiking_Sichel-1.7_2006	977
Wiking_Sichel-2.32_2007	1,081
Total	**11,702**

Table 13. Number of recorded flakes with proximal preservation per knapper and artefact.

process would have been analysed. As this thesis's main concern is to establish a base for comparing knappers and learning traditions, which will quite likely be more perceptible in smaller details, high resolution was chosen, despite the time-consuming work. The count of included artefacts in the analyses thus sums up to 11,702 pieces (Table 13).

Evidently, the daggers account for the largest inventories. The difference in numbers can easily be explained by the generally bigger nodules (Table 14), meaning more material has to be removed, as well as the additional production stage compared to the sickles (see Chapter 4). Another factor for higher flake counts could be care given to the production. The production of a dagger usually takes more time and the artefact is regarded with higher prestige, at least among modern flint knappers, which justifies a more cautious and careful manufacture. By implication, this can translate to a less risk prone approach and the choice of removing several smaller flakes, where one big one could have been sufficient. Lastly, higher flake counts can also relate to the quality of the material. If inclusions, cracks and tough material spots interrupt the process, more flakes need to be removed for a successful outcome (Eren *et al.* 2011).

The raw material chosen by the knappers was of differing quality. A. Benke always chose the nodules with the least best quality available during the experiments, which left him with more difficult work due to inclusions and flaws. A choice, which was certainly influenced by the knowledge that he could keep all the nodules not used in the session. The included inventories by G. Nunn were of good to mediocre quality. The Texas flint nodule was of good quality[10], while the nodules 26 and 33 of the Hillerslev flint were more mediocre. The sound of the two nodules was good, but they both contained rather serious inclusions and flaws. The nodules 7 and 32 worked by P. Wiking were of very good to good quality, respectively. The latter nodule contained a big cement-like inclusion but was otherwise good.

The decision to record these inventories instead of some of the others was indirectly influenced by the raw material quality. For A. Benke, no additional inventories were available, but the other two knappers had several inventories to choose from. From the Lejre experiments in 2006, the first inventory of a sickle

10 Due to being a tougher material than Scandinavian flint, Texas flint had to be heat treated prior to parallel flaking to reach a similar knapping quality. See also Subchapter 4.2.1.

production was chosen to get an impression of the knappers at the same level. From 2007, not the first inventories were chosen, but two which resulted in a successfully produced object. This was done, as the aim of the project was not to compare the skill levels of the knappers, but rather the general production and their individual choices during the process, so the complete process was needed to be comparable to the other inventories. This biased the choice to more good quality inventories for which the entire sequence was available.

5.2 The raw material

A short description of the chosen nodules will be given here, as far as information was available (Table 14). All nodules were acquired from the Hillerslev limestone factory in Thy, Northern Denmark, with the sole exception of G. Nunn's type IC dagger, which was made from Edwards Plateau Texas flint. Bifaces need rather good quality, homogeneous flint, which is quite abundant in Denmark. Along most of the shoreline of the Baltic Sea, usable flint nodules can be found in secondary deposition. This flint has been relocated during the last Ice Age and transported to Denmark and Northern Germany with the glaciers or washed out of the chalk cliffs. For geological reasons, Denmark is also rich in primary outcrops of flint of different geological age and quality (Thomsen 2000). Often, the outcrops can be seen and more or less easily accessed from the shores (*e.g.* Glob 1951; Weisgerber 1999a; 1999b). In addition, mining activities dating back to the Neolithic have been discovered in Jutland, with evidence for the manufacture of four-sided axes and bifaces (Becker 1951; 1958; 1959; 1966; 1999a; 1999b; 1999c; 1999d). Thy is especially interesting as geological processes in the Thisted region ensured the easy accessibility of flint of different qualities (Thomsen 2000, 34; Eriksen 2010, 87-88). The outcrops of interest for bifacial artefacts are of Maastrichtian age. The chalk from this period is inlaid with highly homogeneous nodules and slabs of black to greyish flint. Despite the good quality, nodules can include light grey, more tough spots in varying degrees, which complicate the reduction process.

Flint working is a reductive process. A flake removed from the nodule can never be reattached and likewise an error not undone. Contrary to clay or metal, which can be remodelled before firing or remelted, flint leaves no way to remake an object without more loss of material. This also implies that no material can be added to the original nodule to get bigger or better results. Especially for the long and prestig-

Table 14. Approximate measurements of chosen raw material nodules included in the thesis. Abbreviations: PW: P. Wiking, GN: G. Nunn, AB: A. Benke.

Knapper/Nodule/Year	Length (cm)	Width (cm)	Thickness (cm)	Weight (kg)
GN/-/2005	38.5	39.0	3.8	5.4
GN/26/2006	24.0	17.0	4.0	2.5
GN/33/2007	27.0	23.0	3.0	~ 3
PW/7/2006	29.0	22.0	7.0	5
PW/32/2007	24.0	19.0	3.5	~ 2
AB/11/2018	29.0	21.0	4.0	4
AB/1/2021	39.5	25.5	---	6.5

Figure 13. Flint band in a primary deposition at the Hillerslev chalk factory. Recognisable is the fractured state of the raw material due to the strong mechanical forces by the heavy-duty machines (Photo: M. Hinrichs).

ious daggers, this requires the use of quite large nodules with no internal damage or major faults. These kinds of raw materials are hard to obtain from secondary depositions, although it is not impossible that the production of large daggers took place on shore sites with raw material in abundance. However, it seems more plausible that known quarries and mines were exploited, where the quality as well as the sizes of the nodules extracted from the ground were more consistent.

The Hillerslev chalk factory is positioned above such an outcrop and mining activities are known from the Late Neolithic, so it is safe to assume that the craftsmen knew this and made use of flint from this region (Becker 1999a; Eriksen 2018, 334). Due to present-day chalk mining, the outcrop is easily accessible and nodules can be selected with a low investment of time and work, and with a little luck. As a result of the heavy work machines, the slabs are, however, unfortunately often crushed and broken and mostly rather small. Again, with a bit of luck and digging, good quality slabs up to 40 cm can be recovered from the rim of the quarry (Fig. 13). On the basis of the archaeological evidence and the practical reasons associated with accessibility, Hillerslev flint was chosen for the modern experiments (Eriksen 2018, 340).

Table 14 and Table 15 summarise the measurements of chosen nodules and the resulting artefacts included in the thesis, as far as information was available. The weight of the nodules is given to the closest possible estimation. Easily seen is the extensive loss of width and weight in contrast to length between a nodule and the finished artefact (see also Table 16). It is also remarkable that the sickles seem to lose more length compared to the daggers. In some cases, this can be explained by the raw material quality. The nodules 1, 11 and 33 appeared to have problematic zones already before work started and nodule 26 also had some serious difficulties that still show on the finished artefact. The deliberate choice of A. Benke to use nodules with lower quality shows that the suitability of raw material is at least as much a choice made by knappers and their skill, as it is restricted by the requirements of the wished-for artefact. Already implied above, the size of a flint object is highly correlated to the size of the available raw material. In addition to predefining the raw material for the working processes, the knappers had descriptions of the *chaîne opératoire* and a finished specimen at hand, which were to be copied. In 2006 and 2007, varying archaeological sickles were presented (Eriksen 2006; 2007b), while A. Benke had a copy made by P. Wiking

Knapper/Artefact/Year	Length (cm)	Width (cm)	Thickness (cm)	Weight (g)	W/T Ratio
GN/D/2005	31.70	4.75	0.95	183.00	5.00
GN/S/2006	22.50	4.91	1.43	216.09	3.43
GN/S/2007	17.92	5.13	1.46	186.69	3.78
PW/S/2006	20.39	5.28	1.54	220.50	3.32
PW/S/2007	20.77	5.38	1.27	179.31	4.23
AB/S/2018	19.65	5.31	1.26	177.90	4.21
AB/D/2021	34.17	5.58	1.22	233.44	4.59

Table 15. Measurements of finished artefacts included in the thesis. Abbreviations: D: Dagger, S: Sickle.

from the 2007 session as a template. Having a template means also that the knappers tried not only to mimic the appearance of the surface and form, but also the measurements of the piece. However, when they were working on daggers, all three knappers chose to keep the maximal possible length.

E. Callahan proposed a sheet for a quick estimation of the production stages for bifaces based on the cross section and width-thickness ratio of the artefact (Callahan 2000, 18 Tab. 5). In brief, according to his ideal sequence, a biface would have reached the finished state more or less with stage V (Subchapter 4.1), which would correspond to a W/T-ratio of 4.00 and higher. In Table 15, the ratio for the included objects was calculated. It can be seen that the sickles do not often meet the 'required' ratio which would have classified them as finished pieces. It should be noted that the sheet is mainly based on fluted points from Eastern North America and despite being bifacially worked, they are much smaller than the average Scandinavian sickles or daggers, and by this also easier to work. As smaller pieces can be supported better during the reduction, the thinning of an artefact can be pushed a bit further than with large artefacts, corresponding to a higher ratio. Another point is that the sickles included here are Bronze Age types, which are often worked a bit cruder (cf. Eriksen 2010; 2018). The ratio could be a 'better' indicator for Late Neolithic sickles. Still, the W/T ratio is probably better considered as a tendency than a strict separation into finished and unfinished pieces, as it is also influenced by later resharpening or edge retouch, in general, as E. Callahan (2000, 18 tab. 5) states himself. It seems that, in general, the ratio is not so significant when dealing with sickles. Here, the ratio is influenced twofold. Firstly, the sickles are already finished at stage IV and, secondly, the final edge retouch probably decreases the ratio further. Concluding, it should be said that the W/T ratio can help to determine which stage the production artefacts exhibited at the time of discard and if the thinning stage of production was mastered by the knapper. But it should be refrained from putting too much weight on the ratio in itself. As we can see here, even highly skilled knappers seem to 'fail' the ideal product.

The percental loss of dimension between nodule and artefact is given in Table 16. It can be seen that length and thickness diminish less uniformly among the knappers than width. This is, on the one hand, influenced by the material. In general, the length of a nodule is lost if the quality of the raw material is poor. Similar, the nodules have unequal thickness, which means some have to be thinned down more than others. On the other hand, the loss in length – or rather the ambition not to lose length – varies depending on the artefacts that are in-

Knapper/Nodule/Year	% Length	% Width	% Thickness	% Weight
GN/-/2005	17.66	87.82	75.00	96.61
GN/26/2006	6.25	71.12	64.25	91.36
GN/33/2007	33.63	77.70	51.33	93.78
PW/7/2006	29.69	76.00	78.00	95.59
PW/32/2007	13.46	71.68	63.71	91.03
AB/11/2018	32.24	74.71	68.50	95.55
AB/1/2021	13.49	78.12	---	96.41
Mean	**20.92**	**76.74**	**66.80**	**94.33**
SD	**10.02**	**5.17**	**8.67**	**2.16**

Table 16. Percental loss of measurements from a raw nodule to a finished artefact.

tended. All three knappers work far more ambitiously and are not inclined to lose length when manufacturing a dagger, compared to working on sickles. G. Nunn's sickle from 2006 as well as P. Wiking's from 2007 are outliers in this context and can rather be attributed back to the general smaller size of the nodule. Loss of weight demonstrates impressively how wasteful bifacial production is, but also how good the knapper has mastered the craft. In general, it should be possible to differentiate between skilled and unskilled knappers based on the loss of measurements. Unskilled knappers tend to lose more length but less width and thickness, which would result in different percental distributions than seen in Table 16. But, the comparison of percental loss between original nodule and finished artefact is nearly impossible in the archaeological record. There are rather few cases in the archaeological context, where the original nodule can be reconstructed and the produced artefact is at hand. Estimations could be gained from inventories which include on site production like Tegelbarg, district Schleswig-Flensburg, Germany (Arnold 1981b; 1990) or Bjerre, district Thy, Denmark (Eriksen 2008; 2018). But this is a very time-consuming approach, as the nodules have to be refitted to a high extent. The gain in information for this sake alone is not worth the trouble. But luckily, a lot of other, more promising details can be gained from refitting, which is why the question about material loss could still be pursued as a sideline.

The quality of the raw material is often very hard to assess when analysing the finished artefact. The successfully manufactured bifaces seldom bear traces of difficulties met during reduction; or a sharp eye and a lot of technological knowledge is needed to identify remaining material faults (and/or knapping accidents) and estimate their impact on the feasibility of finishing the artefact. Refitting helps to get an overview of troubles and material faults along with the ability of the knapper to cope with them. So, if we want to know more about the requirements that prehistoric flint knappers had towards their raw material, we need to analyse the knapping products, not the finished tools. As can be seen from Table 16, not much of the original nodule is left after the successful production of a biface. Which thoughts and requirements guided the selection of the raw material is thus hidden in the countless flakes, removed in the process. The quality of the raw material provides, however, not only insight into skill levels but can also give hints about accessibility and ambition. This has already been addressed in Chapter 4. There are two options for skilled knappers when encountering problems in raw materials: to give up or to follow through by adding time and care. The first option is a logical decision from an economic point of view. Why should one bother to invest time, stress and nerves into a product, when the outcome is unsure? If enough and better material is available, it will be far easier to discard the faulty nodule and to start anew on a more promising one. The second option is more likely a choice born from ambition. It can be that no other material is available (probably not often the case in Scandinavia) and the artefact has to be made regardless, but it can just as likely be a way to show off skill: despite the encountered problems, the artefact was finished. Analysing the left-behind knapping products can help us to gain insights into these topics, above all, which qualities did the raw materials have, what quality was deemed appropriate for the task and how ambitious or wasteful were the knappers. These are just a few questions for which the finished artefacts provide little insights. In this context, it is beneficial to take a closer look at mining and quarrying sites. Often, the extracted material was tested or even worked to semi-finished products before being transported. The sizes and the quality of the material can then be reconstructed and assessed. In many cases, it will probably not be possible to distinguish which type of biface was produced from the first few stages. But maybe differences in size and quality form distinguishable groups which could be interpreted functionally. Likewise, the quality available could be connected to the skill level of the knapper, meaning some kind of restriction in the distribution of raw material was present. Flint mining sites in Denmark are rather simple and shallow compared to other European mines (*e.g.* Collet *et al.* 2008), but their exploitation is still a community project and it is not difficult to imagine that people with a better reputation as knappers would have gained the right to choose material first. These are questions, which cannot be pursued in this thesis, but which would be worth following up.

5.3 Reconstructing production stages

At the beginning of the chapter, the sorting of the knapping products by size was mentioned. This will be explained here in a bit more detail. The size classes used in the thesis are loosely based on V. Arnold's (1981b, 40) work on Tegelbarg, district Schleswig-Flensburg, Germany. The size classes proposed by him have no technical background, but are rather an estimate how easy a flake is to be discovered during the excavation (Arnold 1981b, 38-41); flakes with bigger surface areas are easier to detect than flakes with small areas. It is thus a means to gain a quick overview of the inventory as well as of the accuracy of the excavation, and to estimate which production stages can be encountered in the recovered material. Decisive for the assignment of a flake to a size class is not the length of the piece but the surface area and weight. Concerning this analysis, in contrast, solely the length was used to assign size classes, as it was solely used for a more convenient recording of flakes and no excavations were included, which would have needed a comparison of care or present production stages. Another idea behind the use of flake size classes was the possible benefit as an instrument for a quick division into production stages (see also Subchapter 3.2.2). This thought had to be rejected, which will be discussed later. The main difference between Arnold's classes and those in this thesis is that size classes I-II (flake length from 9 cm and longer) were often not present or in such small numbers that a division would not have provided additional information. Similarly, the smallest size in Arnold's work

Flake size class	Length (mm)
I	≥ 100
II	≤ 99.99
III	≤ 75
IV	≤ 50
V	≤ 25
VI	≤ 15
VII	≤ 10
VIII	≤ 7

Table 17. Boundaries of flake length used to manually assign flake size classes to inventories.

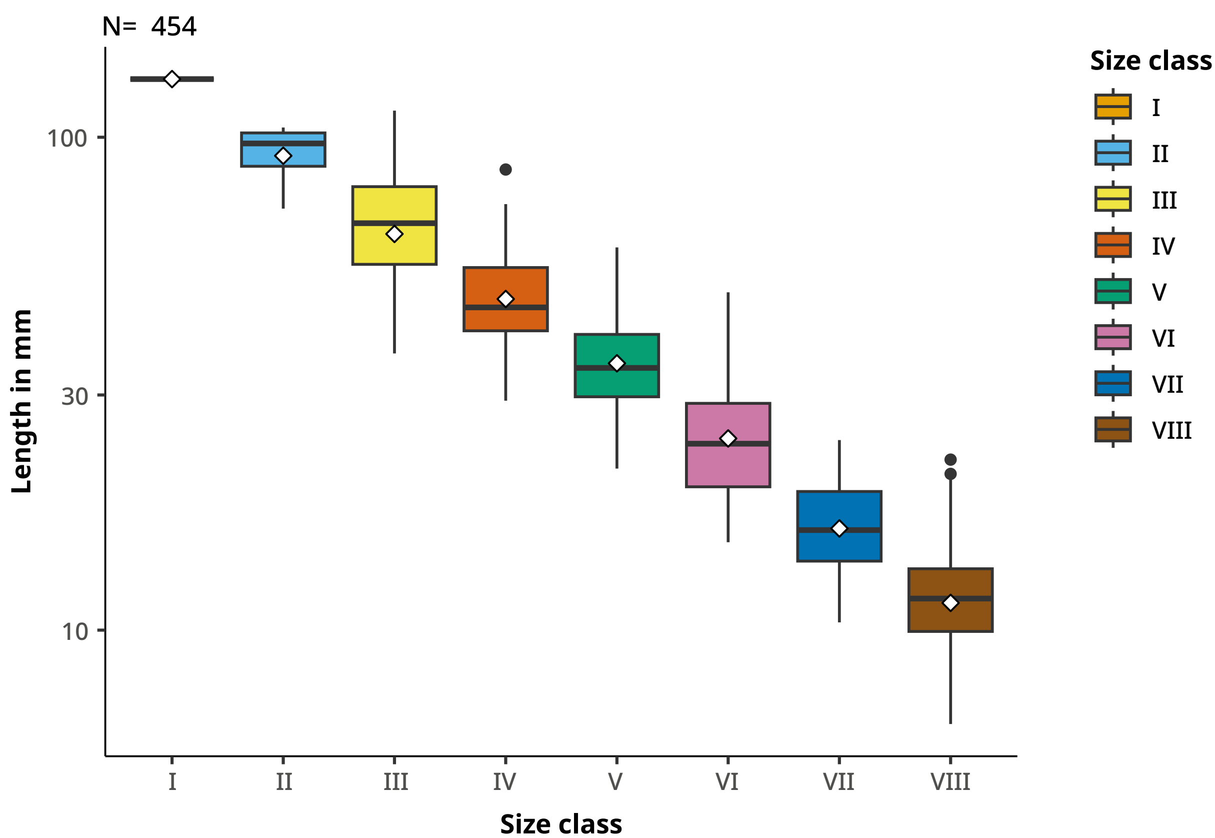


Figure 14. Sorted size classes of P. Wiking's sickle from 2006.

is at least 1.8 cm long, which would have made the distinction between smaller flakes from maintenance of the edge, pressure flaking and final pressure retouch impossible. For this thesis, the classes I-II were mostly regarded as one and the other classes were split and extended to include all flakes as short as 0.5 cm.

As the division by size was more a convenient help in measuring the progress of the recording and made the sorting for proximal preservation easier, no fixed size classes were established during the recording. For the sake of comparability during the analysis, G. Nunn's dagger and A. Benke's sickle inventories had to be assigned to size classes during the analysis, which were computed based on the flake length shown in Table 17. This has two consequences for the inventories. All

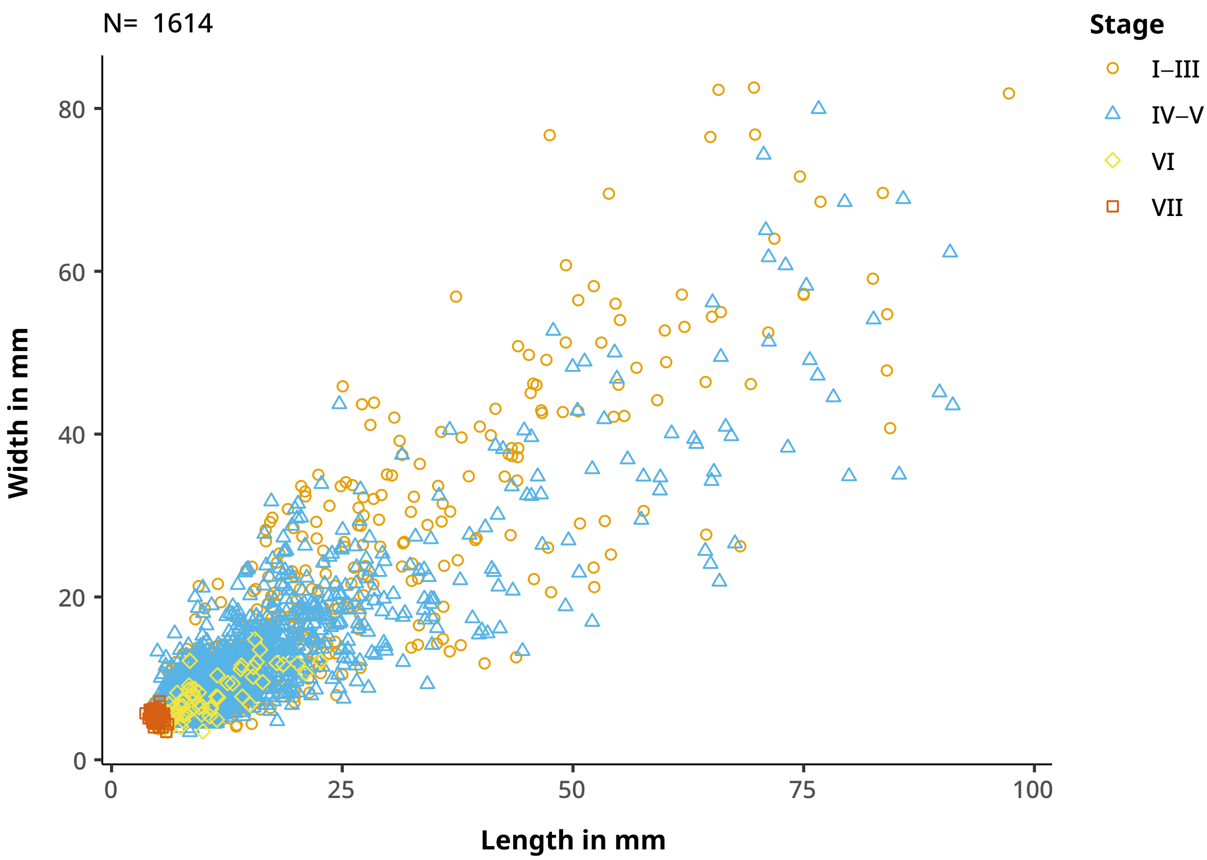


Figure 15. Flake size distribution coloured by recognised stages for the type IC dagger by A. Benke.

flakes, regardless if broken or complete, were measured in the sickle inventory, so every flake could be assigned to a size class here. As all the other inventories were also sorted according to the preserved size and not to the actual size, this should not influence the results compared to the other inventories. In contrast, during the recording of the dagger inventory, only complete flakes were measured, which excludes a lot of flakes from the list when assigning size classes. The data frame assembled for size classes consists of 1,407 flakes. This implicates that during the analysis when the attributes are displayed according to size classes, for G. Nunn's dagger inventory only complete flakes are displayed, while the original list including all flakes with proximal preservation is used when the inventories are compared to each other.

The distribution of length for the manually sorted inventories is shown, exemplified by the sickle of P. Wiking from 2006, which was the first one to receive treatment (Fig. 14). It can be seen that the classes fall more or less into categories, with an overlap between the sizes, which is due to the sorting by sight instead of by fixed measurements.

Establishing a succession of flakes and corresponding production stages is not an easy task but would help the statistical analysis greatly. As the literature often states how early stages produce bigger flakes than later stages (*e.g.* Burton 1980; Stahle and Dunn 1982), one idea was to use the size classes to get a rough staging of the inventories. Considering the controversial discussion of establishing successive production stages based on the measurements of flakes (*e.g.* Amick *et al.* 1988; Patterson 1990; Shott 1994; 1996), it seemed safest to attempt this for an inventory, where the stages were known. As this was only true for the type IC dagger by A. Benke, which was collected per stage during the reduction, first tests were run on this inventory to get an impression about what to look for in the other inventories. It was not expected to see clear cut divisions, as A. Benke has a less structured and less staged way of working than. *e.g.* G. Nunn, but even so, the result was discouraging (Fig. 15). The flake lengths do decrease progressively through the stages, but there is no way of safely telling when a flake was removed based on its length or width.

Figure 15 clearly shows the enormous overlap between the stages. Basically, there is no difference in flake sizes between the stages I-V. A. Benke makes no clear-cut separation between the stages; he works in a more continuous way; but divided his work into two stages, by own accord (see Subchapter 4.2.2). His first stage corresponded roughly to the stages I-III. The second stage was made up of the stages IV-V. Stages VI and VII denote the parallel flaking and final pressure retouch.

A closer look at the length and width for the stages was nonetheless undertaken to see if some information was hidden behind the many data points. Figure 16a shows how big the overlap between the measurements and the stages is. The mean does differ, but there is no clear separation which would allow us to reconstruct the production stage purely on the measurements of the flakes. The only stage which can be distinguished at least by the length of the flakes is the final pressure retouch, which is distinctly separated from the other stages; a pattern not repeated in the width distribution (Fig. 16b). It could be argued that A. Benke's work stages are not expressive enough in themselves and therefore no pattern can be seen, but I think it is more a general problem concerning the production process, which has also been recognised by different authors (Patterson 1990; cf. Shott 1996). Likewise, weight does not show tendencies between the stages, again with the exception of the final pressure flaking (Fig. 17). The size and by this also the weight of flakes produced during bifacial reduction is affected by much more than just the overarching goal of the stage. Seen from the ideal production sequence, A. Benke's second stage should be mainly concerned with forming the piece and flattening the surface prior to grinding. Nonetheless, there are still quite large flakes, which correspond better to the first stage of the rough out. A problem could be that A. Benke enters a new stage of work in his mind in between two ideal stages, so to speak. By this, there could still be a lot of thinning work going on, which would lead to larger and wider flakes. But, at this point, the nodule has also been narrowed down a lot, so flakes should generally be shorter than in the stage before. As can be seen in figure 16a, the flakes in the second stage generally tend to be shorter, but still a higher number of flakes are present, which are not significantly shorter than in the previous stage. Another problem obscuring the picture could be the inclusions encountered during production, which forced A. Benke to progress more carefully and concentrate on the edge rather than the thinning. This has certainly resulted in more shorter flakes in the first stage of production.

Another process, which obscures the picture, is the preparation of the edge. Work on this is restricted to the fringes of the piece, regardless of the size of the nodule, and produces a lot of shorter flakes. Since bifacial reduction is not possible without a circumferential edge in the right position and in adequate condition, a lot of work is invested into maintaining it. In a way, this is the major part of the work throughout the stages. It is still true that the biggest flakes will be part of earlier reduction stages, where the artefact also had a wider outline than in the later stages, but it seems not to be best practice to exclude the majority of flakes

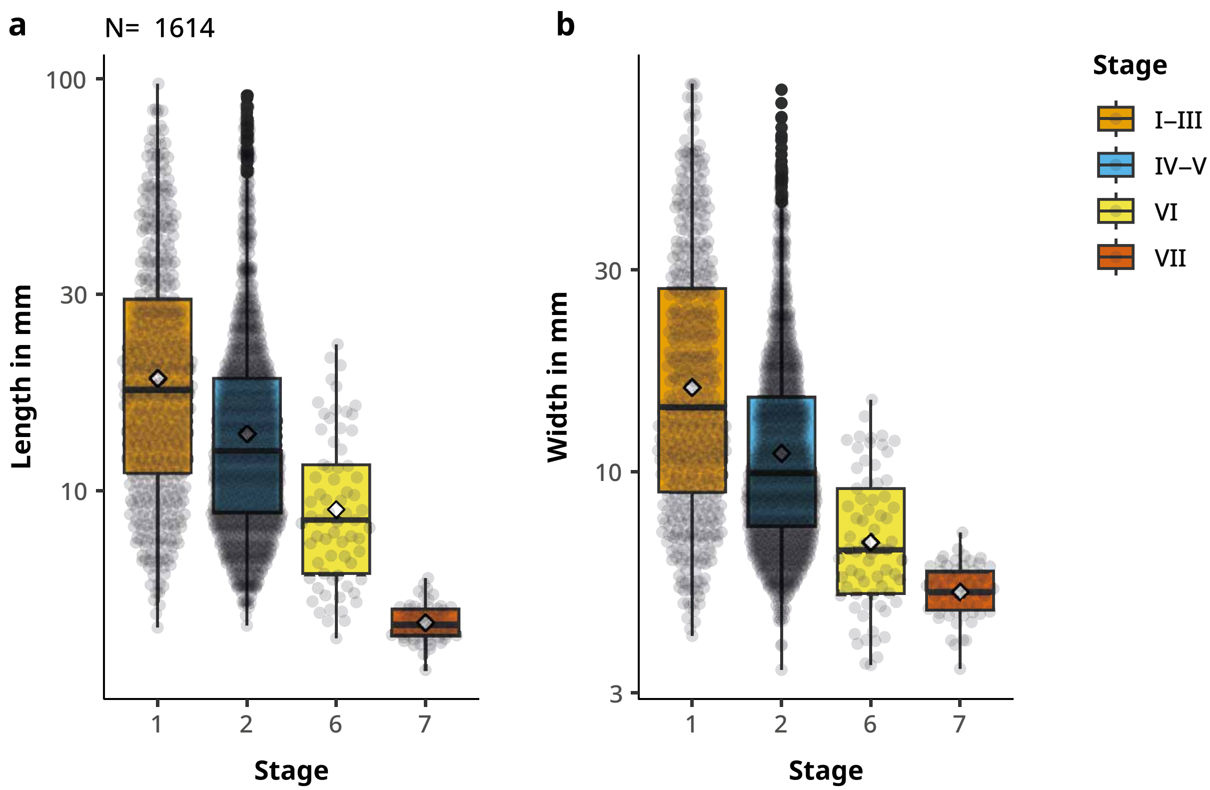


Figure 16. a) Boxplots of length distributions of stages for the type IC dagger by A. Benke; b) Boxplots of width distributions of stages for the type IC dagger by A. Benke.

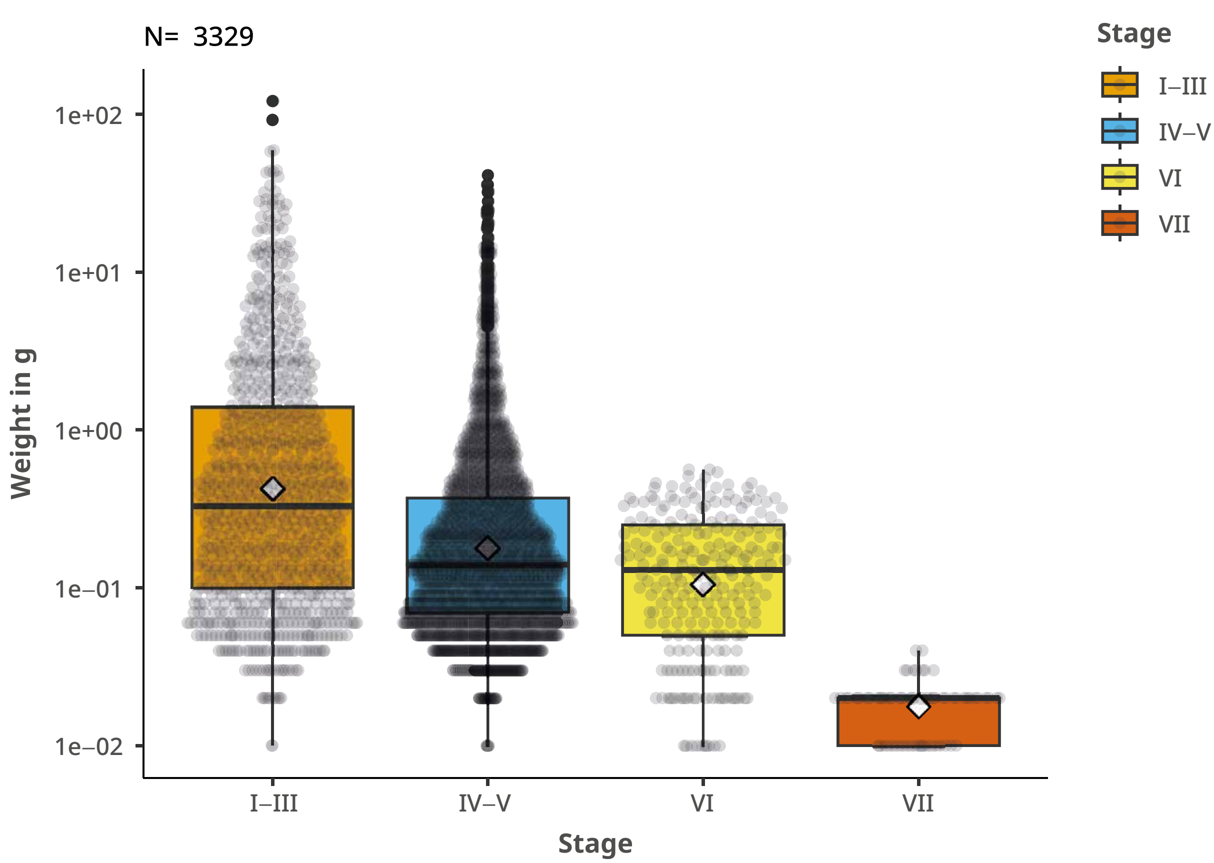


Figure 17. Boxplot of weight compared to production stage for the type IC dagger by A. Benke.

from the analysis, just because they cannot be attributed to a certain stage only based on their size, especially since the biggest differences between knappers seem to lie in the preparation. Focusing on clearly distinguishable flake types solely, like thinning flakes (Whittaker 1994, 185-187; Apel 2001, 137), will only provide answers to questions whether bifacial reduction took place and which part or parts of the production sequence has happened on a site, but it will not give a detailed description of the technical work and decisions included in the process.

Given the distribution here, the only thing possible is to exclude stages when a certain length is exceeded. These limits will vary greatly between knappers, types of artefacts in production and size of raw material nodules used, so no fixed limits can be given. For A. Benke's dagger inventory, it means that flakes longer than 6.13 mm do not originate from the final pressure retouch, as these are the longest measured complete flakes. But this does not imply that all smaller flakes are automatically pressure retouch flakes from the last stage of production. The smallest recorded flake from parallel flaking is 4.38 mm and even from the first stage, a flake with a length of 4.65 mm was recorded. The picture is probably not that straight forward, as broken flakes were not measured, so longer or shorter flakes could have been present in every stage. Moreover, A. Benke includes pressure flaking early on in the production process. Pressure flaking in early stages is mostly not concerned with the sharpness of the edge but applied to remove knapping errors or problematic material areas from the surface of the biface. This implies that the flakes for the most part are bigger than the observed flakes during the final pressure flaking. However, it can also be used to straighten the edge or get it back into the wanted plane, so smaller, finishing retouch-like flakes are possible. Likewise, during parallel flaking, smaller pressure flakes also have to be removed to maintain the edge, which would resemble the flakes from the final pressure flaking.

Leaving the simple statistics, a multivariate approach is used to identify structuring patterns in the flake measurements.

Working with numeric variables, principal component analysis (PCA) is the adequate choice to look for patterns in the data. PCA reduces the dimensions by identifying the maximum direction of correlation in the data and can allow a summary of the variables in few dimensions, if the data is highly correlated (Joliffe and Morgan 1992; Tabachnick and Fidell 2007, chap. 13; Jolliffe 2014; Baxter 2015a, chap. 3; Härdle and Simar 2015, 320; Johnson and Wichern 2015, 9; Carlson 2017, 265; Fan *et al.* 2018). It was further decided that all the variables are equally important, so a correlation matrix is used for the analysis (Madsen 1988a, 13; Carlson 2017, 267). As the output of the matrix shows below, the metrics of the flakes are indeed highly correlated. This is not surprising, as longer flakes also tend to be wider, thicker and by this heavier. For the test, only flake length, width and thickness were used. Weight had to be excluded as the PCA requires normal distributed data and the weight data was so severely positively skewed and the measurements so small that a transformation was not successful. The other data groups were transformed by the square root (Carlson 2017, chap. 6; Madsen 1988a, 13; Baxter 2015b, 7; Baxter 2015a, 40-42; Johnson and Wichern 2015). Furthermore, the data was standardised by setting the argument scale.=TRUE which ensures that differences in scale do not affect the result (Carlson 2017, 269). Not available observations were excluded from the data frame before running the analysis. Extreme values have not been excluded from the data set, so the results are influenced by the presence of outliers in terms of a few very large flakes. Very small flakes will not contribute as outliers, as the recording only included flakes around 0.5 cm in length and, for all inventories, an abundance of such flakes was present, which was the reason for the heavily skewed weight and made the exclusion of the very light flakes inappropriate.

```
##       AL    AB    AD
## AL 1.000 0.866 0.616
## AB 0.866 1.000 0.728
## AD 0.616 0.728 1.000
```

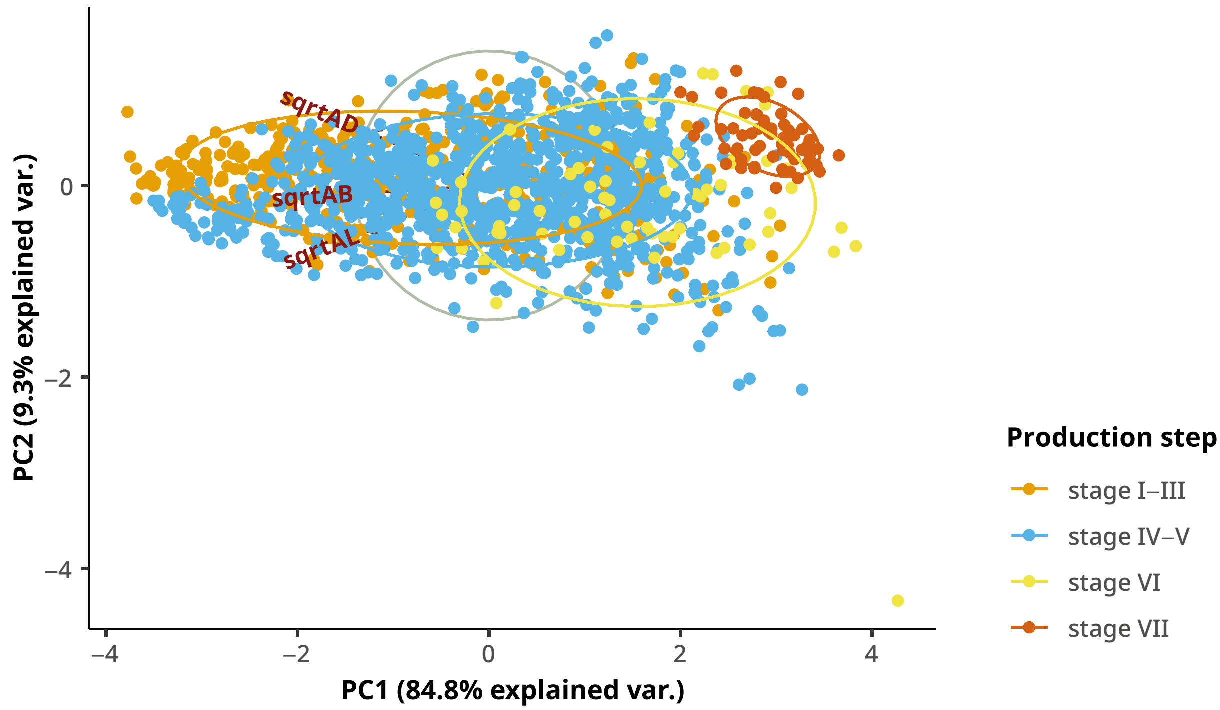
```
## Standard deviations (1, .., p=3):
## [1] 1.595 0.528 0.419
##
## Rotation (n x k) = (3 x 3):
##           PC1    PC2    PC3
## sqrtAL -0.574 -0.643 -0.506
## sqrtAB -0.589 -0.104  0.801
## sqrtAD -0.568  0.758 -0.320
```

```
## Importance of components:
##                          PC1    PC2    PC3
## Standard deviation     1.595 0.5285 0.4194
## Proportion of Variance 0.848 0.0931 0.0586
## Cumulative Proportion  0.848 0.9414 1.0000
```

```
## [1] 2.545 0.279 0.176
```

Above, the computed result of the PCA can be seen. Deciding how many components to include can be done in various ways: based on a more or less arbitrary value of the explained variation often around 70 or 80%, a cut-off value of the eigenvalues, mostly between 0.7 and 1, and/or a scree plot (Baxter 2003, 80; 2015a, 59-61). The first principal component often represents a variation in size, when the data used is measurements of objects. This is probably also the case here, as can be guessed from the coefficients of the first component; they bear the same sign and are very similar in magnitude (Baxter 2003, 75; 2015a, 71; Carlson 2017, 270). The higher-order components then probably explain different aspects of shape, which is also reflected in the mix of positive and negative coefficients (Baxter 2015a, 71). Shape and size aspects are not always the information wished for when performing a PCA, but in this case, when trying to identify differences in flake morphology to identify groups corresponding to knapping stages, it is desirable.

84.8% of the variation is explained by the first principal component itself. Including the second component, 94.1% of the variation can be explained. This huge dominance of the first component can also be seen in the eigenvalues, where only the first has a score above 1 and needs to be included (Carlson 2017, 270-271). Including only the first two components is reasonable, based on the best practice suggestions.



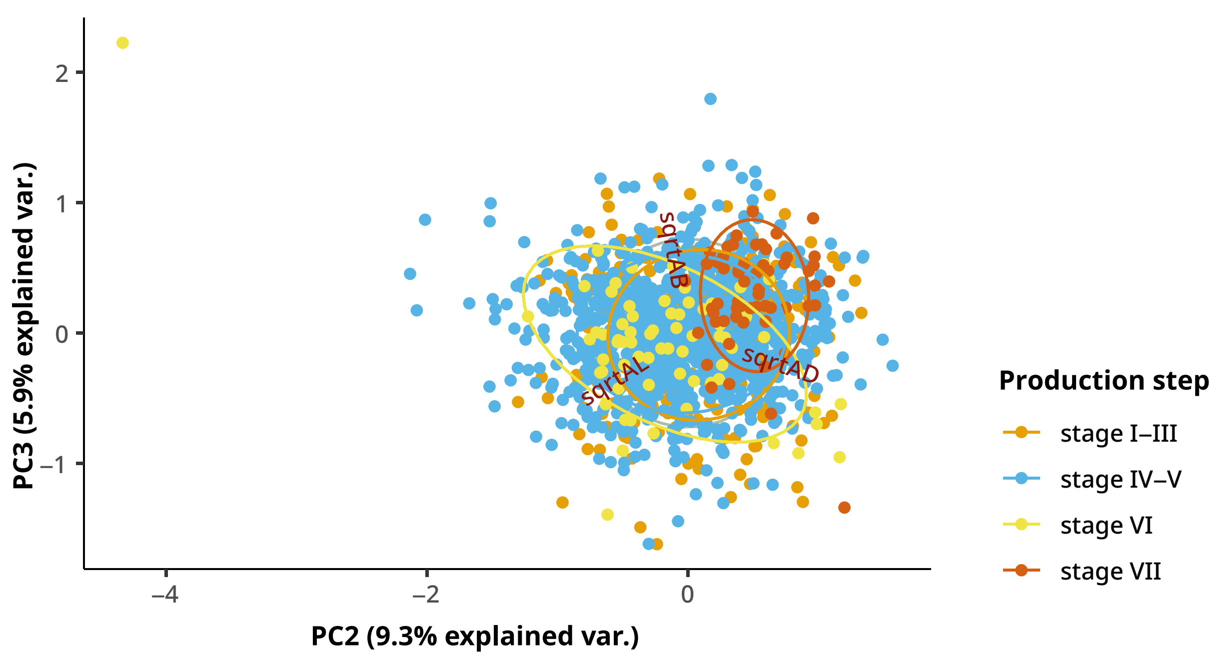


Figure 18 shows the biplot of the PCA. The equal length of the vectors[11] indicates that all the variables are explained equally good in the first two dimensions (Baxter 2003, 78; Carlson 2017, 273). Distinctive clusters are not formed, but it can be seen that the first component indeed expresses the size of the flakes, with larger flakes on the left and smaller flakes on the right side of the plot, indicat-

Figure 18 (top). Biplot of the first two principal components for flake metrics in A. Benke's dagger inventory.

Figure 19 (bottom). Biplot of rotated PCA showing the second and the third component for flake metrics in A. Benke's dagger inventory.

11 Sadly, the arrows are hidden behind too many points in this visualisation, but the position of the labels indicates the same length for all three.

ed by the positions of the stages. Another indication is the positive correlation of the variables, expressed by the sharp angles between the vectors in the plot (Baxter 2015a, 70-71).

Plotting the second and third component to look at the shape aspects does not help further to identify groups. It seems that more elongated flakes are on the left side, while more square-like flakes are on the right side, which can be deducted from the position of stage VI, parallel flaking which produces blade-like flakes, and stage VII, final pressure retouch flakes, which are mostly as wide or even slightly wider than they are long (Fig. 19). To look for underlying clusters, which could be hidden in the huge overlap of groups in the plots, a structured matrix of the correlation between the variables and principal components was calculated.

```
##           PC1    PC2    PC3
## sqrtAL -0.916 -0.340 -0.212
## sqrtAB -0.940 -0.055  0.336
## sqrtAD -0.906  0.401 -0.134
```

Each variable is correlated strongest with the first principal component. In the second and third component, flake thickness and width, respectively, contrast with the other variables. Squaring the correlation loadings and summing across the rows will calculate the communalities. As the result will be 1 if all variables are included, just the first two are used here. A communality of 1 indicates that the variable is perfectly represented by the components, while a score of 0 indicates that the variable is perpendicular to the components (Carlson 2017, 276). As can be seen below, all variables are very well represented.

```
##         [,1]
## sqrtAL 0.955
## sqrtAB 0.887
## sqrtAD 0.982
```

For all three variables, the variability is explained by the first two components, which makes it quite unlikely to separate groups from the data. The results would probably have been more expressive and clusters more distinguishable, if the flakes had been sorted according to which part of work they came from. Instead of collecting the flakes during ‘natural’ breaks in the work, it could have been stopped every time that the work goal changed, *e.g.* selecting for thinning flakes, platform preparation, straightening of the edge and so on and so forth. This would have caused major disruptions in the work flow of the knapper, which was not the goal of the analysis. It would be interesting to see if different flake types formed clusters and could be predicted and sorted statistically. This would not only help to determine from which stage of work a flake directly came from, but could also help to determine how much and which kind of work was performed or is present in the analysed assemblage. It could also help in determining technical differences during the work of knappers in more detail. Another issue, which hinders a general applicability of metrics to form clusters in flakes, is that the size is strongly correlated to the exploited nodule. This means that clusters would have to be identified for each production process, which is probably manageable for experimental inventories, but would cause some trouble in archaeological environments, where it mostly is not clear which flakes really belong to the same

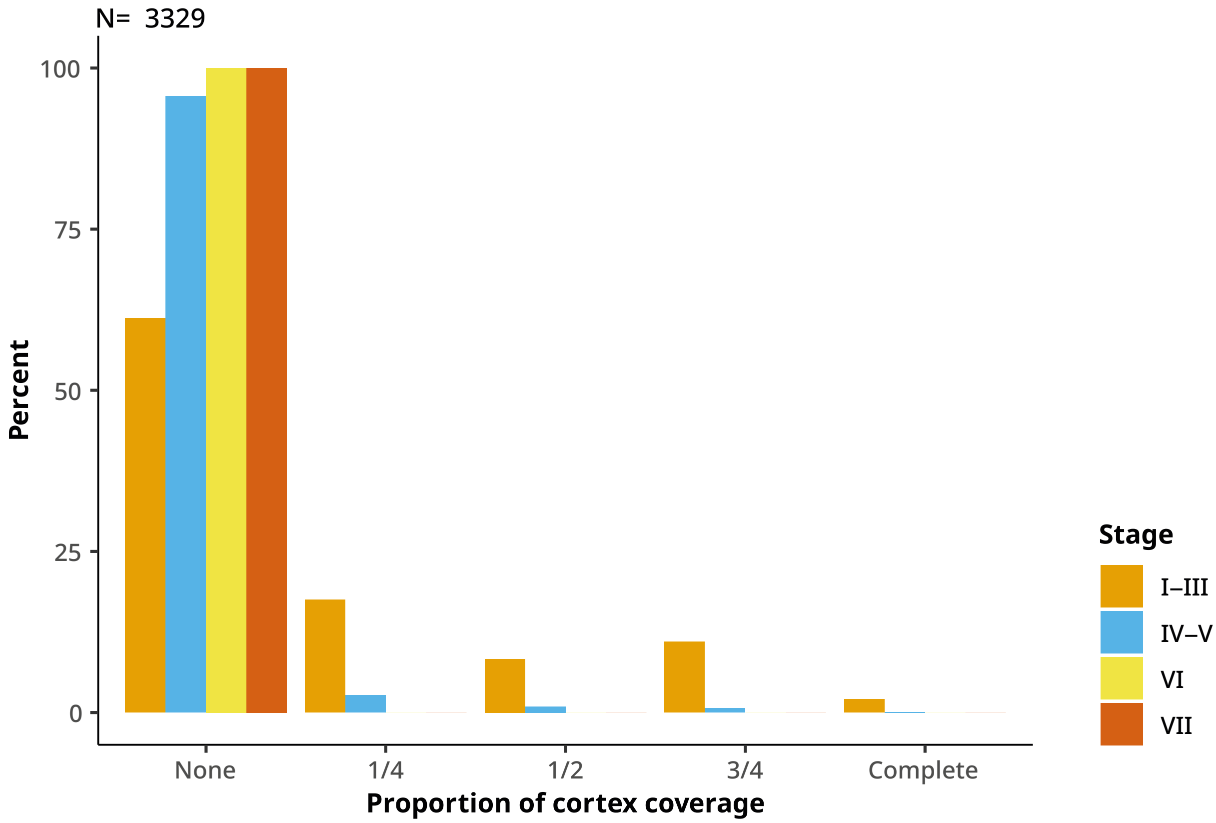


Figure 20. Percentage distribution of flakes for the proportion of cortex coverage per production stage for the type IC dagger by A. Benke.

artefact's reduction sequence. Refittings would have to be done to secure the affiliation of flake and reduction sequence and determine the size of the nodule (Cziesla 1990; Inizan *et al.* 1999, 94-96).

The distribution of size can still help to determine the dimensions of the available raw material, but the cortex coverage is possibly a better index for stage than size, which can be surmised in figure 20. Still the informative value is rather low. Not surprisingly, the highest proportions of coverage are found in the first stages, but it can also be seen here that it is not impossible to find later removals with a relatively high proportion of cortex left on the surface. In addition, a high frequency of artefacts from the first stages are not covered with cortex whatsoever. This will in most cases be the smaller flakes from the preparation of the edge. The amount of cortex and time to remove it from the surface entirely is also influenced strongly by the quality of the raw material and the size of the nodule. Also, in combination with the flake length and width, cortex coverage does not show reliable results. Unsurprisingly, there is a trend for longer and wider flakes to have a higher coverage and likewise, entirely covered flakes originate from the very early stages (see Fig. 21). The length of the flake in combination with cortex coverage seem to provide a bit more distinguishable results, but the overlap between length and possible coverage is still extensive. Again, the only stage seemingly distinguishable from the others is the final pressure retouch, which in itself is already quite easy to separate from all the other flakes. Cortex cover can only be used to exclude flakes with cortex originating from final stages of production. It is a good indicator for assessment if early stages of production are represented in a given inventory or if the nodules are brought in as preforms for further manufacture. But from the point of answering which moment of production a flake came from, the coverage is not a very suitable attribute.

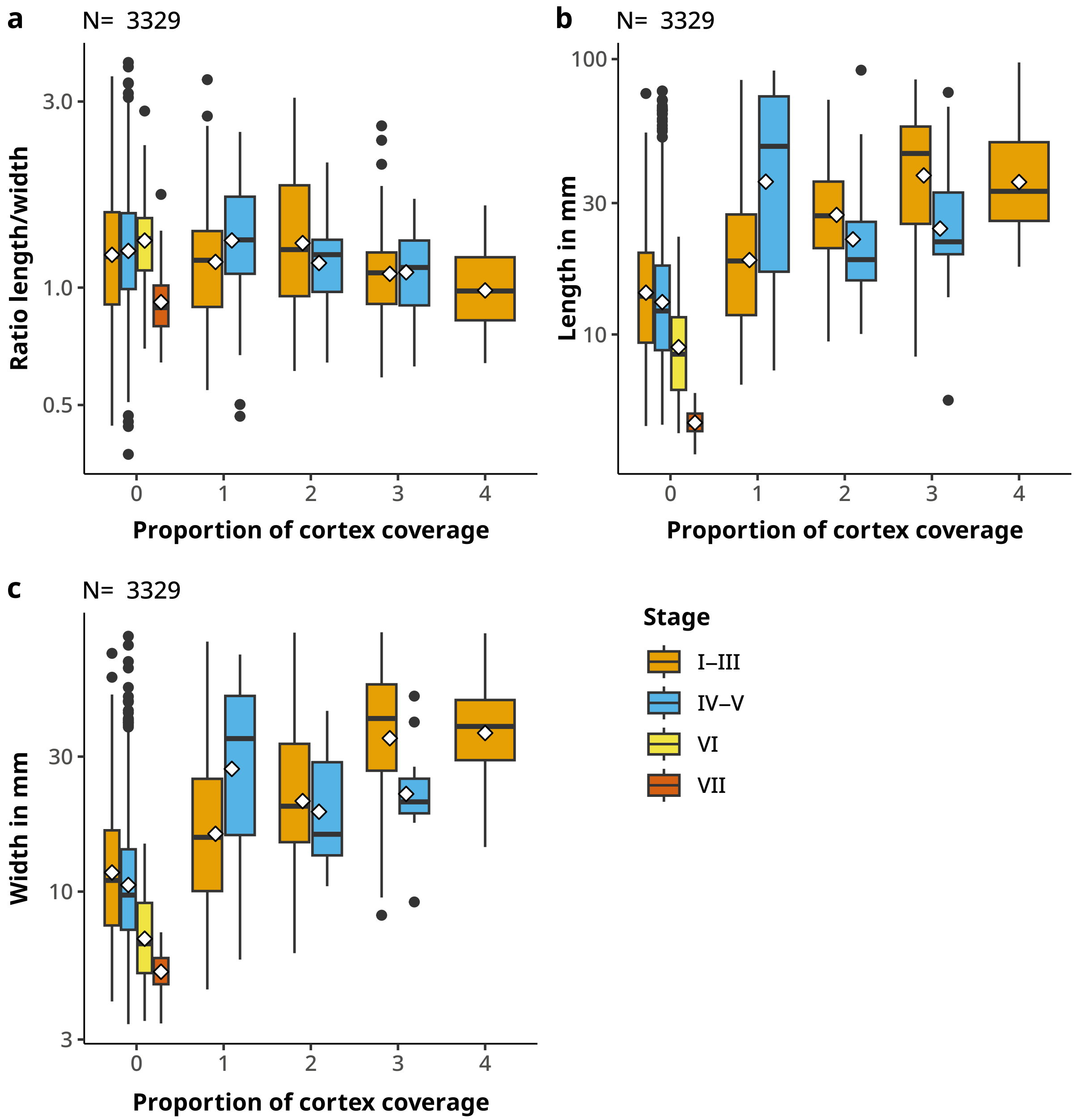


Figure 21. Proportion of cortex coverage in comparison to flake length and width per production stage for the type IC dagger by A. Benke.

A last try for a staging of the flakes was to look and compare the platform remnant thickness. Early removals are ideally done with hard hammer percussion and farther behind the edge, which should result in thicker remnants compared to later removals. Unfortunately, again, A. Benke's inventory did not show marked differences (Fig. 22). The thickness of the remnants peak around one millimetre and decline in number more or less rapidly for thicker remnants.

Although A. Benke's mode of work is distinguishably different from P. Wiking's and G. Nunn's, a comparison with their work has nonetheless been done. The former uses nearly exclusively soft direct percussion with the antler billet, while the latter two start out with hard hammer percussion and continue using hammerstones in late stages. In general, hard hammer percussion with a hammerstone would leave bigger platform remnants than soft organic percussion with the antler billet. But the picture is often not so clear when soft stone

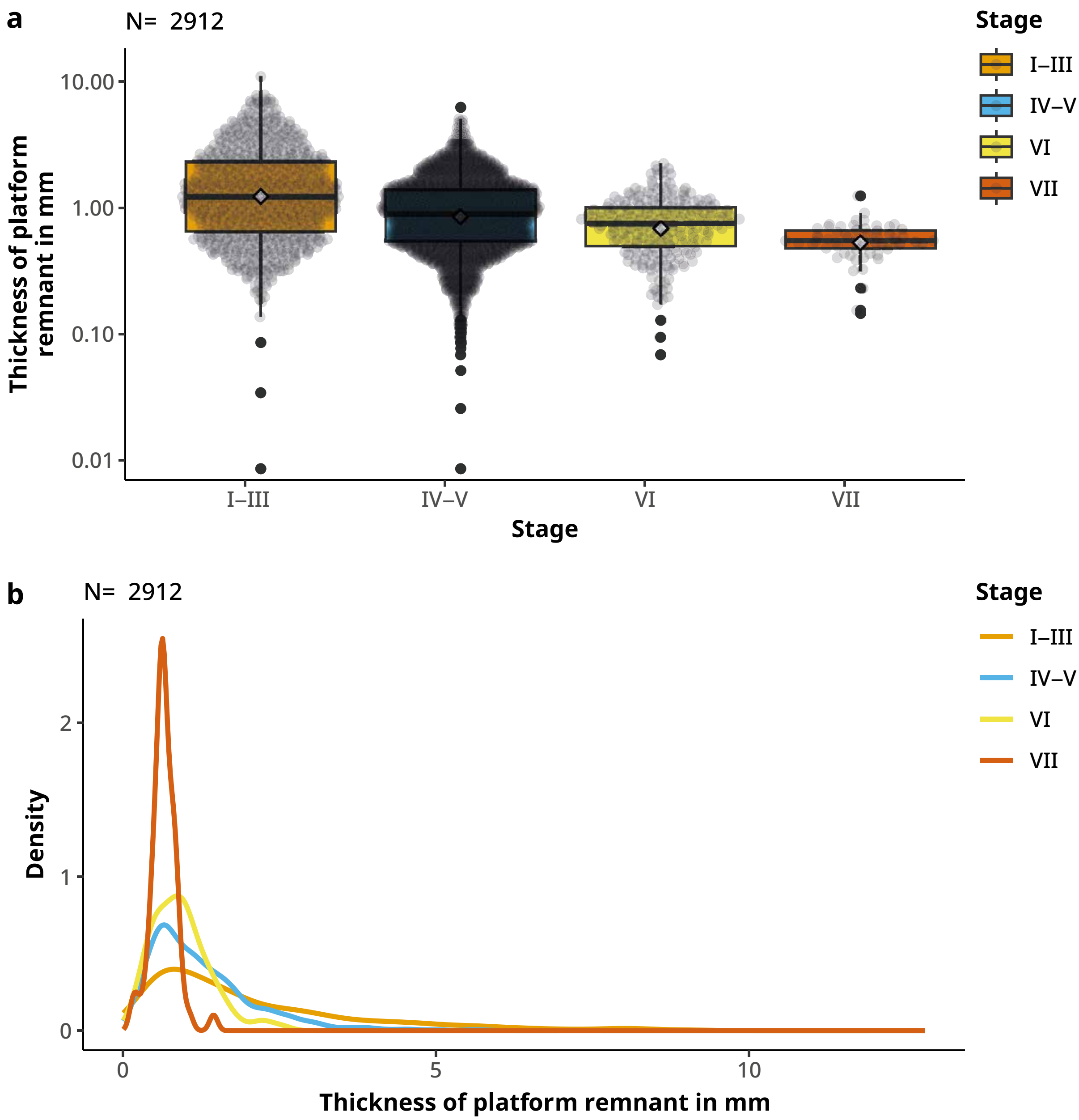


Figure 22. Summary of platform remnant thickness of knapping products from A. Benke's type IC dagger: a) Boxplot of platform remnant thickness by production stage; b) Density distribution of platform remnant thickness by production stage.

hammers are included, as they can be used in a way, which is more in line with organic soft percussion.

In the figures 23 and 24, the distribution of platform remnant thickness for the sickles by G. Nunn and P. Wiking is shown. As no production stage was known for the individual flakes, the size class was used to print the differences. In contrast to A. Benke, a more marked decline in platform sizes can be seen, but the variability in platform size within the size classes is higher. The break in the gentle decline of sizes in G. Nunn's inventory from 2006 (Fig. 23a) is caused by the fact that the last two size classes here also correspond to the sequence of recording. Bags 7 and 8 were not included in the size sorting, as the pieces from bag 7 contained further information regarding the production sequence. The knapping products represent the last removals before the work was halted and resumed the next day, which is represented in bag 8. Due to this, bag 7 contains flakes approximately from the size

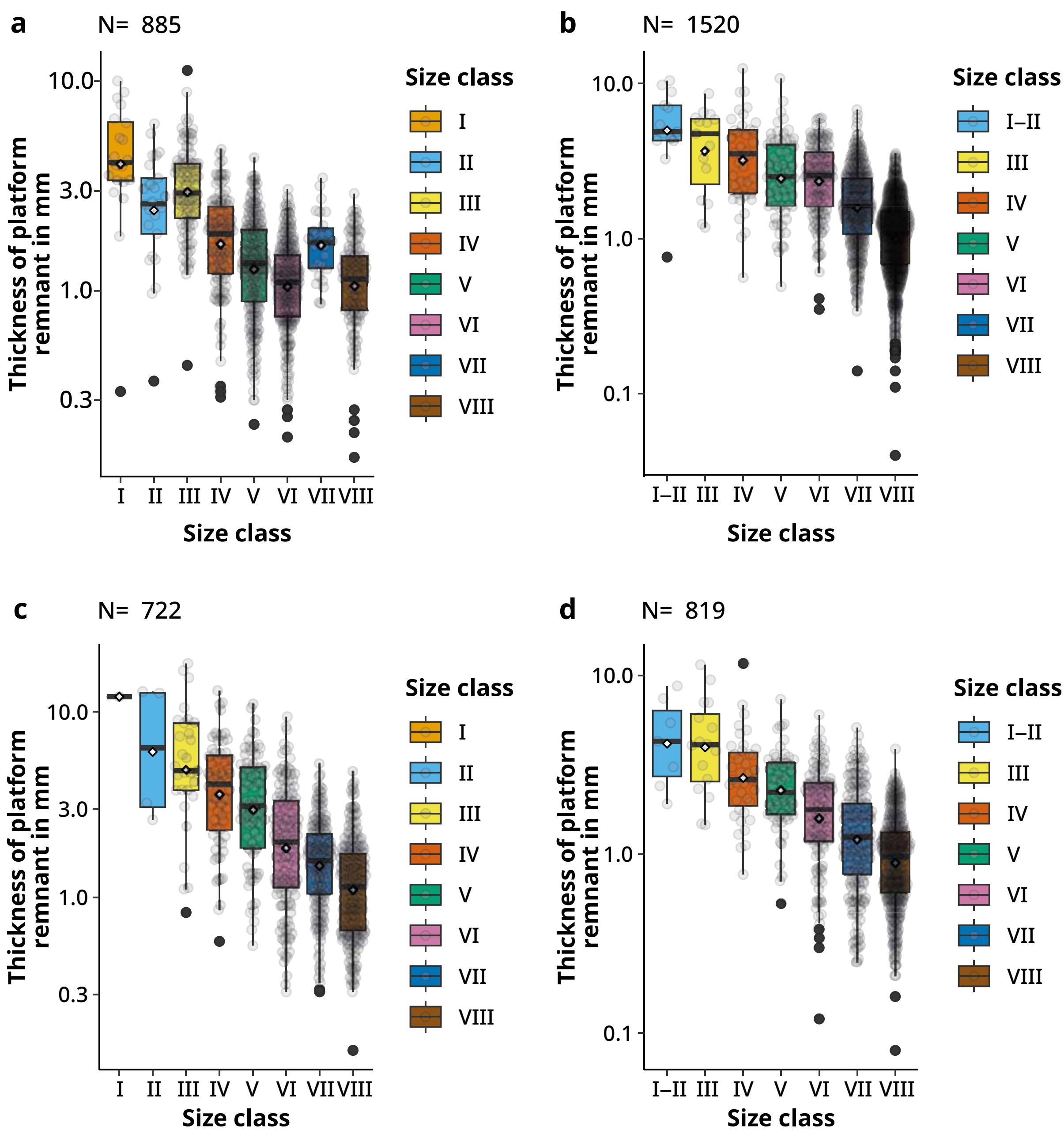


Figure 23. Boxplots of platform remnant thickness: a) G. Nunn 2006; b) G. Nunn 2007; c) P. Wiking 2006; d) P. Wiking 2007.

classes IV-VI and bag 8 from VI-VIII. If the flakes had been sorted accordingly, the picture would have been more in line with the other inventories' distribution. What can be seen is the higher variability in platform thickness compared to A. Benke. This is nicely in line with the higher variability of knapping implements used in their production sequence and also slightly displays the trend, which one expected to see. Seemingly earlier removals – simplified as the lower size classes – tend to have bigger platforms, corresponding to the application of direct percussion with hammerstones. It may not be possible to discern exactly which moment in production that a flake comes from, based on the thickness of the platform, but it is quite obviously possible to draw conclusions about the structure of the work. As can be seen from A. Benke's distributions, a rather restricted involvement of tool types and materials results in a denser distribution and more similar platform thicknesses

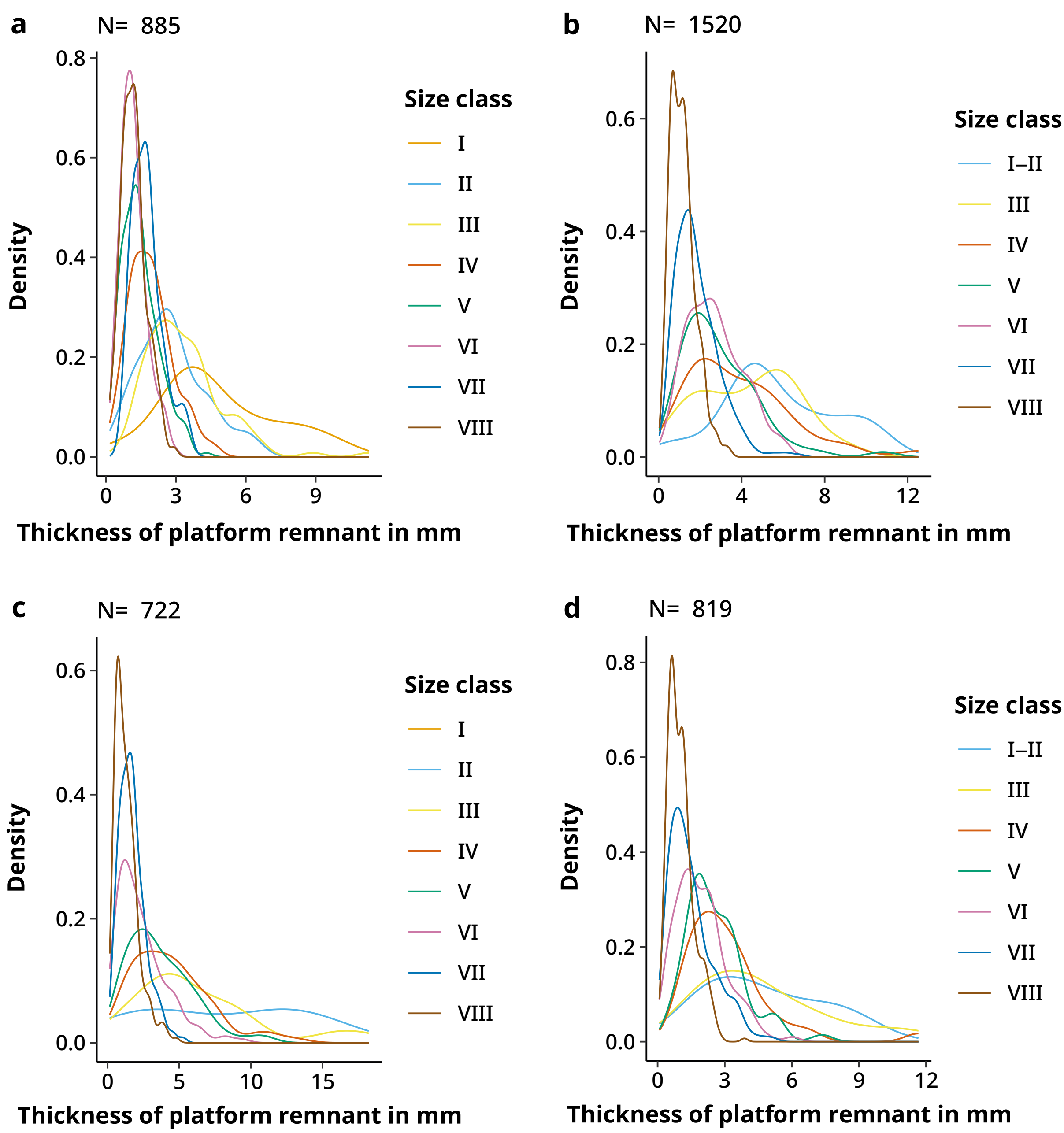


Figure 24. Density plots of platform remnant thickness: a) G. Nunn 2006; b) G. Nunn 2007; c) P. Wiking 2006; d) P. Wiking 2007.

throughout the sequence, while changing application of a variety of tool types and materials shows a more widely spread distribution. This will be explored a bit more in the following analysis.

In Table 18, some statistically descriptive values are summarised for the platform remnant thickness in the inventories of the knappers. The mean and median values underline the tendency, which was seen in the figures 22, 23 and 24: A. Benke has slightly thinner platform remnants on average than the other two knappers, but from the range and maximum thickness it is quite obvious that this does not generally imply thinner platforms. The results based on two inventories are rather vague, but from the table it could be concluded that A. Benke also has a more stable way of working between artefact types; the statistical summaries of platform related values are very similar to each other, while G. Nunn shows a

Knapper and artefact	n	mean	sd	median	min (mm)	max (mm)	range (mm)
Benke_Dolch_IC	2912	1.38	1.15	1.06	0.01	12.8	12.8
Benke_Sichel_2018	1094	1.30	1.28	1.00	0.00	11.8	11.8
Nunn_Dolch-IC	1788	2.13	1.42	1.75	0.10	16.9	16.9
Nunn_Sichel-1.26_2006	885	1.74	1.27	1.38	0.16	11.3	11.1
Nunn_Sichel-3.33_2007	1520	1.68	1.31	1.33	0.04	12.5	12.5
Wiking_Sichel-1.7_2006	722	2.42	2.24	1.73	0.15	18.2	18.1
Wiking_Sichel-2.32_2007	819	1.59	1.29	1.23	0.08	11.7	11.6

Table 18. Descriptive summary of platform remnant thickness per knapper and inventory.

more marked difference between the dagger and sickle inventories. This could also be related to the changing raw material between dagger and sickles. Without further inventories, this is hard to assess. P. Wiking, on the other hand, shows more variation overall in his work, with his later inventory being more similar to G. Nunn's sickle from 2007. A point in favour of the differences between the knappers is the knowledge that A. Benke's knapping strategy is more stable, as he prefers a more restricted tool set during reduction and by this has less variation in techniques implemented than G. Nunn and P. Wiking.

So far, the analysis has not given positive results for a division of knapping products by stages. Shott (1996) made similar observations in his study. It seems that bifacial production always mirrors a continuum rather than a stage distribution, regardless of the mental template with which the knapper proceeds. It was expected that one could see a much clearer division in G. Nunn's knapping products than in those of P. Wiking and A. Benke, but no such thing was encountered.

A division solely based on measurements or cortex cover into stages does not seem possible from the results here. However, it is possible to exclude some production stages based on the attributes, but in a rather vague way. For example, rather big flakes with preserved cortex cannot have been removed in stages after grinding, while it is quite likely that all cortex has been removed even earlier. Still, the technically interesting flakes are the smaller ones from the edge preparation, which unfortunately do not differ significantly in size between the stages. Due to this, no separation of stages for the inventories will be attempted. The technical analysis might contribute to a bit more structure or at least show changing work modes when linked to the descriptive documentation.

5.4 Technical differences in production

As the direct approach by comparing production stages is not possible, the search for significant differences will firstly be based on the description of the technical variations between the knappers (see Subchapter 4.3 and Subchapter 4.4). The most promising differences seem to be the form of the platform remnant and the preparation of the edge.

5.4.1 Preparation before the strike

Figure 25 shows the empirical cumulative distribution of the preparation of edge types for each knapper and inventory included in this thesis. Easily seen is the

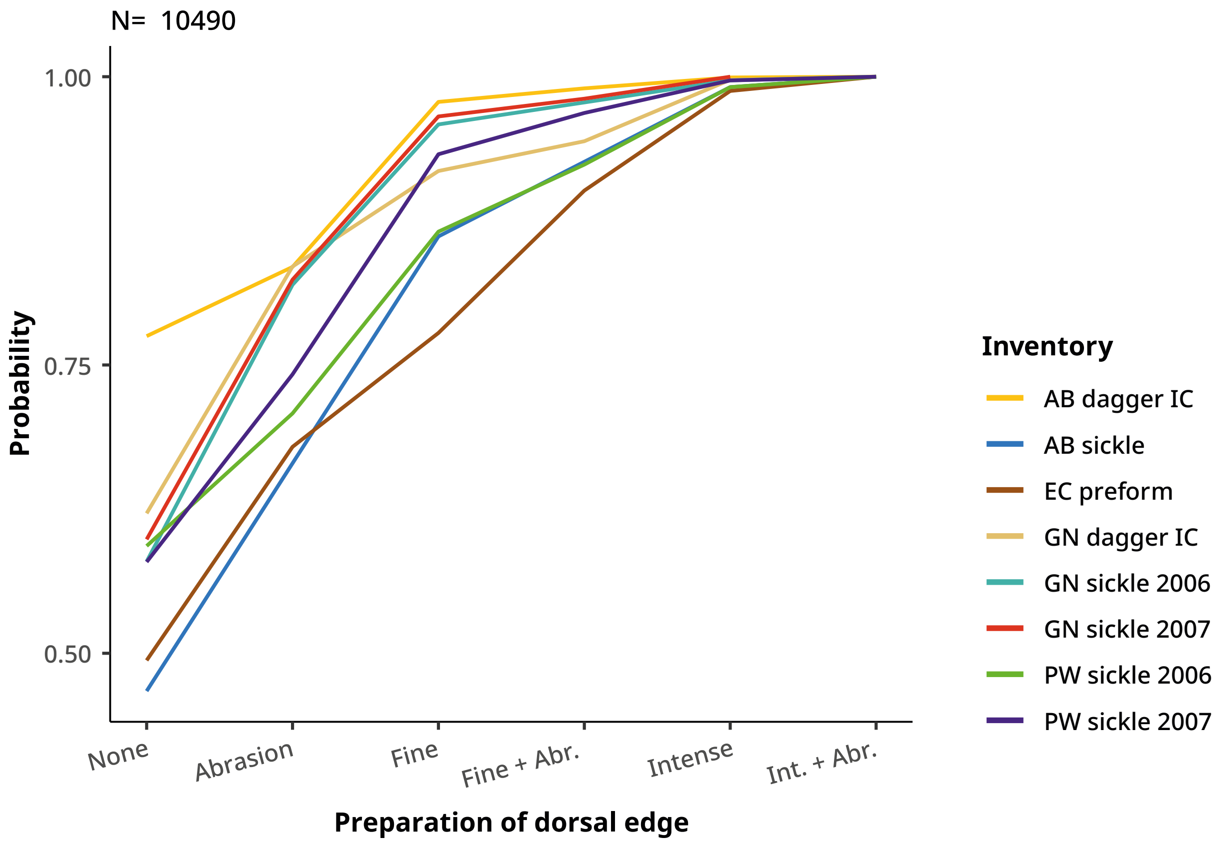


Figure 25. Empirical cumulative frequency plot of preparation forms of the dorsal edge split by inventories.

rather high probability of flakes without any kind of preparation, which had been noted already during the recording and came as a surprise. With the exception of A. Benke's sickle and E. Callahan's dagger preform, all inventories have a probability of more than 0.5 to contain flakes with no preparation of the edge at all. The probability is especially high for flakes from A. Benke's dagger inventory, which is a stark contrast to his sickle. Likewise, for E. Callahan's dagger preform, the low probability is surprising, as it consists only of early stage flakes, where preparation of the edge does not play a major role, as the circumferential edge is still in creation and the blows are more often dealt behind the edge.

For all knappers, abrasion and fine reduction contribute most. The other preparation types and combinations do not contribute much. Exceptions are the sickle inventories by P. Wiking from 2007 and G. Nunn's dagger inventory, which show higher contributions for fine reduction in combination with abrasion and intense reduction. There is no real pattern corresponding to knapper or artefact in production, although some tendencies can be guessed. The probability curves of G. Nunn's sickles resemble each other more than the curve of the dagger, which could indicate that he works slightly different between the artefact types. But the difference could also be explained by raw material, as it differs between the types. P. Wiking's and A. Benke's curves show that they put more emphasis on fine reduction and less on abrasion than G. Nunn. The shift to a higher probability of encountering abrasion and fine reduction in P. Wiking's inventory from 2007 compared to 2006 could be a hint towards a changing style of work, due to the influence of G. Nunn. Without further inventories, it is hard to determine how expressive the differences in the graphs are. Raw material quality and other problems do have a high influence on the time and effort invested into the prepa-

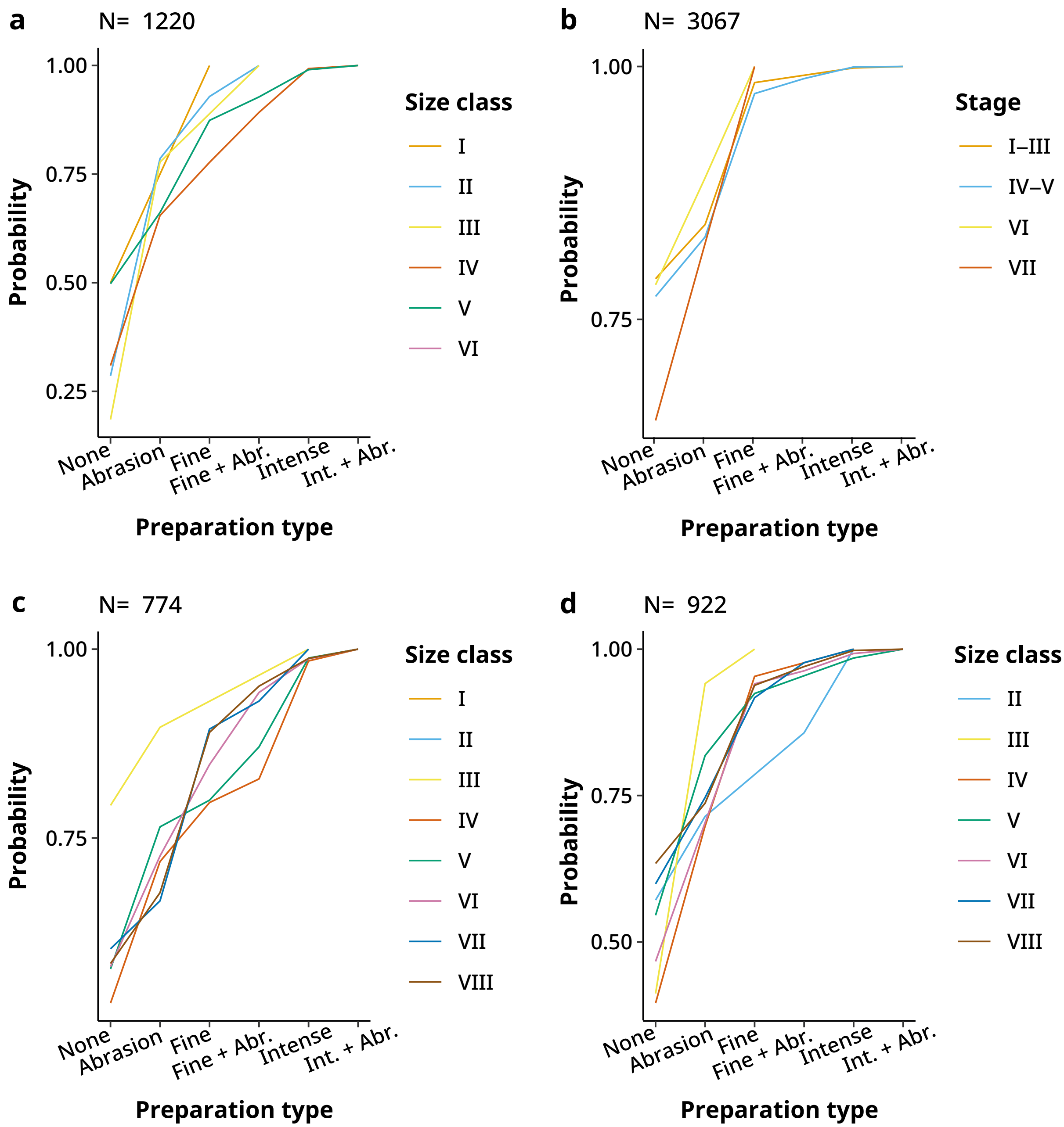
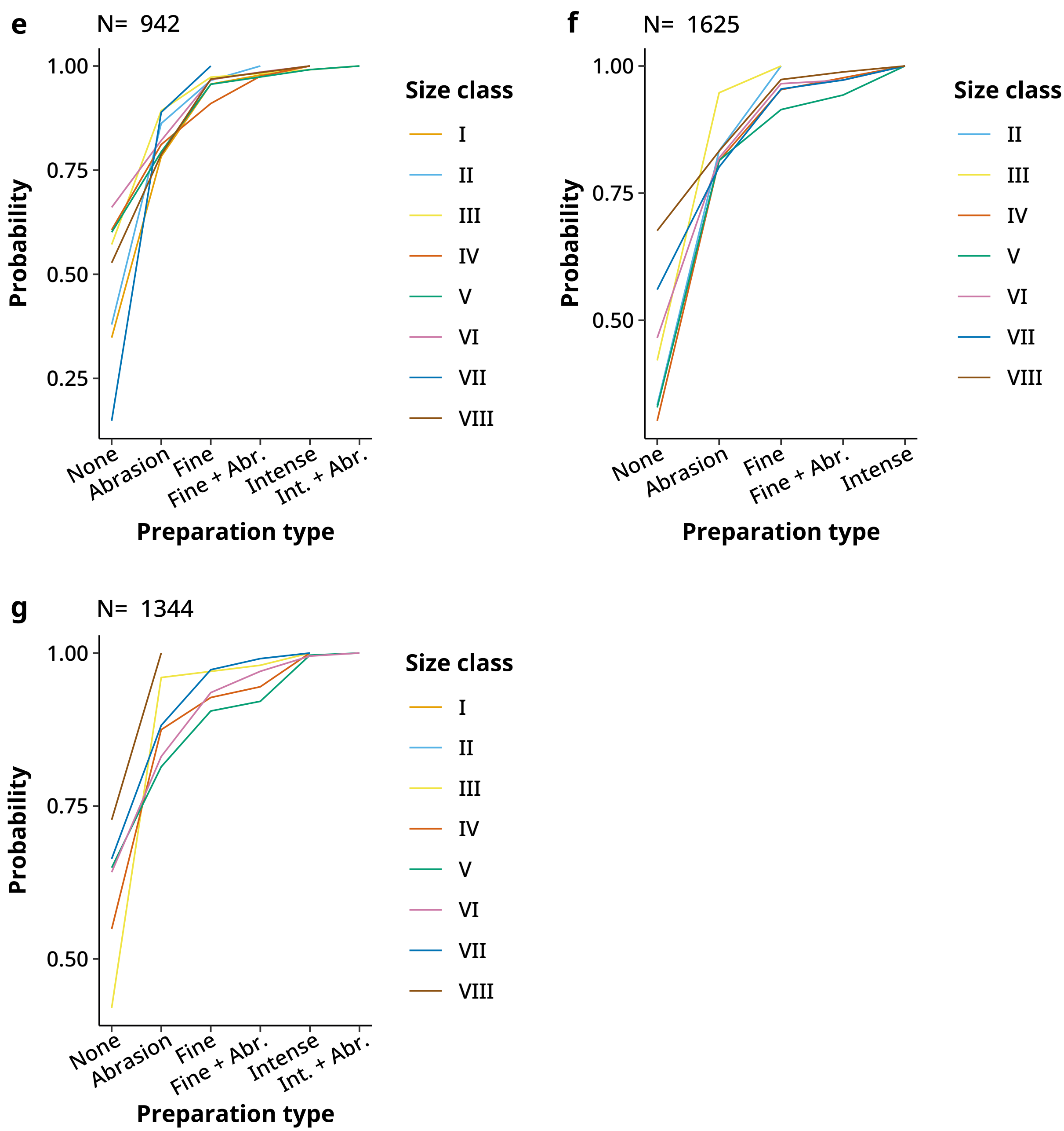


Figure 26. Cumulative frequency plot of preparation forms of the dorsal edge split by knappers: a) A. Benke sickle 2018; b) A. Benke dagger 2021; c) P. Wiking sickle 2006; d) P. Wiking sickle 2007.

ration of the edge and some choices are predefined by the applied technique. Still, it seems there is some leeway for personal preferences.

To get a better view of the personal preferences and differences between knappers, the cumulative curves were applied to the individual knappers and inventories were split up for the size classes (Fig. 26 and Fig. 27). The included size classes for P. Wiking's and G. Nunn's sickle from 2007 differ from the others, as the flakes are smaller in those inventories in general and no really big flakes were removed. This is highly related to the fact that the used nodules were rather small (see Table 14).

Comparing the various curves with each other, it can be seen that G. Nunn has a personal preference for abrading the edge throughout the production sequence (Fig. 27). P. Wiking and A. Benke seem to prefer fine reduction. In general, the curves are more or less aligned between the stages and size classes



for the knappers, which speaks for a rather constant way of working throughout the sequence. Only A. Benke shows some variation between stages in his sickle inventory and a greater variation in the probability of applying preparation. The number of flakes in the size class I is too low to make a statement, but it seems that he prefers abrasion in the early stages, while fine reduction is more prominent in the later stages. At first glance, this seems to contradict the distribution of the dagger inventory, but it can be seen that only his first two stages have a contribution of abrasion, and later stages a higher contribution of fine reduction. If the flakes from the dagger inventory had been recorded for size classes, it would have been expected to see a similar distribution as for the sickle, which sets A. Benke's inventories slightly apart from the other two knappers. Intense preparation seems to have been implemented more by A. Benke and P. Wiking,

Figure 27. Continued cumulative frequency plot of preparation forms of the dorsal edge split by knappers: e) G. Nunn sickle 2006; f) G. Nunn sickle 2007; g) G. Nunn dagger.

especially the latter's first sickle inventory has a high contribution of intensely prepared edges. This distribution gives a rather counter-intuitive picture, having cautious reduction techniques in the early stages, while latter, smaller flakes are treated in a more intense and less careful way. This is possibly also influenced by the size of the flakes. As the distinction between intense and fine preparation was not decided on predetermined metrics, but rather on the extent of preparation in relation to the flake, smaller flakes need a lot less material removed to reach an intense preparation.

The picture of general high probabilities of encountering flakes without preparation does not continue fully in the split curves. Again, there is also a seemingly different approach between G. Nunn and the other two knappers. While the former has a rather continuous range in probability throughout the flake size classes, the latter two display some kind of breaks in the range, although not so much in A. Benke's dagger inventory. A general tendency seems to be that rather big and rather small flakes tend to have a higher probability for no preparation. Assuming the bigger flakes come from earlier stages of production and/or are knapped with hammerstones, while the smaller flakes come from late stages, especially the size class VIII, and are done in pressure technique, this picture fits quite good but does not apply in every case. It is not so clear, why P. Wiking has such a perceptible gap between flakes above and below a probability of 0.5. A similar gap can be seen in A. Benke's sickle inventory, slightly lower than in P. Wiking's inventories. As it is not so clear in A. Benke's dagger inventory, the reason could be the use of the flake size classes, but then G. Nunn probably would have shown a similar distribution, which he does neither for the sorted nor the assigned inventories. The more intuitive approach to the material could be a possible explanation. Due to exploiting possibilities offered by the material, they could use less preparation for certain parts of the work, while some parts require preparation due to technical reasons or also material constraints. This oscillation between having to and choosing not to prepare the edge could translate into the observed breaks in the distribution curves as encountered here. It could also explain, why G. Nunn does not show such a break, as his attitude during work resembles more a 'better safe than sorry' kind of progress, which means he would choose to prepare areas of the edge more often than the other two would. Still it seems that there is no general rule or choice behind the decision to prepare the edge based on stage or the size of the flake that one wished to remove. However, a personal preference in the type of preparation could be detected.

Surprising was the distribution of preparation types in P. Wiking's sickle from 2006 (Fig. 26c). The curves are quite close to the normal distribution and show few increasingly marked slopes like the other knappers. This suggests a more equal application of the various types of preparation. Size class III can be treated as an outlier here. The classes I and II are not represented as no values were available and size class III only includes four flakes contributing to the graph. The high variability in preparation types is not continued in 2007 (Fig. 26d). The output from that year resembles the graphs of the other knappers more, especially G. Nunn's. This could be the impact of the knowledge exchange that they had between the two knapping seasons. More inventories would have to be compared to make a safe conclusion. As it is, the inventory from 2006 could also be different from his inventory from 2007 because of the unfamiliar artefact type. In comparison to the other two knappers, his experience with bifaces at that time was not comprehensive, which meant he probably had to cope with more unfamiliarities than just the form of the artefact and the raw material. Yet, it seems to be a promising indicator for a transmission of knowledge and changing mental templates, while still incorporating personal preferences, because, despite shifting the focus on the less intrusive preparations, P. Wiking continues to prefer fine reduction unlike G. Nunn, who has a higher impact for abrasion.

From a technical point of view, the graphs show the expected spread. Bifacial reduction is carried out with soft organic percussion for the major part (cf. Subchapter 4.1). This implies edges, which are rather stout and smooth, so as not to destroy the billet. In contrast, P. Wiking and G. Nunn use a lot of percussion with stone hammers compared to A. Benke, which does not need as extensive or fine preparation as soft organic percussion. But the major part of the work done with hammerstones is actually preparation and maintenance of the edge, while just a few 'target' flakes are removed with stone the farther the work progresses. From the graphs in figures 26 and 27, the applied technique seems to have a rather slim impact on the chosen type of preparation. The knappers' preferences, possibly also the familiarity with the type of artefact and raw material, seem to have a higher influence on the decision process.

The edge preparation could be treated as ordinal measurements with rising investment in preparation for each category. Considering that abrasion in some cases can represent more invested time and labour than a fine or an intense reduction, the attribute will nonetheless be treated as a nominal variable for the analysis. The test for the independence of the variables from one another is then the Chi-square test, whereas the Cramér's V measure will be used to assess the strength of the relationship between knappers and type of preparation (Argyrous 1997, chap. 20; Drennan 2008, 2099; Heumann *et al.* 2016, 76-77; Carlson 2017, 190-198). Cramér's V measure ranges from 0 to 1, with 1 indicating the strongest relationship, while 0 means no relationship at all.

```
##
## Pearson's Chi-squared test
##
## data: inv_SFPD
## X-squared = 1093, df = 42, p-value <2e-16

## [1] 0.125
```

From the results of the analysis above, the hypothesis that the types of preparation and knappers are independent from another, has to be rejected, as the p-value is very small. But the Cramér's V value shows that the relationship is weak. This does not contradict the evaluation of the graphic representations. What could be seen and also detected in the Chi-square test is a slight difference between personal approaches, but guided by technical necessities.

Like for the edge, work can be invested into the preparation of the platform itself. Already during the assessment of the documentation, differences between the knappers were perceived. In figure 28, these can be seen in more detail. It is quite obvious that G. Nunn and P. Wiking invest more time into preparation before a strike, which is also indicated by the observation that their faceted remnants are more often clearly intentionally worked and not faceted due to earlier removals. A. Benke has a surprisingly high number of flakes without any preparation at all in his sickle inventory. The difference between his sickle and dagger

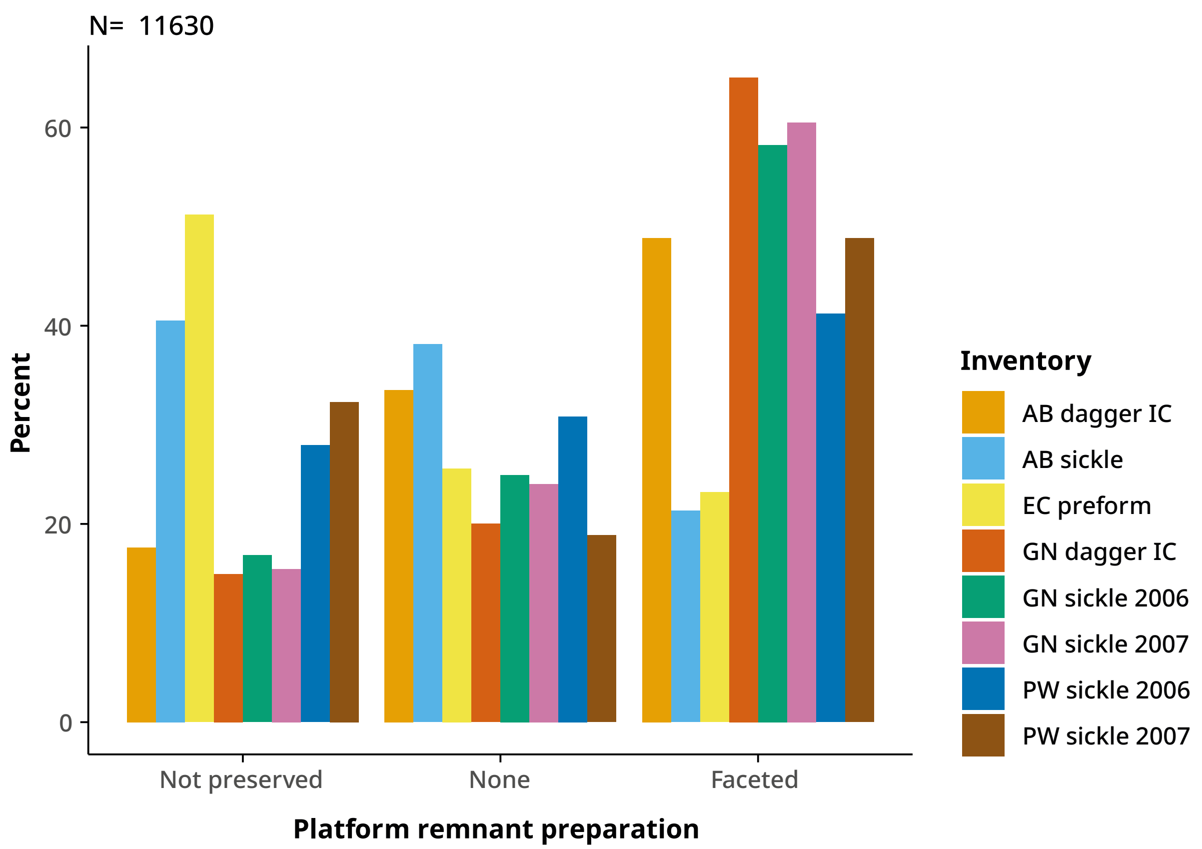


Figure 28. Frequency of platform remnant preparation for each knapper and inventory.

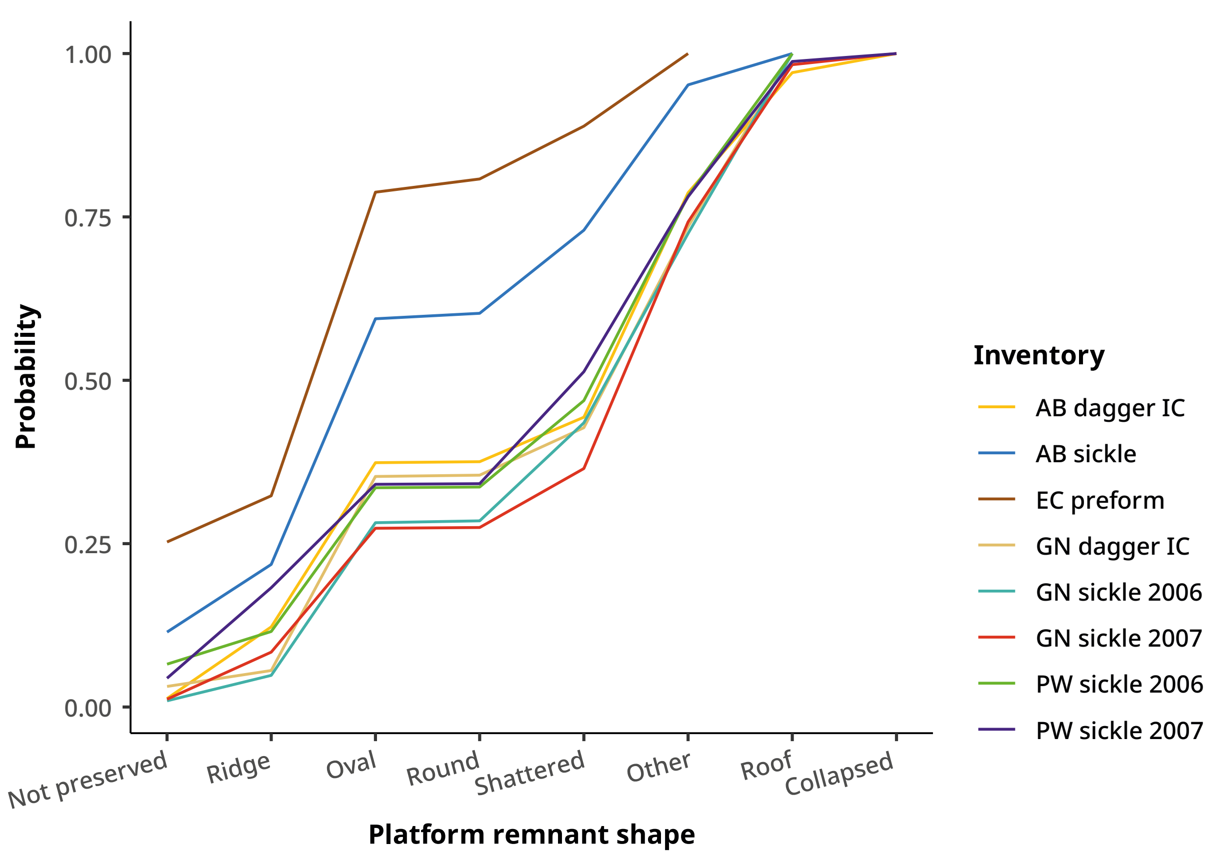


Figure 29. Cumulative frequency plot of platform remnant forms for the included inventories.

inventory can be explained by raw material constraints and a more ambitious approach, which seems to result in a more careful work strategy. Unlike the sickle, the nodule used for the dagger had some critical flaws and A. Benke was a lot more ambitious to keep the maximal possible length. This can be traced in the increase of preparation, not just of the platform remnant but also of the edge (cf. Fig. 25). Moreover, as can be seen in figure 29, A. Benke has a higher contribution of roof-like platform remnants in the dagger inventory than in the sickle inventory, and also the shattered platforms contribute less. The remnants are more similar to the distribution of the other two knappers in the dagger inventory, while the sickle has some offset. Naturally, to get a roof-like remnant, the remnant has to be faceted. The difference between the three knappers here is more the markedness of the roof. A. Benke has quite low and unobtrusive ridges, resembling more incidental negatives meeting most of the time, compared to G. Nunn's and P. Wiking's. This difference cannot be represented in the curves here, but can be shown directly from the artefacts (cf. Fig. 12).

```
##
## Pearson's Chi-squared test
##
## data: inv_SFRP
## X-squared = 956, df = 14, p-value <2e-16
```

```
## [1] 0.203
```

The p-value of the analysis result above does show dependency of the knappers and the preparation of the platform, but again, the Cramér's V test gives a low strength of the association. This would probably have provided better results, if the faceting of the platform had been further divided into intentional and unintentional faceting, which, however, would have been very hard to determine in most cases.

The platform remnant shape is influenced by the chosen technique, but seems also to have been influenced by the personal approach to production. As both of these can and will differ between the knappers and the stages of work, another cumulative distribution was created (Fig. 29). For a technology mostly worked in soft organic percussion, there is a surprisingly little impact by oval remnants for most of the inventories. This could also be influenced by the choice about what to code during the recording. If, *e.g.,* a roof-like remnant has an oval outline, it was nonetheless recorded as roof-like, as it was deemed more significant from the technical perspective.

As roof-like remnants also contribute with a comparable impact, the general picture still speaks in favour of organic percussion (Pelegrin 2000, 78-80). A. Benke's sickle inventory is the only complete inventory, which breaks the picture, having a higher probability of oval remnants and a slightly lower contribution of roof-like remnants. As this is not repeated in the dagger inventory, this has probably less to do with a personal preference for a technique, but is mostly influenced by the material's necessities and the knapper's work mode. Another difference, which can be observed in the curves, is the higher contribution of shattered remnants in P. Wiking's and G. Nunn's sickle inventories. This can be influenced by unfamiliarity with the raw material, which needs less force to flake than the material the knappers normally work with. In contrast, it can also indicate that a less careful approach is chosen when working on the sickles. G. Nunn's and A. Benke's dagger inventories are very much aligned, with the exception that A. Benke has a higher contribution of ridge-like platforms. In contrast to the sickle, A. Benke follows G. Nunn's work template during dagger production, with some adjustments. This seems to show here that the difference with the ridge-like platforms is probably due to A. Benke mainly working with the antler billet throughout production.

Ridge-like remnants are also more common in soft stone percussion. The problem with the vagueness of knapping attributes becomes visible here. From the graphs, A. Benke's inventories, especially the sickle, have a higher impact by ridge-like platforms, which would then have been assigned to the application of soft stone percussion, in combination with other attributes. But from the documentation of the experiments, it is quite clear that he hardly ever applied stone percussion. This is a good example why technical analysis never should be based on single attributes or flakes.

Circular platforms were included to assess the implementation of pressure technique, which was used by all knappers in all inventories, but the occurrence of circular platform remnants is negligible. Likewise, the collapsed remnants do not contribute much. They were only recorded for the last three inventories, as they were made aware to me during the knapping session with A. Benke in 2021. They are indicators for blows dealt with too much force mainly during organic reduction. They were included that late in the recording to see if a distinction could be drawn between knappers, who work mainly with organic percussion, and those who prefer the hammerstone. This does not seem to be the case, but then again, skilled knappers with a lot of experience are compared here. Using too much force during reduction is not likely a problem that they encounter, which can also be seen in the contribution of shattered remnants. The picture could be a totally different one when dealing with inexperienced knappers, who did not have enough time to gain the experience needed to estimate the needed force for the removal of certain flakes.

Similar to the preparation types, the curves of the remnant shapes are mostly identical between the knappers, so the inventories were again plotted by themselves, grouped by stage or size class (Fig. 30 and Fig. 31). Remnants that were not preserved were excluded from the graphs. Slight differences can be observed between the knappers, although nothing so noteworthy as in figures 26 and 27. Not surprisingly, in A. Benke's inventories, oval platforms contribute a lot, likewise also other remnants, which are not as expressive for technical predictions. The other remnant forms are less represented than those in the inventories of P. Wiking and G. Nunn, especially the roof-like remnants. Noteworthy is the higher probability of encountering oval shaped platform remnants in G. Nunn's dagger inventory, compared to his sickle inventories. The sickle inventories are also much more similar to each other than to the dagger inventory. This could indicate that his choices are different between the types, probably indicating that he implements the antler billets more during dagger production. However, it could also be due to the different raw materials worked here. Texas flint has a good quality, but it is not as glassy as Hillerslev flint, which has an impact on the choice of tools and techniques. As the curves are again more like those of A. Benke's dagger inventory here, it seems that there is a slight difference in application of techniques between daggers and sickles. Additionally, the added production step probably also influences the picture. The daggers include a lot more work with pressure flakers, especially during parallel flaking of the surface.

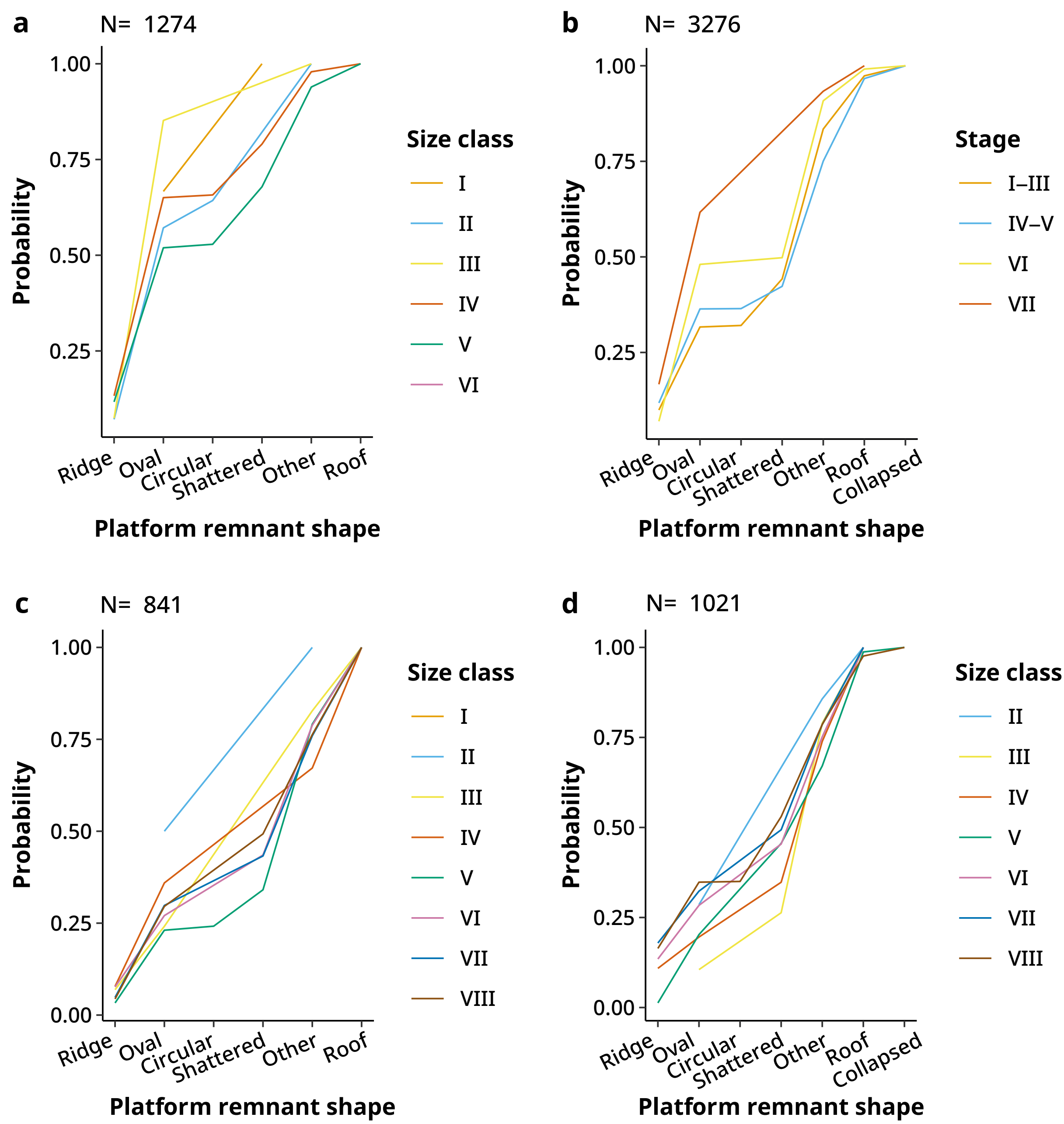


Figure 30. Cumulative frequency plot of platform remnant shapes according to knappers: a) A. Benke sickle 2018; b) A. Benke dagger 2021; c) P. Wiking sickle 2006; d) P. Wiking sickle 2007.

There is again no clear distinction or pattern for remnant shapes by stage or size class, which is in good accordance to the observed application of techniques (see Chapter 4). The sheets for knapping implements used during the work sequences showed that all the techniques were used more or less continuously throughout the production. The curves slightly underline the different modes of working by the individual knappers and artefact types. Indications of the more restricted choice of techniques by A. Benke can be presumed, while P. Wiking and G. Nunn show a slightly higher variability, corresponding to the different choices in technique and tool material. But, without knowing that there is a difference between the knappers, the differences in the curves would probably not be particularly perceptible.

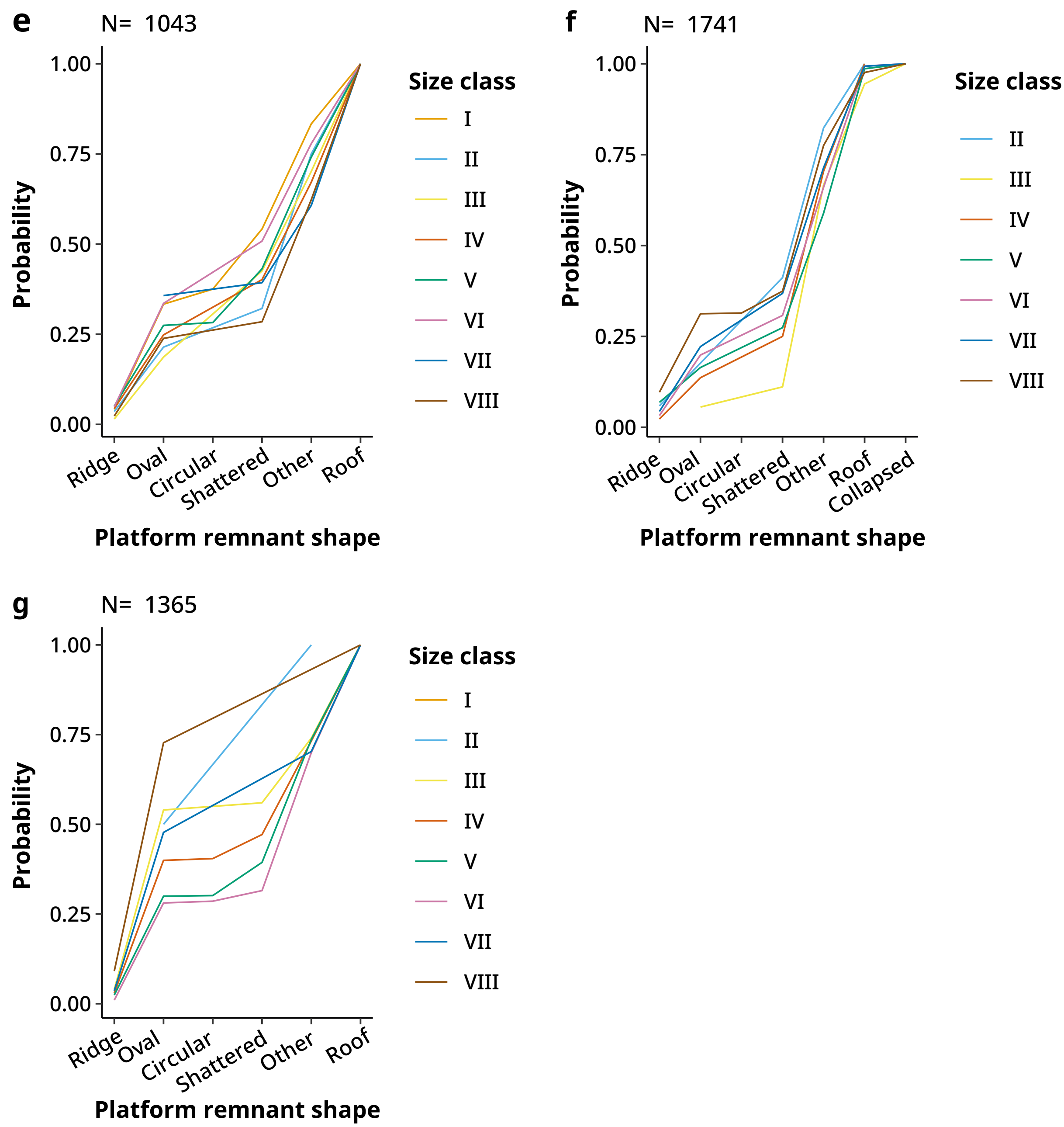


Figure 31. Continued cumulative frequency plot of platform remnant shapes according to knappers: e) G. Nunn sickle 2006; f) G. Nunn sickle 2007; g) G. Nunn dagger.

As we are still working with nominal data, the Chi-square test continues as the appropriate way to test if the distribution of the variables is independent from each other. Likewise, the Cramér's V measure is calculated to test the strength of association.

```
##
## Pearson's Chi-squared test
##
## data: inv_SFRF
## X-squared = 1578, df = 49, p-value <2e-16

## [1] 0.139
```

Again, the p-value indicates that the variables are not independent of each other, but the Cramér's V measure shows that this relationship is a rather weak one, which fits with the results discussed above. The remnant forms are to some extent associated with the knappers, due to the choices in tool application, but a lot of other factors related to the fracture mechanics and the raw material have an influence on how the stone splits and which forms are achieved.

As slight differences were encountered so far, correspondence analysis is used to look for structuring patterns in the relationship of the attributes. For the analysis, the data had to be newly arranged. A table of counts of the presence of edge preparation types, preparation of the platform and the form of the remnant was assembled. Excluded were all rows with missing observations or which were coded as not preserved, as these are mostly comprised of flakes, where the platform remnant was missing or in part missing. Additionally, for the platform remnant, flakes with collapsed and shattered types were excluded, for the former type, because they were not recorded for every inventory and behaved like an outlier in the first test analysis. Furthermore, with both types, they do not so much describe a form, but rather the misjudgement of force of the blow, which was not the question pursued here.

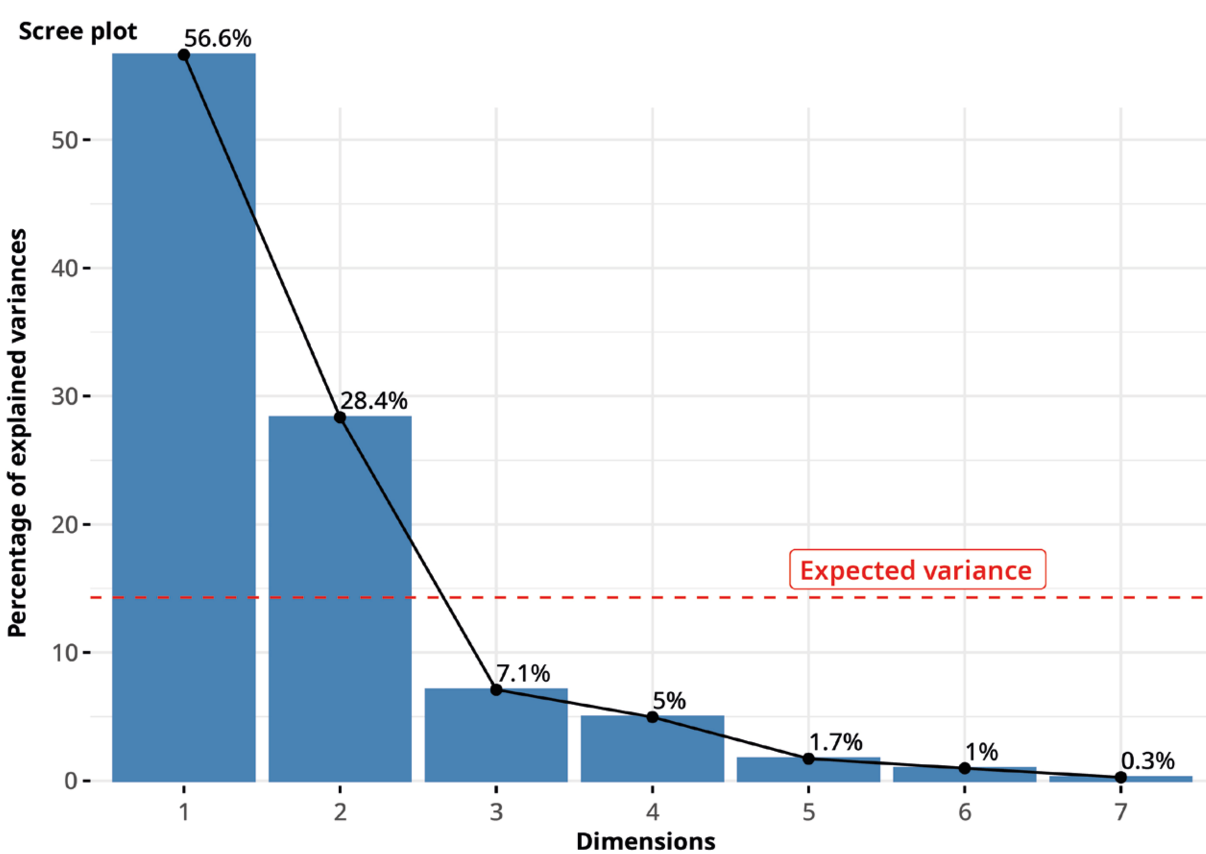
Correspondence analysis is an exploratory test for relationships between categorial variables with the goal of displaying complex data sets graphically. The first step is to determine if there indeed is a relationship between the variables (Backhaus *et al.* 2016, chap. 16; Carlson 2017, 193). This was already done in the steps before, individually for the attributes, so it will not be repeated here. There is a significant relationship between the variables.

```
##
## Principal inertias (eigenvalues):
##
## dim        value           %      cum% scree plot
## 1          0.041766       56.6     56.6 **************
## 2          0.020912       28.4     85.0 *******
## 3          0.005238        7.1     92.1 **
## 4          0.003660        5.0     97.0 *
## 5          0.001268        1.7     98.8
## 6          0.000716        1.0     99.7
## 7          0.000197        0.3    100.0
##            --------      -----
## Total:     0.073756      100.0
##
##
## Rows:
##       name  mass  qlt    inr  k=1     cor    ctr  k=2     cor    ctr
## 1 |  AB202 | 295   987    187 |   9       2      1 |-215     986    649 |
## 2 |  AB201 | 108   986    411 | 518     952    691 |  98      34     49 |
## 3 |   ECBT |   6   826     66 | 716     641     74 | 384     184     43 |
## 4 | GN2005 | 190   756    120 |-133     377     80 | 133     379    161 |
## 5 | GN2006 |  93   765     51 |-131     423     38 | 118     342     62 |
## 6 | GN2007 | 158   677     85 |-152     586     88 |  60      91     27 |
## 7 | PW2006 |  75   126     52 |  80     124     11 |  11       3      0 |
## 8 | PW2007 |  76   424     29 | -97     332     17 |  51      92      9 |
```

```
##
## Columns:
##       name mass  qlt  inr   k=1  cor  ctr  k=2  cor  ctr
## 1  | E_np | 212  909   70 | -61  152   19 |-136  757  188 |
## 2  | E_br |  58  888  159 | -41    8    2 | 424  880  495 |
## 3  | E_fn |  45  466   30 | 133  356   19 | -74  110   12 |
## 4  | E_fa |   9  763   75 | 556  523   69 | 377  241   64 |
## 5  | E_st |   9  533   66 | 361  232   27 | 411  301   70 |
## 6  | E_sa |   1  846   20 | 906  604   22 | 572  241   17 |
## 7  | P_pl | 121  961  173 | 308  897  275 | -83   64   39 |
## 8  | P_fc | 213  961   99 |-175  897  156 |  47   64   22 |
## 9  | F_rd |  11  773   38 | 398  617   42 |-200  156   21 |
## 10 | F_vl | 107  850  116 | 253  800  164 |  64   51   21 |
## 11 | F_rn |   1  926   19 |1061  801   27 | 418  125    8 |
## 12 | F_th | 130  604   28 | -66  277   14 | -72  327   32 |
## 13 | F_rf |  84  914  105 |-285  886  164 |  51   28   10 |
```

In the summary of the analysis above, it can be seen that the first two dimensions explain a high amount of the variation in the data. As we are working with seven dimensions, the expected percentage of variance of a dimension is 14%. This implies that including just the first two dimensions is sufficient for the analysis, although the 'elbow', the distinctive bend in the curve, happens at three dimensions (Fig. 32). In the summary of the correspondence analysis, a column 'qlt' is displayed, which stands for quality and describes how well the extracted

Figure 32. Scree plot of the correspondence analysis of preparation.



two dimensions represent the rows and columns in per mills. It can be seen that all the preparation types (columns) are reasonably well represented, with the fine type of edge preparation (E_fn) having the lowest quality. For the rows, it is remarkable that P. Wiking's inventories are least well represented, with quite low qualities, differing markedly from the other inventories.

The k-columns are the coordinates for the dimensions which will be used later for the plotting of the analysis. The cor-columns are more interesting here, as they represent the squared correlation of the rows with the dimension. They are also given in per mills, which means that a value of 1.000 would indicate a perfect fit of the row variability with the dimension (Carlson 2017, 287). The ctr-column shows how much a row contributed to the definition of the dimension. It can be seen that A. Benke's inventories are the major contributors to the first two dimensions, respectively, and also fit best into the respective dimension, while P. Wiking's inventories do not contribute much and also are not described very well by the dimensions. For the columns, the major contributors are the preparation of the platform in the first dimension and to some extent platform remnant forms. In the second dimension, the major contributors are edge preparation types, namely abrasion and no preparation (E_br and E_np).

It does not become immediately clear from the biplot (Fig. 33) which kind of variability is explained by the axis of the first dimension. A probability is the form of the platform remnant, with roof-shaped remnants on the left and round remnants on the right. It could also imply that size is a factor here, as round platforms tend to be generally smaller than the other platform types. But in this case, the inventories would probably be aligned in another way, as E. Callahan's inventory is just comprised of early flakes and by this has a higher number of bigger remnants than the other inventories. It could also indicate a decline in invested labour, as faceted platforms are closely aligned with the roof-like forms, and plain remnants are located farther to the right. Also along the second dimension, some kind of workload for the preparation of the edge seems to be displayed, with less input in

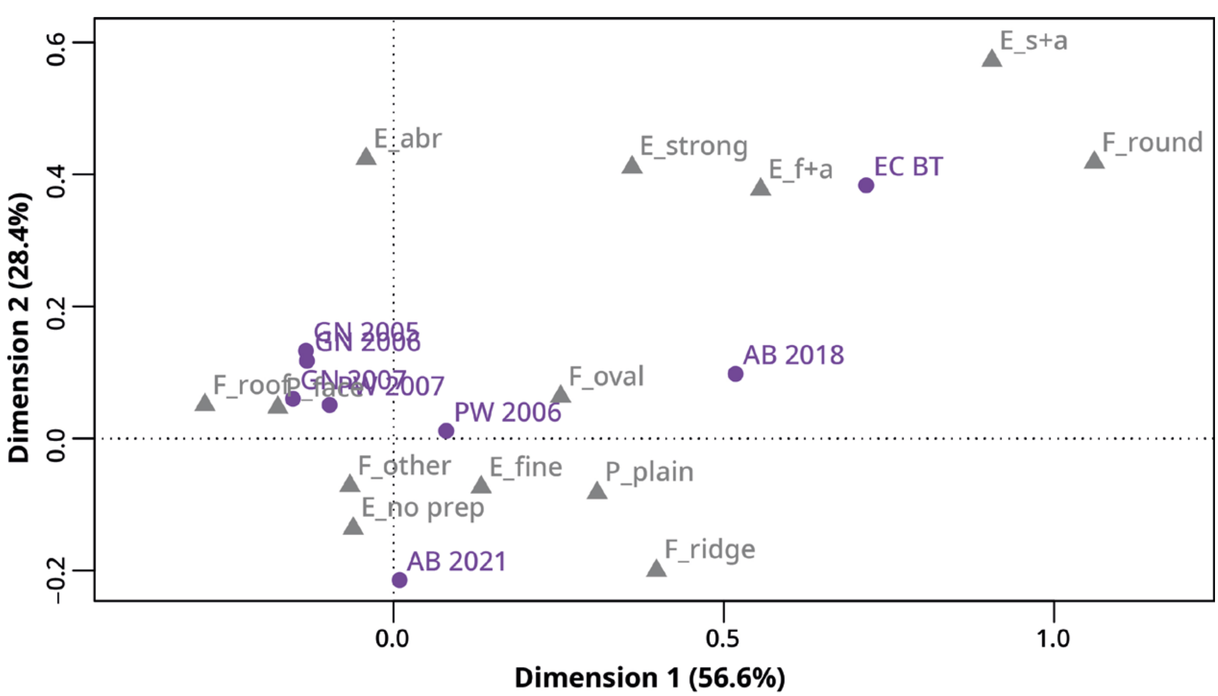


Figure 33. Biplot of the correspondence analysis of preparation types.

the lower half and more input in the upper half. In the lower half, we find edges without preparation as well as unfaceted remnants and at the highest point in the upper half the strongly prepared edges. This does not imply any kind of statement of the intensity of preparation, as fine reduction and abrasion can be – and have been done – in a far more intense way than strong reduction. But, a strong reduction tends to remove more material than an intense abrasion can.

As E. Callahan's inventory just represents the first few production steps, it was not clear how much influence this had on the analysis. Another analysis excluding the test inventory was conducted. Beside the flipping of the coordinate system, no changes in the positioning of the variables and inventories happened. Moreover, the percental contributions of the dimensions also did not change significantly. It was decided to keep the analysis with his inventory. It should be kept in mind that not every production step was available here and the position would definitely be different if a full inventory by E. Callahan had been included. Likewise, the dagger inventories could have a stronger influence on the analysis, as they include the highest number of flakes. Another test was run, excluding them. No major changes were encountered except the change that P. Wiking's inventory was the major contributor to the second dimension, while the other inventories did not contribute much and generally fitted better in the first dimension. Again, the analysis's results were not included due to time restrictions of the project.

The largest part of the variability of the inventories seems to correspond to the workload of preparation and it seems that the tendencies seen before are also described here and really do mark patterns in the data. At least G. Nunn's inventories seem to form a group together. Noteworthy is also the approximation of G. Nunn's and P. Wiking's inventories from 2007. It seems that the change in procedure noted before is also observable here.

In the biplot, some groups seem to be formed from the variables. Slightly above the 0.0 intersection on the left side of the plot, roof-shaped and faceted remnants seem to be closer together. More in the middle lower part of the plot no and fine edge preparation seem to be closer associated with plain platforms as well as other, oval and ridge-like forms. In the upper right part of the plot, the variables are spread more across the space.

Likewise, groups of inventories were perceived. G. Nunn's inventories seem to be more similar to each other and closely associated with roof-shaped and faceted platform remnants, which was already noted during the recording. P. Wiking's inventory from 2006 lies a bit in between the groups of the variables, which also fits well with the observed conditions. Both G. Nunn's and P. Wiking's inventories from 2007 depart from the respective earlier inventories and seem to form a group together, which underlines the slight changes in production which had been noted. It is especially noteworthy for G. Nunn, as his changes were not so pronounced, but the position of his 2007 inventory in the plot shows a rather marked offset from his earlier works. A. Benke's inventories do not form a group and show the highest variability among the knappers, which also fits quite well with the more intuitive approach in comparison to the other two knappers.

As the visualisation can be misleading, cluster analysis was conducted to see if the observed groups are represented in the data (Backhaus *et al.* 2016, 625). As a frequency list was used for the correspondence analysis, the same data set was used for the cluster analysis, meaning analyses for count data had to be used. To have an unbiased result, hierarchical clustering was used, which does not need a priorly defined number of groups, as for example, k-means clustering (Carlson 2017, Chap. 15; Baxter 2015a; Backhaus *et al.* 2016, 476; Lowrimore and Manton 2016; Schmidt *et al.* 2022). The first step for data sets of counts is a transformation of the data, as Euclidean distances should not be applied directly (Legendre and Legendre 2012, 300; Schmidt *et al.* 2022). There are different ways to transform the data, here the chord-transformation was used before calculating the Euclidean distances, as the occurrence of rare types was not deemed to be the main reason for dissimilarity in the types (Legendre and Legendre 2012, 301-302; Schmidt *et al.* 2022). Ward's method was used for the analysis. It looks for clusters in multivariate Euclidean spaces by minimising the increase in the sum of squares within clusters (Aldenderfer 1982, 63; Shennan 1988, 217-232; Murtagh and Legendre 2014, 275; Baxter 2015a, 142; Carlson 2017, 334). The method strives to form groups that are homogeneous by combining objects which do not expand the variance of the group significantly (Aldenderfer 1982, 63; Shennan 1988, 217; Baxter 2015b, 158; Baxter 2015a, 142; Backhaus *et al.* 2016, 484). In other words: Ward's method forms groups based on the similarity of objects. Working with the hclust package of R, the ward.D2 method was chosen, as it produces true ward distances (Murtagh and Legendre 2014, 294). Nonetheless, different transformations and cluster methods were tried during the analysis[12] (Aldenderfer 1982, 70; Shennan 1988, 229-230; Baxter 2015a, chaps. 7 and 8). All analyses yielded similar results, which strengthens the solution of clusters obtained. The choice for displaying Ward's method was based on the notion that it is the seemingly more appropriate approach to the data. The average linkage algorithm produces exactly the same clusters with slightly different fusing of clusters in the last step. Some problems with Ward's method are that it tends to form spherical clusters of the same size and does so although presented with totally random data (Baxter 2003, 93; 2015a, 158). On the other hand, the method has also been identified to ignore clusters if they are not spherical (Baxter 2015a, 158) and due to this, it has problems with correlated data, which does not form spherical clusters (Baxter 2015a, 167). The positive side of Ward's method is that it does not form clusters based on individual observations, such as single or complete linkage, which leads to better interpretable clusters (Baxter 2003, 93; 2015a, 146). In general, the choice of method and algorithm is a more pragmatic selection than a methodological one (Baxter 2015a, 160). In the end, the result has to help the interpretation and further knowledge on the topic. Although it has been mentioned that a better integration and discussion of all the results obtained from differently applied techniques and algorithms should be done (*e.g.* Baxter 2015a), due to time constrictions this was regrettably not done here.

To see how many clusters would be meaningful, a scree plot was calculated (Fig. 34) (Backhaus *et al.* 2016, 495-496). The first distinct elbow in the curve happens at two clusters. Additionally, the silhouette plot identifies two clusters as optimal for the data set (Fig. 35).

Figure 36 shows the dendrogram of the hierarchical clustering. At first glance, it seems to mirror the groups identified from the correspondence analysis, clustering G. Nunn's inventories together with P. Wiking's inventory from 2007 and leaving the other slightly more independent from each other. But, as the analysis identified only two clusters, this picture does not prevail. The red boxes highlight the identified clusters by the analysis and do not help to identify structures for work, artefact type or knapper, although G. Nunn's inventories seem to be more similar to each

12 Applying different techniques has been done in every analysis, when possible and reasonable, but will not be commented due to the reasons stated below.

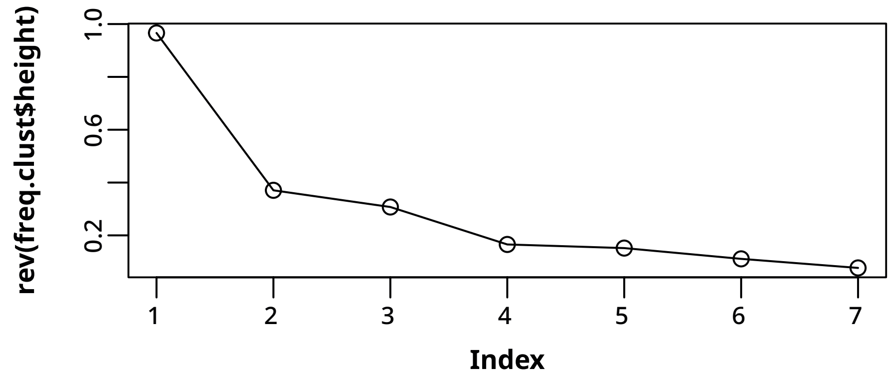


Figure 34. Scree plot for preparation types with hierarchical clustering.

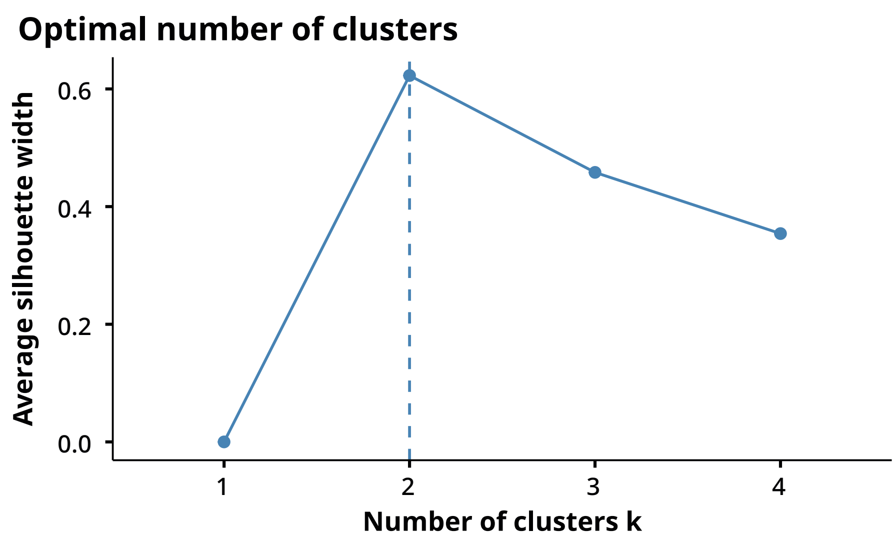


Figure 35. Silhouette plot for preparation types with hierarchical clustering.

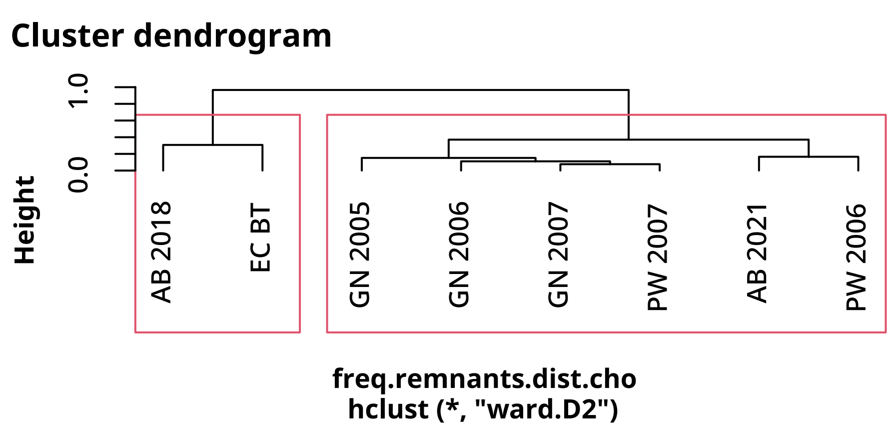


Figure 36. Cluster dendrogram of the hierarchical cluster analysis on preparation types and highlighted clusters.

other than to the others. Likewise, P. Wiking's inventory from 2007 also seems to be more similar to G. Nunn's work than to his prior work and A. Benke's, who shows the greatest variability in the clustering. Moreover, it is also the dagger inventory, which is more similar to G. Nunn's work here, and whose production was influenced to some extent by G. Nunn's work, as already mentioned.

The last step is to validate the identified clusters and compare the quality of the clusters. This can best be done in a silhouette plot, which calculates an index for the individual points and clusters ranging from -1 to +1. High values close to +1 indicate very well-clustered points, while -1 suggests the wrong placement

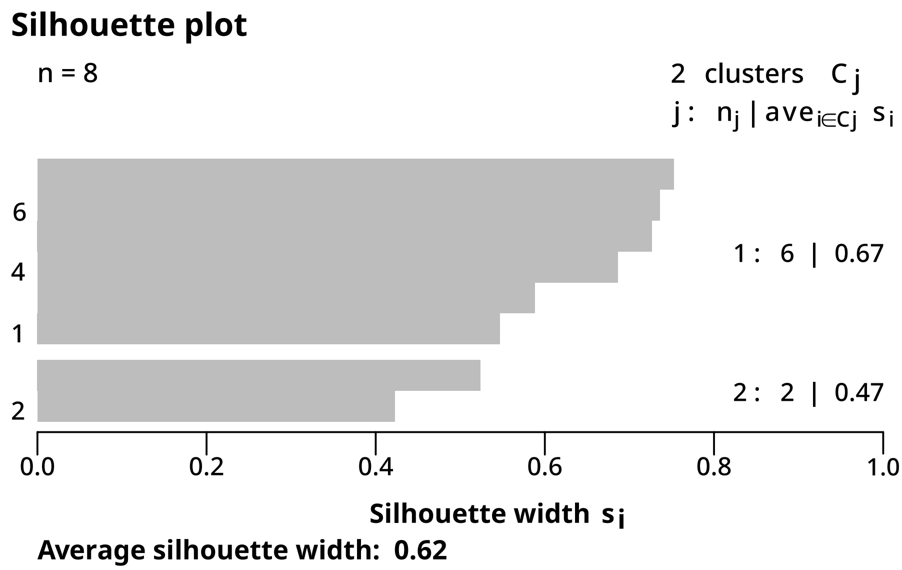


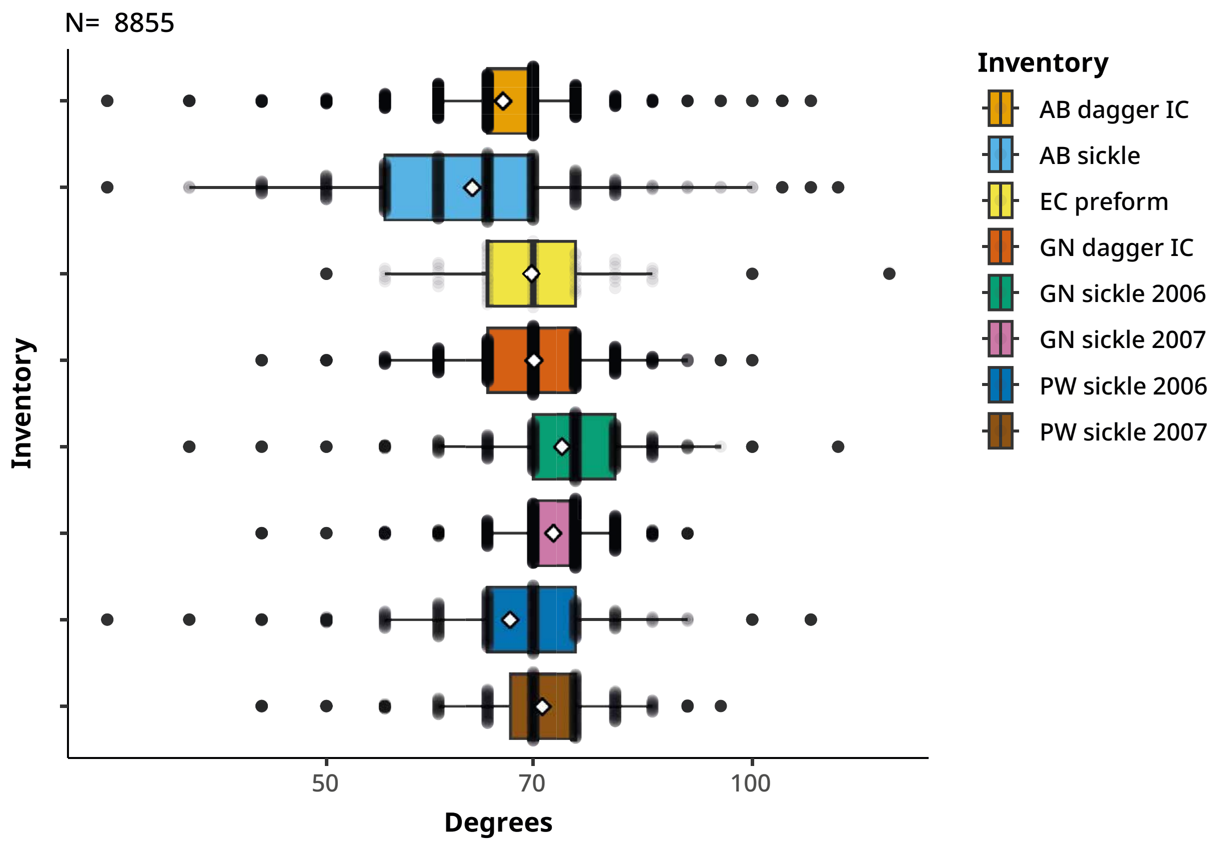
Figure 37. Silhouette plot of the hierarchical clustering.

inside a cluster. Values around 0 show a placement in between two clusters (Rousseeuw 1987; Carlson 2017, 330). From figure 37, it can be concluded that the clusters are reasonably well separated, with an average distance of 0.62. Cluster 1 is better separated than cluster 2, which has a considerably lower distance.

In conclusion for the work related to edges and platform remnants, it can be said that the personal differences, which were encountered during the assessment of the documentation and recording of the artefacts, are not so strongly expressed in the statistical analysis. This was expected to some degree, as the recording needs a necessarily simple coding to be comparable. This simplicity does cover the distinguishing details, but still some hints were encountered where to look for differences. Likewise, the differences between production processes could not be defined clearly. The analysis split up for size classes did help a bit in identifying tendencies during production, but results would probably have been better, if the individual flakes could have been assigned to a specific stage of work or even better to a specific work goal. In contrast, the statistical analysis also revealed patterns, which had not been perceived so clearly from the material. A shift in P. Wiking's inventory was vaguely perceived between 2006 and 2007, without being able to exactly pinpoint the difference between the inventories. The later inventory was more similar to G. Nunn's work without being particularly identical. The change in the curves of the preparation of the edge as well as the correspondence analysis show this notion quite well. Furthermore, in the cluster analysis, those two inventories are the first ones to be combined, marking them as more similar to each other than to the other inventories. While the cumulative curves suggested an influence, the correspondence and cluster analyses show a more marked shift of P. Wiking's variable types to resemble G. Nunn's more. Although it was not possible to really detect changing choices of techniques during production, the variability in tool choice was detectably different between the knappers. This is an important result, which is applicable to archaeological contexts.

5.4.2 Tracing differences in the application of techniques

In the next part of the analysis, the focus will shift more to the technical attributes, which are more determined by the applied technique and do not leave much room



Knapper and artefact	n	mean	sd	median	min (°)	max (°)	range (°)
Benke_Dolch_IC	2553	67	7.8	70	35	110	75
Benke_Sichel_2018	1000	64	10.1	65	35	115	80
Nunn_Dolch-IC	1740	70	7.3	70	45	100	55
Nunn_Sichel-1.26_2006	832	74	7.9	75	40	115	75
Nunn_Sichel-3.33_2007	1384	73	6.4	75	45	90	45
Wiking_Sichel-1.7_2006	679	68	8.8	70	35	110	75
Wiking_Sichel-2.32_2007	667	71	7.4	70	45	95	50

Figure 38 (top). Boxplot of exterior edge angles by knapper and inventory.

Table 19 (bottom). Descriptive summary of exterior edge angle per knapper.

for personal variation. Once more, the analysis will start out by looking at single attributes and comparing characteristics and frequencies between knappers, before moving on to multivariate statistics.

Fracture mechanics set the range of possible exterior edge angles for the successful removal of flakes. The termination will fail or the flake will not detach if the angle is too obtuse or too acute. In general, the ideal exterior edge angle is around 70°, but the possible range in which a flake is removed successfully varies a bit between applied techniques. This implies that there is some room for personal variation in chosen angles, be it a conscious or unconscious selection. Figure 38 shows the range of measured exterior edge angles on the flakes in the different inventories. Not surprisingly, the values are distributed around 70° with sometimes quite high or low outliers. Again, the overlap is very large. From the figure and also Table 19, it seems that A. Benke prefers angles below 70°, but still has the highest range of occurring angles. Commonly, it is said that a removal with angles above 90° is not possible, but exceptions have been recorded (Pelegrin 1994; Méry *et al.* 2007; Dibble and Rezek 2009). Flakes or rather blades with such exceptional angles are mostly attributed to skilled knappers and indirect or pressure technique, as the removal needs a high level of control to be successful. For all inventories included here, these points apply, except for blade production which was not conducted. All three knappers are very skilled and have applied indirect and/or pressure technique. Some of the values above 90° could certainly be measurement errors (see also Subchapter 3.2.2), but in general the values are possible although probably not strived for.

Another interesting thing to note in Table 19 are the seemingly close values for G. Nunn and P. Wiking from 2006 to 2007. They already work with quite equal angles in 2006, but in 2007, the range has narrowed down notably for both and the mean angle value is more aligned than before. This can again have more reasons than that the two knappers exchanged experiences. With regard to G. Nunn's dagger inventory, it is also likely that the first sickle was kind of an outlier in the way he works. Again, it must be stressed that all three knappers were not familiar with the artefact type before being asked to replicate a sickle, and the raw material was likewise either unfamiliar or not the usual material that they worked with. All this can have an important influence on the technical choices and also on the willingness to take risks during the production.

The goal remains to look for significant individual differences in the production sequence, thus the density of the chosen exterior edge angles was plotted for each inventory and grouped by production stage or flake size class (Fig. 39 and Fig. 40). On first sight, the curves do not show much difference in angles grouped by size classes. In some cases, more obtuse angles happen more often on flakes from the higher size classes. For the sake of simplicity, let us consider the lower size classes (bigger flakes) as originating from the first stages of production and the higher size classes (smaller flakes) as coming from the later stages. For the sequence applied by G. Nunn and P. Wiking, this would imply the use of hammerstones in the early stages, which would explain the more obtuse angles. As a reminder from Subchapter 3.2.2, direct percussion ideally exhibits angles between 60-90° or 75-80° for hard or soft stone, respectively, while organic direct percussion is associated with angles ranging ideally from 60-80°. Pressure and indirect technique are ideally worked with angles around 80-90°. So more obtuse angles in early stages are exactly what was to be expected, when looking for percussion with hammerstones. The picture then becomes more diffuse in the stages in between, as both knappers skip back and forth between a variety of antler billets and hammerstones, and at least in P. Wiking's case, between direct and indirect technique. The only clear shift between stages can be seen in A. Benke's dagger inventory, where the final pressure flaking has a clearly narrower range and peaks at a more obtuse angle than the rest of the production knapping products, fitting the observation of ideal angles for pressure and indirect technique. The likewise narrow and pronounced curve of flake size class I in his sickle inventory can be ignored as a statistical outlier, as only two observations contribute to the curve.

A bit puzzling is that G. Nunn's and P. Wiking's curves look much alike in both years. In 2006 (Fig. 39c and Fig. 40e), nearly all size classes peak around 70°. In 2007

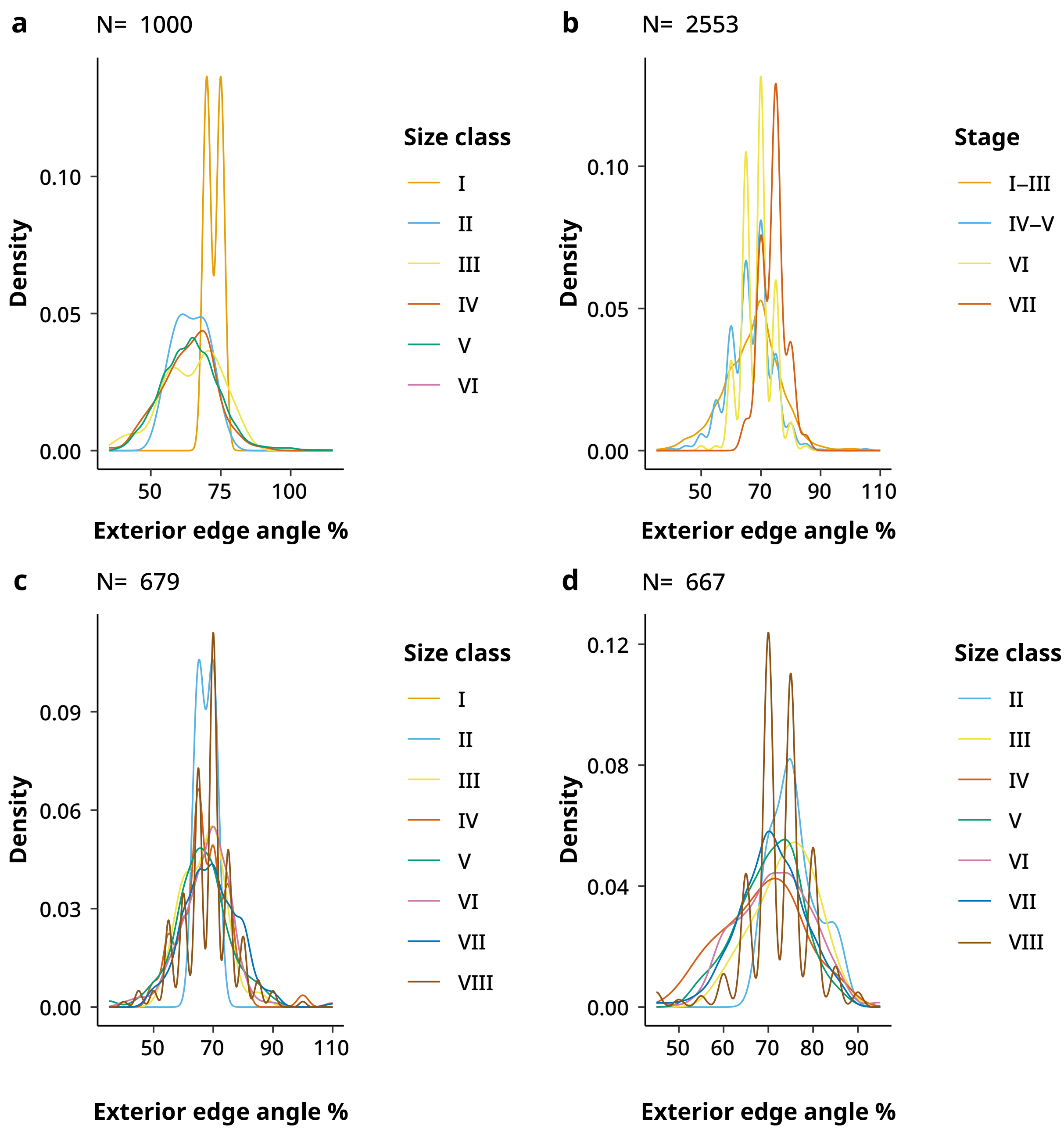


Figure 39. Density plot for the exterior edge angles by production stage or size class for the individual inventories: a) A. Benke sickle 2018; b) A. Benke dagger 2021; c) P. Wiking sickle 2006; d) P. Wiking sickle 2007.

(Fig. 39d and Fig. 40f), the bigger size classes are shifted to slightly more obtuse angles. It could still be that the curves differ due to the unfamiliarity with the artefact type and raw material in 2006, which leads them to stick closer to the ideal way of working, compared to 2007, when then their personal preferences could be prevailing. To answer this, more inventories would have to be recorded and analysed.

Probably, there would have been more marked differences between the stages of A. Benke's curves if he had used more and different percussors in his work. The signal of direct organic percussion is obvious. The application of pressure technique has not enough impact to show in the curves for the sickle. The graph of the dagger inventory shows again impressively, how the final pressure retouch is distinguishable from the rest of the production, peaking at a slightly more obtuse angle than the rest of the knapping products. It would have been

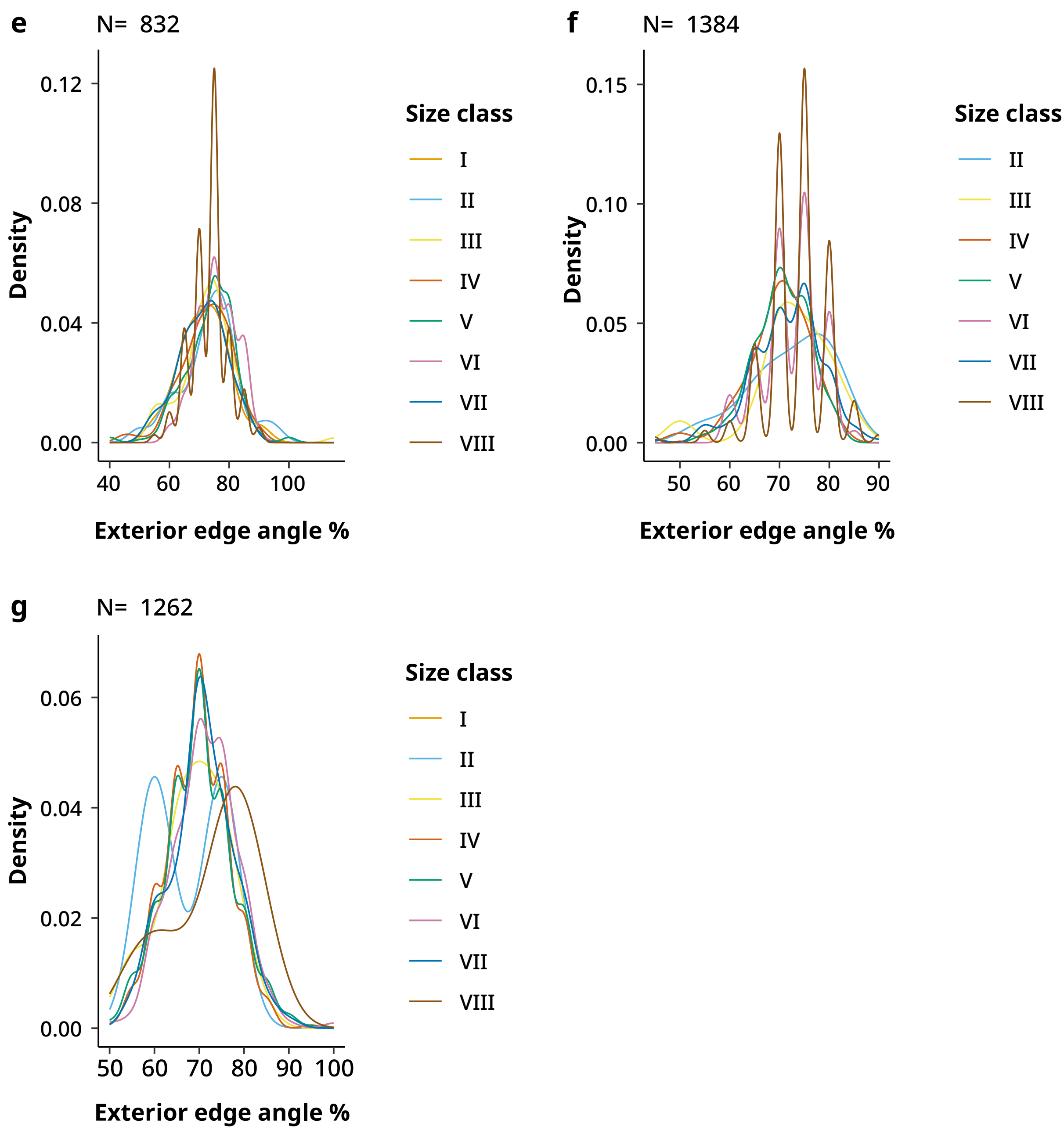


Figure 40. Density plot for the exterior edge angles by production stage or size class for the individual inventories: e) G. Nunn sickle 2006; f) G. Nunn sickle 2007; g) G. Nunn dagger.

interesting to compare this to the other two knappers, but size class VIII does not only contain the pressure retouch flakes, and so the density is influenced by other techniques. It would also be quite interesting to see if there are differences between pressure applied with different materials. The pressure here was done solely with copper, but it would also have been possible with antler. P. Wiking even suggested final retouch with flint as a pressure medium, resulting in an even sharper edge of the artefact (pers. com. 2022). Comparing the results of pressure retouch flakes done with different materials could give further answers to the question of available and utilised techniques in the archaeological record. Final pressure retouch flakes are more or less easily recognised and selected from the inventories, and could answer the question of the availability of copper pressure flakers in the Late Neolithic and the Early Bronze Age, in the event that an excavation was detailed enough to recover such small flakes. Such a comparison could also help in understanding the technical differences in the production of sickles and daggers if there were some.

To see if there really are significant differences in the choice of exterior edge angles, an analysis of variance (ANOVA) has been attempted. As more than two groups are compared here, the ANOVA was the reasonable choice (Carlson 2017, 178-186). The mean of the edge angles was compared and the Tukey honest significant difference test was applied to the data to see which groups differ from each other.

```
##              Df   Sum Sq Mean Sq F value  Pr(>F)
## Kontext       6    76796   12799     206  <2e-16 ***
## Residuals  8848   549124      62
## ---
## Signif. Codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
## Tukey multiple comparisons of means
##     95% family-wise confidence level
##     factor levels have been ordered
##
## Fit: aov(formula = ABW ~ Kontext, data = ABW_all)
##
## $Kontext
##                   diff     lwr   upr p adj
## AB 2021-AB 2018 2.911  2.0444  3.78 0.000
## PW 2006-AB 2018 3.787  2.6318  4.94 0.000
## GN 2005-AB 2018 6.238  5.3164  7.16 0.000
## PW 2007-AB 2018 7.229  6.0679  8.39 0.000
## GN 2007-AB 2018 8.406  7.4414  9.37 0.000
## GN 2006-AB 2018 9.618  8.5280 10.71 0.000
## PW 2006-AB 2021 0.876 -0.1271  1.88 0.134
## GN 2005-AB 2021 3.327  2.6050  4.05 0.000
## PW 2007-AB 2021 4.318  3.3080  5.33 0.000
## GN 2007-AB 2021 5.495  4.7191  6.27 0.000
## GN 2006-AB 2021 6.707  5.7797  7.63 0.000
## GN 2005-PW 2006 2.451  1.4000  3.50 0.000
## PW 2007-PW 2006 3.442  2.1757  4.71 0.000
## GN 2007-PW 2006 4.619  3.5300  5.71 0.000
## GN 2006-PW 2006 5.831  4.6296  7.03 0.000
## PW 2007-GN 2005 0.991 -0.0670  2.05 0.084
## GN 2007-GN 2005 2.167  1.3306  3.00 0.000
## GN 2006-GN 2005 3.380  2.4006  4.36 0.000
## GN 2007-PW 2007 1.176  0.0813  2.27 0.026
## GN 2006-PW 2007 2.389  1.1814  3.60 0.000
## GN 2006-GN 2007 1.213  0.1934  2.23 0.008
```

The summary above shows a p-value far below the .05 level of significance. This means that the hypothesis, which assumes that the means of the groups are the same, is false. The Tukey's test shows further that there are significant differences between the mean of the exterior edge angles between the major parts of the different inventories.

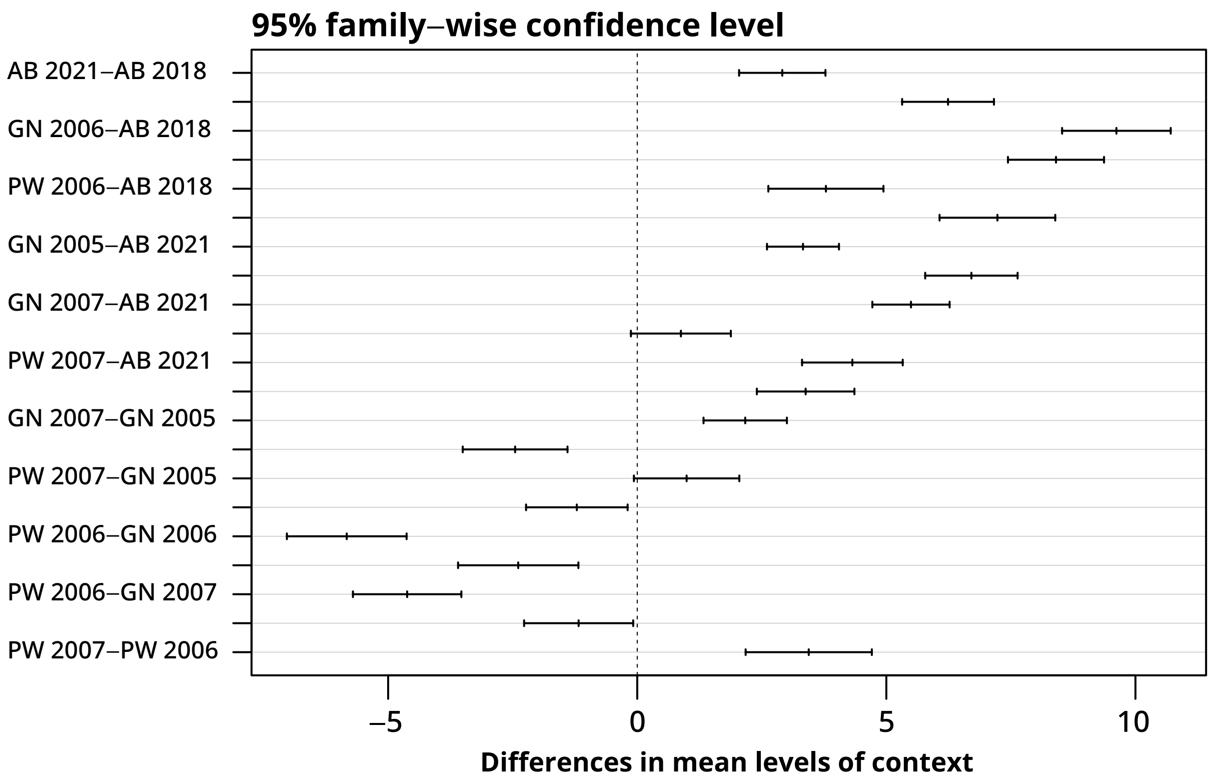


Figure 41. Comparison analysis of mean exterior edge angle using Tukey honest significant difference.

As a lot of significant differences between the groups were detected, the data was visualised for a better understanding (Fig. 41). Just two groupings cut the vertical line at 0, indicating that the difference is not significant (Carlson 2017, 181; Wollschläger 2020, 294). The sorting of the compared inventories is a bit different in the plot than in the output, but the two combinations without significant difference in the mean of the exterior edge angle are P. Wikings's sickle from 2006 and A. Benke's dagger, as well as P. Wiking's sickle from 2007 and G. Nunn's dagger, which have the highest p-values. To help the interpretation of the results, they are further shown as compact letter display, which assigns letters according to the grouping of cases.

```
## AB 2018 AB 2021 GN 2005 GN 2006 GN 2007 PW 2006 PW 2007
##     “a”     “b”     “c”     “d”     “e”     “b”     “c”
```

As we can see, five groups were identified, nearly corresponding to a group per inventory. Not surprisingly, P. Wiking's inventories do not fall in a separate group, but group together with A. Benke's and G. Nunn's dagger inventories. The result slightly underlines the observed differences from the curves. It is compelling to look at the shift here, from being more similar to A. Benke to being more similar to G. Nunn, as an expression of the shared learning experience between the two knappers. A similar shift was already seen in the cluster analysis of the preparation of platforms and edges (Fig. 36). As the inventories do not seem to group by knappers, personal choice does not seem to be the grouping factor. Likewise, chosen techniques or artefact type do not seem to influence the grouping. The best option at the moment seems to be raw material requirements, which influence the dimensions of the flakes that have to be removed and by this also the exterior edge angle. This would also explain this high variability, as no two nodules are ever exactly the same. However, the raw material and quality are seemingly not the only factors. Firstly, in 2006, P. Wiking chose a nodule with an excellent sound and good quality, while the nodule that A. Benke chose in 2021 was more of mediocre quality. Secondly, the raw material of G. Nunn's dagger and P. Wiking's sickle from 2007 differ completely. What factors cause the significant differences is not immediately discernible, but it does not seem to help to identify personal variation in mental templates or working tool choices.

Earlier in the analysis, the platform thickness did not help with the identification of sequences, but another look is cast on the data to see if there are differences which could relate to application of different techniques during production. Again, an ANOVA, followed by the Tukey honest significant difference test, was calculated (Fig. 42).

```
##              Df   Sum Sq Mean Sq F value  Pr(>F)
## Kontext       6     1180   196.6     105  <2e-16 ***
## Residuals  9733    18255     1.9
## ---
## Signif. Codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

## Tukey multiple comparisons of means
##     95% family-wise confidence level
##     factor levels have been ordered
##
## Fit: aov(formula = SFRD ~ Kontext, data = SFRD_all)
##
## $Kontext
##                    diff     lwr   upr p adj
## AB 2021-AB 2018 0.0830 -0.0602 0.226 0.610
## PW 2007-AB 2018 0.2892  0.1026 0.476 0.000
## GN 2007-AB 2018 0.3802  0.2201 0.540 0.000
## GN 2006-AB 2018 0.4438  0.2612 0.626 0.000
## GN 2005-AB 2018 0.8288  0.6738 0.984 0.000
## PW 2006-AB 2018 1.1191  0.9255 1.313 0.000
## PW 2007-AB 2021 0.2061  0.0464 0.366 0.003
## GN 2007-AB 2021 0.2972  0.1694 0.425 0.000
## GN 2006-AB 2021 0.3608  0.2058 0.516 0.000
## GN 2005-AB 2021 0.7457  0.6244 0.867 0.000
## PW 2006-AB 2021 1.0361  0.8682 1.204 0.000
## GN 2007-PW 2007 0.0910 -0.0840 0.266 0.725
## GN 2006-PW 2007 0.1547 -0.0412 0.350 0.230
## GN 2005-PW 2007 0.5396  0.3692 0.710 0.000
## PW 2006-PW 2007 0.8300  0.6238 1.036 0.000
## GN 2006-GN 2007 0.0636 -0.1071 0.234 0.929
## GN 2005-GN 2007 0.4486  0.3077 0.589 0.000
## PW 2006-GN 2007 0.7389  0.5564 0.921 0.000
## GN 2005-GN 2006 0.3850  0.2190 0.551 0.000
## PW 2006-GN 2006 0.6753  0.4728 0.878 0.000
## PW 2006-GN 2005 0.2904  0.1123 0.468 0.000
```

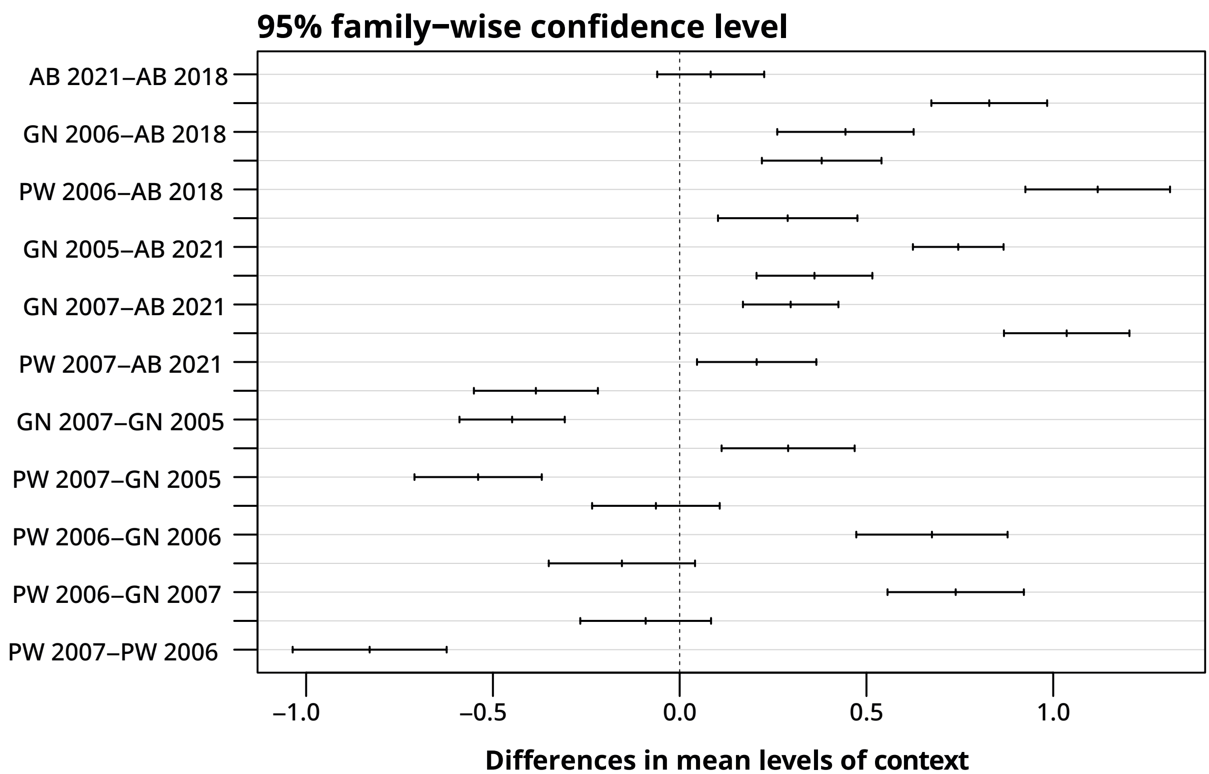


Figure 42. Comparison analysis of mean platform thickness using Tukey honest significant difference.

The results show that there are significant differences between the groups and that again multiple groups can be gathered. The compact letter display helps to identify the groups:

```
## AB 2018 AB 2021 GN 2005 GN 2006 GN 2007 PW 2006 PW 2007
##     "a"     "a"     "b"     "c"     "c"     "d"     "c"
```

This time, the groups make more sense when looking at differences between the knappers. As we can see, A. Benke makes up his own group, which fits nicely with him, working with a more limited set of tools compared to the other two knappers. In particular, his focus on organic percussion with antler billets has a strong effect on the platform thickness, which is underlined by the results here. The next group is made up of G. Nunn's sickles and P. Wiking's sickle from 2007. This fits nicely with the results so far that P. Wiking seems to work more similar to G. Nunn after their mutual exchange. The last two groups are G. Nunn's dagger and P. Wiking's sickle from 2006. Being its own group, the latter fits with the documented and observed differences. It was expected and some tendencies have already been marked that P. Wiking did work differently in 2006, at a time when he was neither familiar with the type of artefact nor as experienced in bifacial production as the other two and probably was relying more on indirect percussion than in 2007. Why G. Nunn's dagger inventory makes up its own group is a bit harder to grasp. One possibility could be that G. Nunn indeed does work differently when working on different artefact types. A more extensive use of one or two techniques compared to the sickles would affect the means of the platform thickness and could be enough to set this inventory apart from the sickle inventories. An anticipated difference between the artefact types would have been a stronger reliance on organic percussion during dagger production, this

Knapper and artefact	None	Present	With conical break	Not preserved
Benke_Dolch_IC	84.6	4.84	0.00	10.6
Benke_Sichel_2018	56.1	8.66	0.18	35.0
Blindtest_Callahan	37.7	12.30	2.46	47.5
Nunn_Dolch-IC	69.2	13.86	0.14	16.9
Nunn_Sichel-1.26_2006	75.3	8.03	0.09	16.5
Nunn_Sichel-3.33_2007	83.7	3.06	0.06	13.2
Wiking_Sichel-1.7_2006	65.8	8.68	0.31	25.2
Wiking_Sichel-2.32_2007	70.1	5.98	0.00	23.9

Table 20. Frequency (in percent) of ring cracks in the recorded inventories.

being the slightly more cautious approach. However, the expected result would then have been a higher similarity to A. Benke's inventories. The second and more likely explanation could be the raw material, which differs here. Texas flint is a bit tougher than Scandinavian flint, which could influence not just the tool type, but also how far behind the edge the blow is dealt to get comparable removals.

The platform thickness seems to be a good way to discern at least the variability of tools included in the production. But the variation should be treated cautiously, as raw material seems to have an influence too. It would probably not have a large impact in archaeological assemblages from Scandinavia, as the raw material is comparable, but this would have to be tested and kept in mind, especially when other raw materials have been identified.

Another attribute which could provide some information about differences between applied techniques are ring cracks, which are more frequent when hard knapping materials, such as stone or copper, are used. Table 20 shows a not so surprisingly low frequency of occurrence of ring cracks. What is surprising is that all the first sickle inventories show a similar frequency of existing ring cracks, despite A. Benke having a lower rate of hammerstone implementation. Most of his ring cracks are probably initiated by pressure and indirect technique, which could hint that ring cracks by pressure and indirect technique possibly also prevail in G. Nunn's and P. Wiking's inventories. This would fit with the observation of them using soft stone hammers, which are not so prone to leave ring cracks. But, during the dagger production, A. Benke used copper as a knapping implement more often than during the sickle production. Likewise, indirect technique with copper punch was only applied while working on the dagger. Nevertheless, the sickle inventory has a nearly twice as high a presence as the dagger inventory, which shows that the implementation of copper in the work process is not the only factor influencing the formation of ring cracks. As A. Benke stated, he uses copper when he wants to be more in control of the knapping process and use less force during the removal. Choosing the harder material here thus seems to translate to less forceful flaking, which reduces the formation of ring cracks. In contrast, E. Callahan's and G. Nunn's dagger inventories show a rather high percentage of ring cracks. This is not surprising for E. Callahan's inventory, as we are only looking at the first production steps, primarily worked in direct hard technique. The similarly high amount of ring cracks in G. Nunn's inventory can be attributed to multiple reasons, for example, to the 'ideal' way of working daggers, as

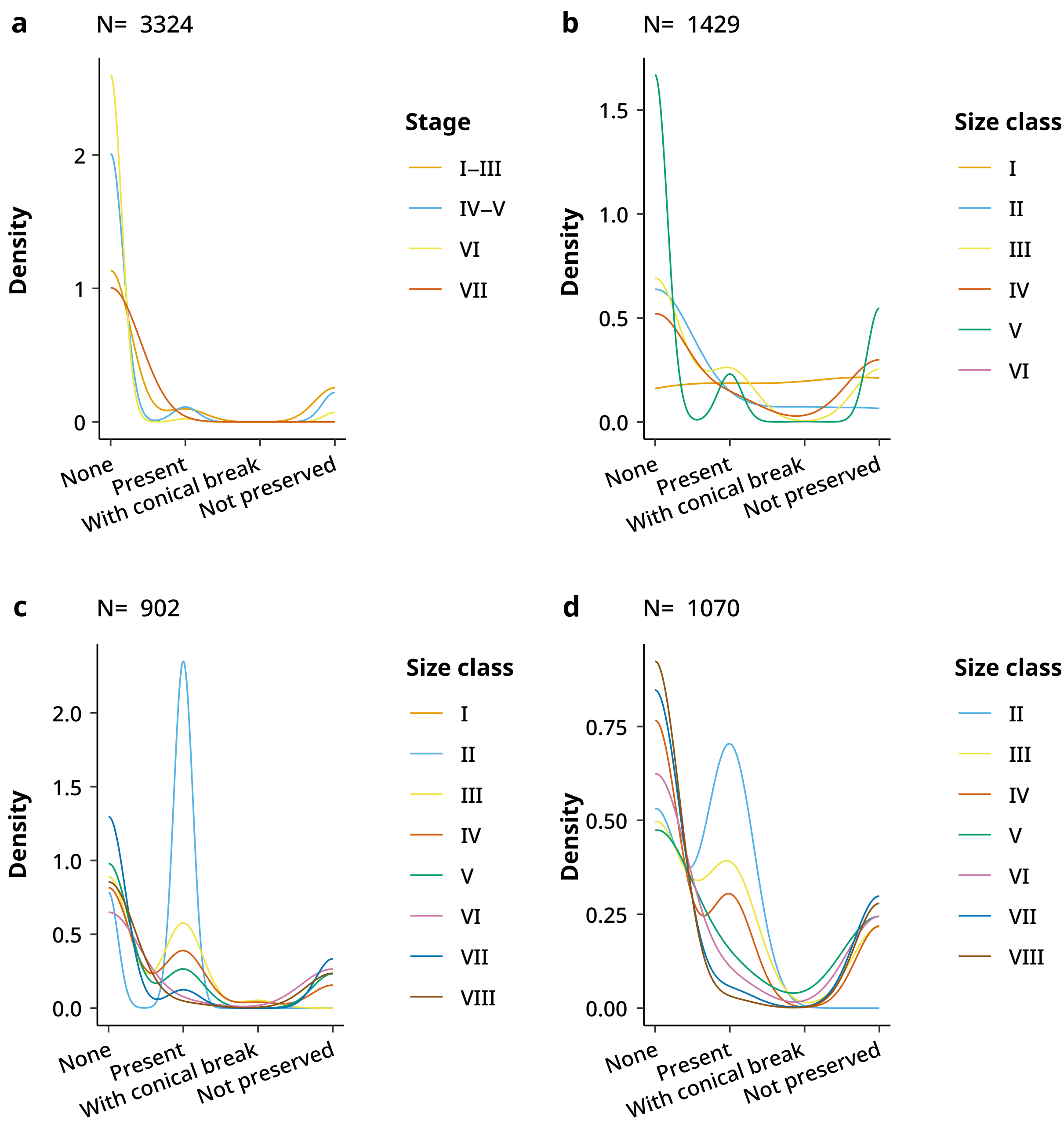


Figure 43. Density plot for ring cracks by production stage or size class for the individual inventories: a) A. Benke sickle 2018; b) A. Benke dagger 2021; c) P. Wiking sickle 2006; d) P. Wiking sickle 2007.

E. Callahan proposed it, and thereby a higher amount of implementation of direct hard technique, as well as to the different raw material. Again, the Texas flint used in this production is a bit tougher than Scandinavian flint and requires more force for the removal of flakes, which increases the possibility for ring cracks.

The most reasonable explanation for the formation and changes in ring cracks seems again to be the unfamiliarity with either the artefact type, the raw material or both. Hillerslev flint is a quite homogeneous and easy knappable flint. As all three knappers are more familiar with more tough quality flint, familiarisation with and adaption to the material takes a moment and affects, among other things, the expenditure of force during the blow.

Identifying which kind of technique initiated the ring cracks is difficult. Very simply put, the early stages should have a higher probability to be initialised by

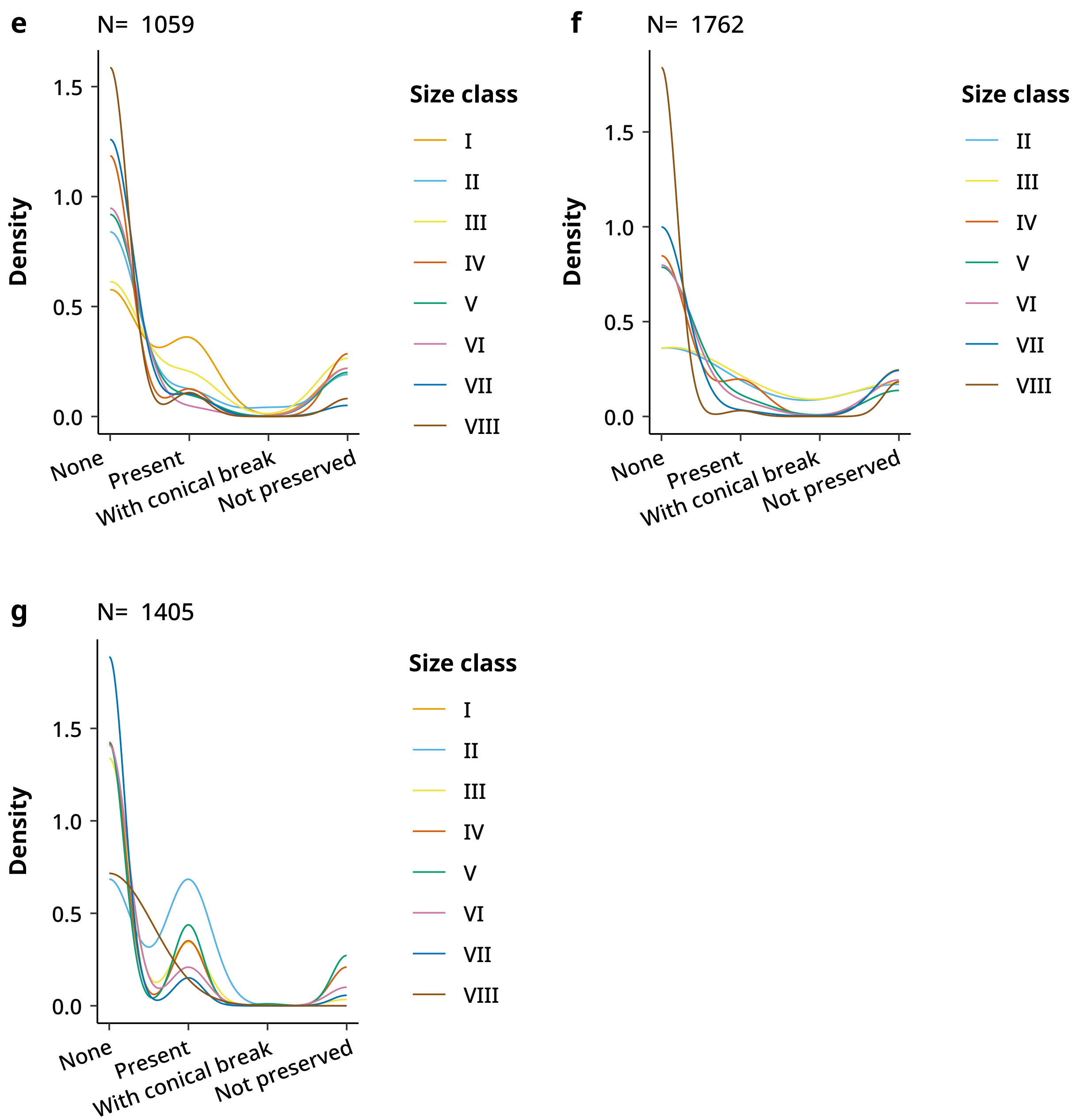


Figure 44. Density plot for ring cracks by production stage or size class for the individual inventories: e) G. Nunn sickle 2006; f) G. Nunn sickle 2007; g) G. Nunn dagger.

stone percussion and the later by copper pressure. But, the separation of techniques by stage is not so straight forward, as has been discussed. A distinction would probably be easiest for A. Benke, as he rarely implements hammerstones. In earlier stages, this would mean that ring cracks are probably associated with indirect technique in the dagger inventory, used to carve out the circumferential edge and for trouble shooting. Pressure technique with copper comes in to play occasionally more in the middle of the production process to remove problematic areas, and at the end for the pressure retouch.

Figure 43a shows the density plot for the presence of ring cracks split up in A. Benke's dagger inventory. It shows that ring cracks appear mostly in his first stages and not so much in the last, which is also detectable in G. Nunn's dagger inventory (Fig. 44g). Here too, nearly no ring cracks have been recorded

Knapper and artefact	n	mean	sd	median	min (mm)	max (mm)	range (mm)
Benke_Dolch_IC	157	1.91	1.20	1.63	0.54	8.88	8.34
Benke_Sichel_2018	138	1.84	1.33	1.50	0.20	7.30	7.10
Nunn_Dolch-IC	291	2.18	1.60	1.81	0.41	20.40	19.99
Nunn_Sichel-1.26_2006	83	2.42	1.47	2.01	0.59	7.81	7.22
Nunn_Sichel-3.33_2007	54	1.99	1.05	1.89	0.47	6.20	5.73
Wiking_Sichel-1.7_2006	86	2.91	2.06	2.34	0.96	17.71	16.75
Wiking_Sichel-2.32_2007	63	2.61	1.77	2.02	0.71	8.13	7.42

Table 21. Descriptive summary of ring crack diameter per knapper.

on the smallest flakes, which are more likely to originate from the final pressure retouch. This strengthens the impression that it is the indirect technique, which is responsible for the ring cracks in the inventories. No or just few ring cracks during parallel flaking and pressure retouch is not particularly surprising, as the amount of force needed is rather small compared to the earlier stages, where more and larger areas of the surface are being removed. The picture is consistent for the other two knappers as well. Mostly the bigger flake sizes bear ring cracks. The overemphasis of size class II in P. Wiking's inventories is probably due to the general small numbers of flakes in this class.

A way to differentiate which tool type produced the ring cracks is to look at the diameters of the cracks. In theory, the harder the material, the more concise the point of impact and the smaller the ring crack should be. Meaning: copper pressure flaker tips leave way smaller cracks than hammerstones. Copper tips are often associated with very small ring cracks around 1-3 mm. From Table 21 it can be seen that there is a high variability in diameters. In two cases, there are even exceedingly large diameters. As these two values stand alone, they will be treated as outliers and are removed from further analysis. Again, the values are quite similar between the knappers, but the number of occurrences differs markedly. While G. Nunn's dagger has an exceedingly high amount of ring cracks, A. Benke has a consistently high number, while the other sickle inventories include significantly fewer. Again, some kind of approximation can be seen in G. Nunn's and P. Wiking's sickle inventories from 2006 to 2007. Not only the numbers but also the mean diameter decline comparably. Although the diameter of P. Wiking's sickle from 2006 is influenced by a large outlier, the median value still shows a reduction similar to G. Nunn. A. Benke's ring cracks seem to be a bit smaller in general, but the range is not so different from the other knappers.

To see if the diameter can be used as an indicator for the technique, density plots by stages/flake size classes have been plotted (Fig. 45 and Fig 46). P. Wiking has a high variability in ring crack diameters throughout the size classes, which probably reflects a different approach to the material, in contrast to the other knappers (cf. Chapter 4). Besides switching between indirect, direct hard and organic percussion technique frequently, he also uses somewhat larger hammerstones and billets, which have a higher weight and larger surface area that connects during the blow and by this will be more prone to leave bigger ring cracks. Likewise, he needs repeated attempts to remove a flake more often, which increases the possibility of the emergence of ring cracks further. His free-handed

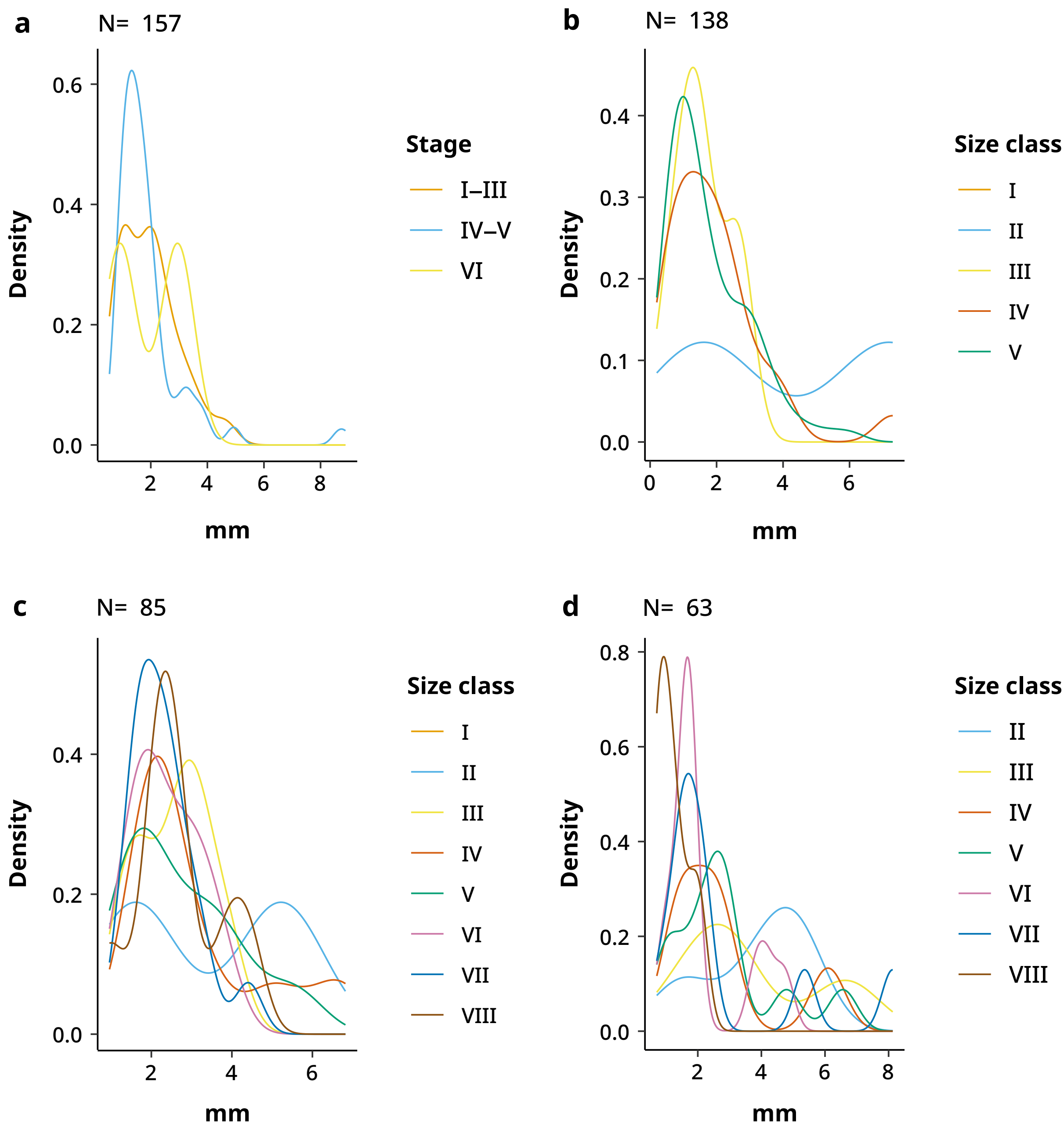


Figure 45. Density plot for ring crack diameters by production stage or size class for the individual inventories: a) A. Benke sickle 2018; b) A. Benke dagger 2021; c) P. Wiking sickle 2006; d) P. Wiking sickle 2007. Ring cracks exceeding 10 mm were removed from the data sets for easier visualisation.

way of working allows more forceful blows, which again provides more opportunities for ring crack formation.

A point worth noting here is the distribution of ring crack diameter to size class. For P. Wiking and G. Nunn, the smaller flake size classes correspond to smaller diameters, which would fit into the interpretation that the smallest flakes more likely originate from late production phases and the ring cracks probably emerge due to pressure flaking with copper tips. But, smaller flakes have in general smaller platforms, which in the first place do not allow for a larger impact area and corresponding big ring cracks. Furthermore, the graph from A. Benke's dagger inventory does not support this interpretation. Firstly, phase 7, the final pressure retouch, is missing completely, which is not totally surprising, as the really short flakes do not need a lot of pressure to be removed. Beyond that,

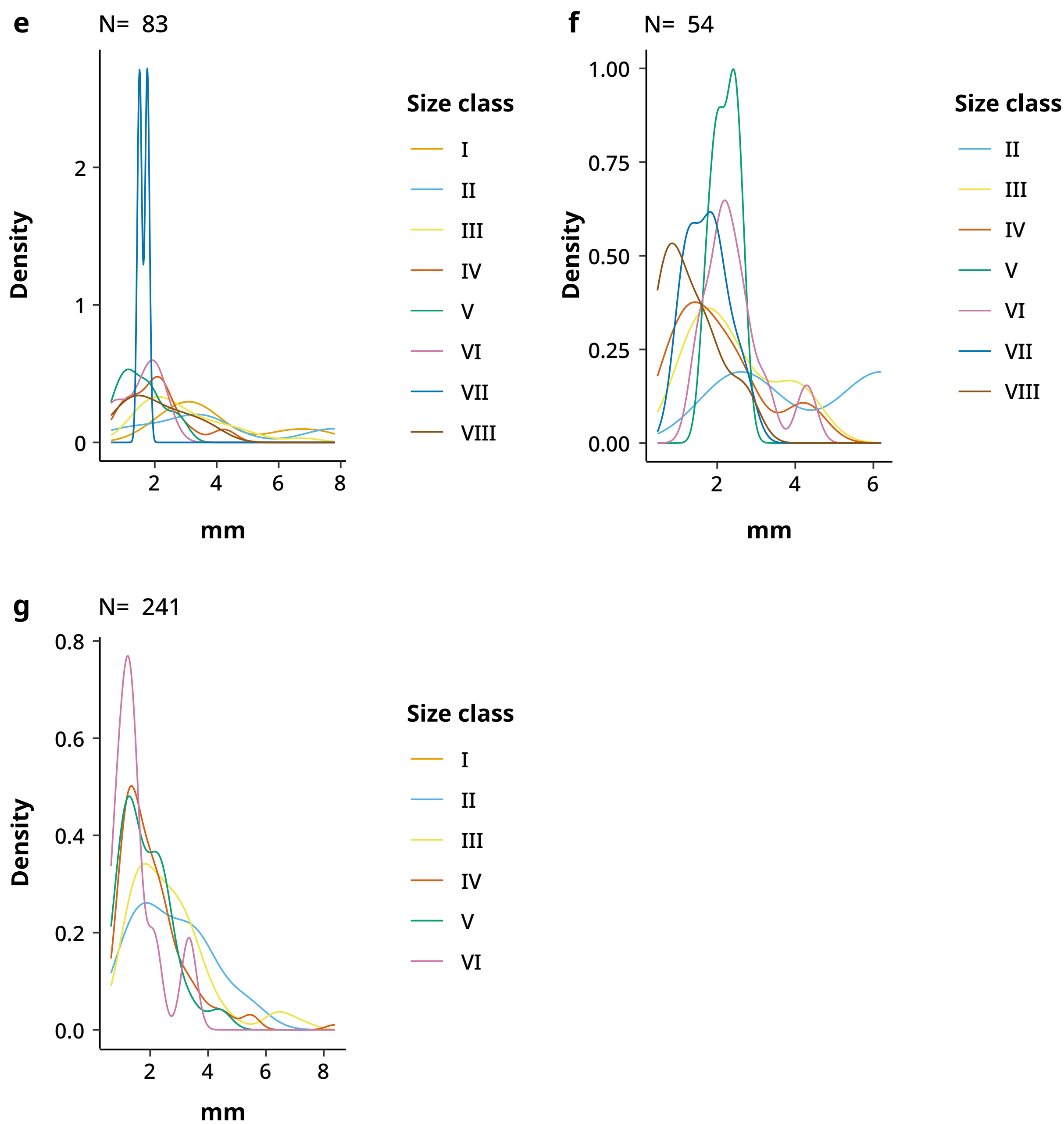


Figure 46. Density plot for ring crack diameters by production stage or size class for the individual inventories: e) G. Nunn sickle 2006; f) G. Nunn sickle 2007; g) G. Nunn dagger. Ring cracks exceeding 10 mm were removed from the data sets for easier visualisation.

the platform remnants of those flakes are barely bigger than the tip of the pressure flaker, which leaves no room for the formation of a ring crack. Secondly, the parallel pressure flaking, phase 6, shows two distinct peaks around 1 and 3 mm which correspond to two flakes.[13] The really low case of occurrences shows how unlikely the formation of ring cracks in parallel flaking is. In A. Benke's case, parallel flaking did not proceed as wished, so no edge-to-edge flaking was achieved. This could be a cause for little signs of ring cracks even with the implementation of a copper tipped pressure flaker, but G. Nunn's dagger inventory shows a similar pattern. No ring crack was recorded on the edge-to-edge pressure flakes. This

13 The same happens in G. Nunn's sickle from 2006 (Fig. 46e) for the flake size class VII. There are just two flakes in this size class, which show a ring crack.

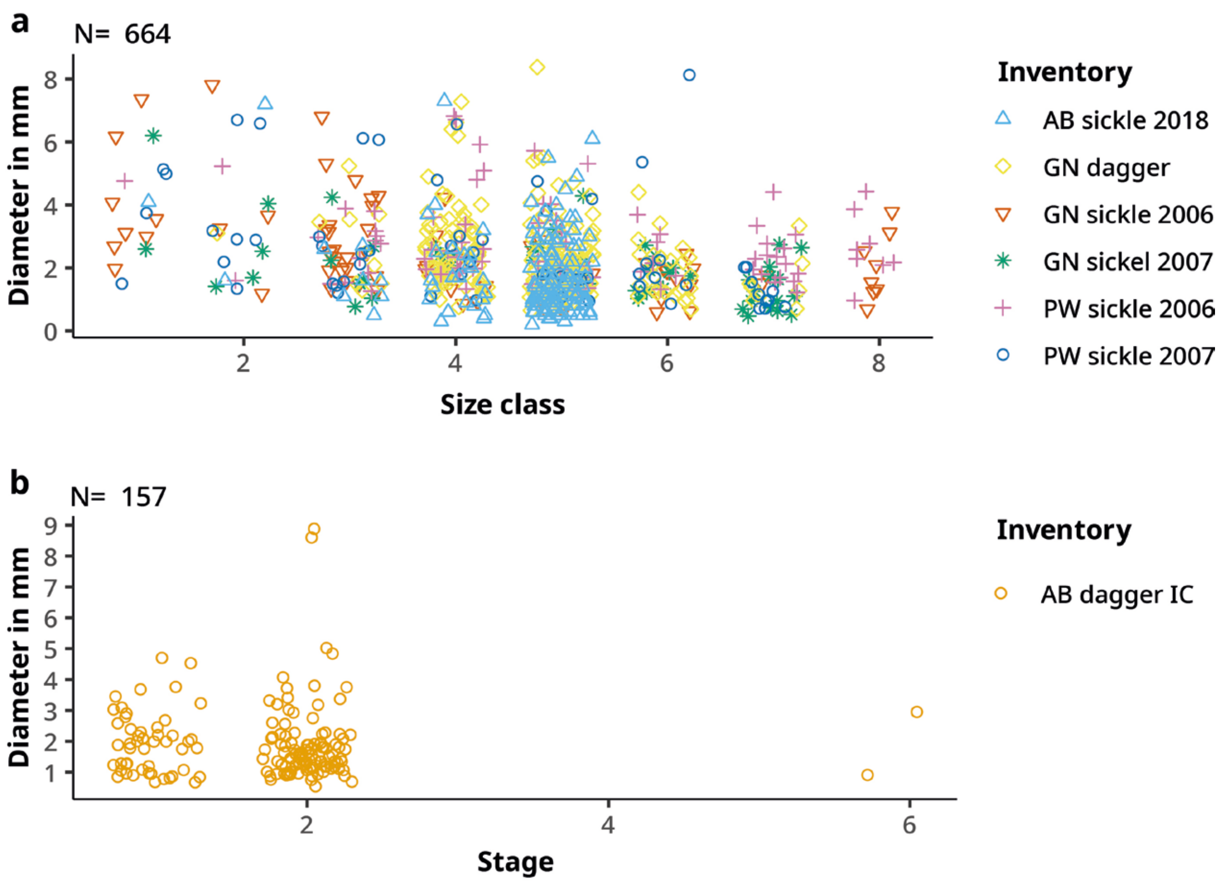


Figure 47. Scatterplot of ring crack diameters by production stage or flake size class. Ring cracks exceeding 10 mm were removed from the data sets.

shows that the force needed to remove the parallel flakes is not high enough to leave ring cracks in a repetitive way and the attribute is not a significant indicator for the use of copper tipped pressure flakers in the archaeological record. Similarly, not just the smallest possible ring cracks are associated with pressure flaking and copper tips (Fig. 49b). A cause for bigger than average ring cracks with copper tips could be the state of the tip. During reduction, the tip is also worn down. If it is not constantly resharpened, the point will become rounded and offer a bigger contact area, which would correspond to bigger ring cracks when formed. Quite likely, this is what can be seen in the graphs here (Fig. 45 and Fig. 46). For P. Wiking and G. Nunn, the smaller ring cracks occur in the smaller flake size classes, which do not automatically correspond with later production phases, but to some extent can be attributed to pressure technique. Throughout the production sequence, pressure flakers have been used for trouble shooting and most flakes removed by pressure are rather small compared to flakes removed with direct percussion in the production phase. As the flakes do not need to be exceptionally small or precise, like during parallel flaking and final pressure retouch, the copper tips are not constantly kept at the sharpest state, which maintains some material on the part of the copper tip and results in bigger ring cracks than predicted from blade production experiments (Pelegrin 1994; Méry *et al.* 2007). Ring cracks, which exceed 4 mm in diameter, seem to be more likely associated with hard hammer percussion. Firstly, because the tip of the pressure flaker is quite likely kept in a better, more pointed state so as not to lose the grip on the flint. Secondly, the occurrence of ring cracks exceeding 3 mm is not as frequent in the inventory of A. Benke, who nearly never works with hard hammer percussion in contrast to the other knappers. The smaller ring cracks throughout the production in his dagger inventory are quite likely initiated by the use of a copper punch during indirect percussion.

To get a better impression if there indeed is a distinction that can be made between ring crack diameters in order to determine the utilised tool, a scatterplot was made (Fig. 47). The plot confirms that the diameter decreases with the flake size, but no clear separation can be detected between production stages, flake size classes or knappers. Like for the exterior edge angles, an analysis of variance was conducted.

```
##            Df   Sum Sq  Mean Sq  F value  Pr(>F)
## Kontext     6       91     15.2      6.6  0.00000078 ***
## Residuals 865     1993      2.3
## ---
## Signif. Codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
## Tukey multiple comparisons of means
##     95% family-wise confidence level
##     factor levels have been ordered
##
## Fit: aov(formula = SAD ~ Kontext, data = SAD_all)
##
## $Kontext
##                    diff     lwr   upr p adj
## AB 2021-AB 2018 0.0699 -0.4535 0.593 1.000
## GN 2007-AB 2018 0.1502 -0.5698 0.870 0.996
## GN 2005-AB 2018 0.3422 -0.1215 0.806 0.307
## GN 2006-AB 2018 0.5780 -0.0451 1.201 0.089
## PW 2007-AB 2018 0.7642  0.0822 1.446 0.017
## PW 2006-AB 2018 1.0713  0.4551 1.688 0.000
## GN 2007-AB 2021 0.0803 -0.6274 0.788 1.000
## GN 2005-AB 2021 0.2722 -0.1719 0.716 0.541
## GN 2006-AB 2021 0.5080 -0.1007 1.117 0.173
## PW 2007-AB 2021 0.6943  0.0253 1.363 0.036
## PW 2006-AB 2021 1.0014  0.3996 1.603 0.000
## GN 2005-GN 2007 0.1920 -0.4727 0.857 0.979
## GN 2006-GN 2007 0.4278 -0.3565 1.212 0.675
## PW 2007-GN 2007 0.6140 -0.2178 1.446 0.307
## PW 2006-GN 2007 0.9211  0.1423 1.700 0.009
## GN 2006-GN 2005 0.2358 -0.3224 0.794 0.875
## PW 2007-GN 2005 0.4221 -0.2012 1.045 0.415
## PW 2006-GN 2005 0.7292  0.1786 1.280 0.002
## PW 2007-GN 2006 0.1863 -0.5633 0.936 0.990
## PW 2006-GN 2006 0.4933 -0.1969 1.184 0.346
## PW 2006-PW 2007 0.3071 -0.4368 1.051 0.886
```

The ANOVA shows that some of the groups differ significantly, although not to the same extent as with the exterior edge angle. Compared to the other test, far fewer groups are significantly different (Fig. 48).

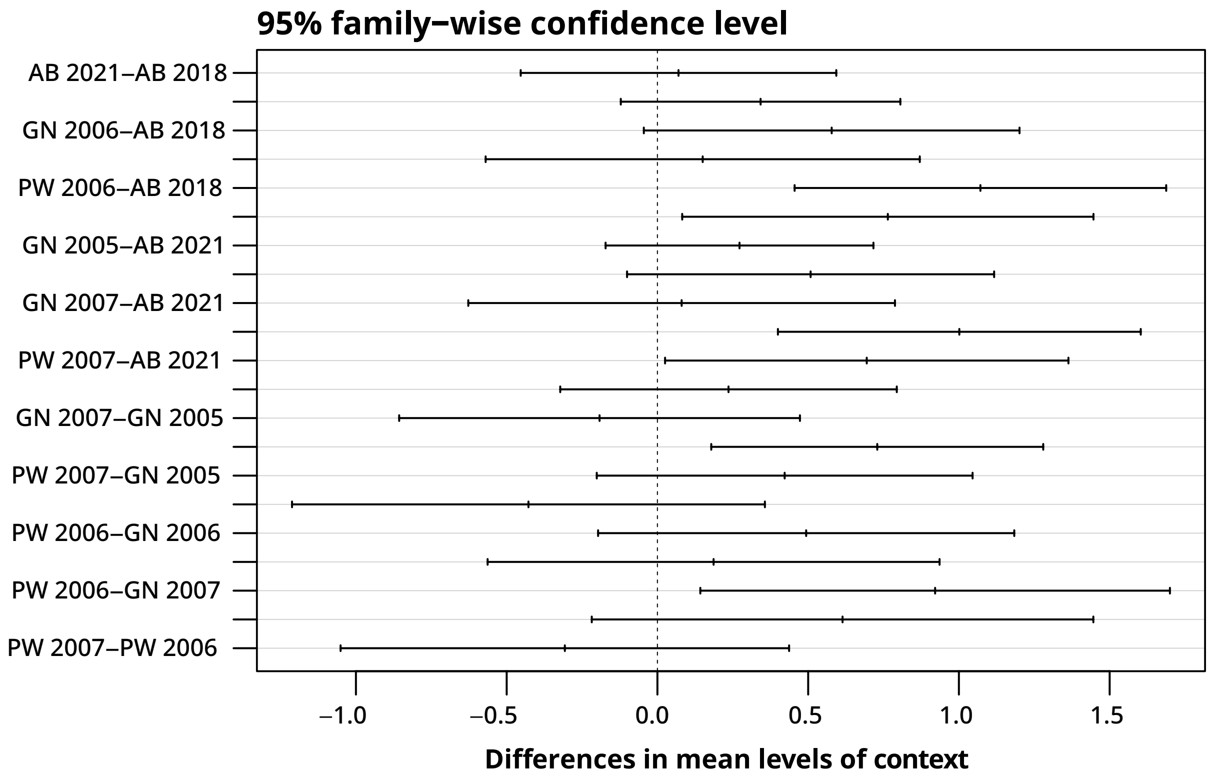


Figure 48. Comparison analysis of mean ring crack diameter using Tukey honest significant difference.

```
## AB 2018 AB 2021 GN 2005 GN 2006 GN 2007 PW 2006 PW 2007
##     "a"     "a"    "ab"    "ac"    "ab"     "c"    "bc"
```

From the six significant pairings, three groups can be compiled, with some inventories fitting into two groups. The groups do not divide into meaningful categories contributing to the questions pursued here. Neither knappers, technical differences nor artefact or raw material types seem to be the dividing factor. One factor here could indeed be the raw material quality. In the first group, the quality was mostly mediocre, while in the last group all nodules were of good quality. It would make sense to assume that more and probably also bigger ring cracks will be present on flakes from not so good quality flint. To remove tough spots and failed terminations, often more force has to be applied, which leads to a higher probability for leaving marks on the platforms.

As the ring crack diameter depends on the area of contact, which differs for varying tools, it could be possible to see a distinction if compared to the distance of the impact point from the edge. Generally, stone hammers connect farther behind the edge and probably leave bigger ring cracks than copper tipped pressure flakers, which connect closer to the edge and leave smaller ring cracks. A scatterplot of the ring crack diameters against the distance of the impact point from the edge on the platform remnant did not show any clustering (Fig. 49a). However, plotting solely ring cracks that are associated with visible traces of copper do support the separation of techniques by diameter. At least the majority of visible copper traces are connected to ring crack diameters below 3 mm and impact points very close to the edge (Fig. 49b). The graph seems to strengthen the assumption that bigger ring cracks are connected to hard hammer percussion. This does not imply that all smaller ring cracks are automatically produced by

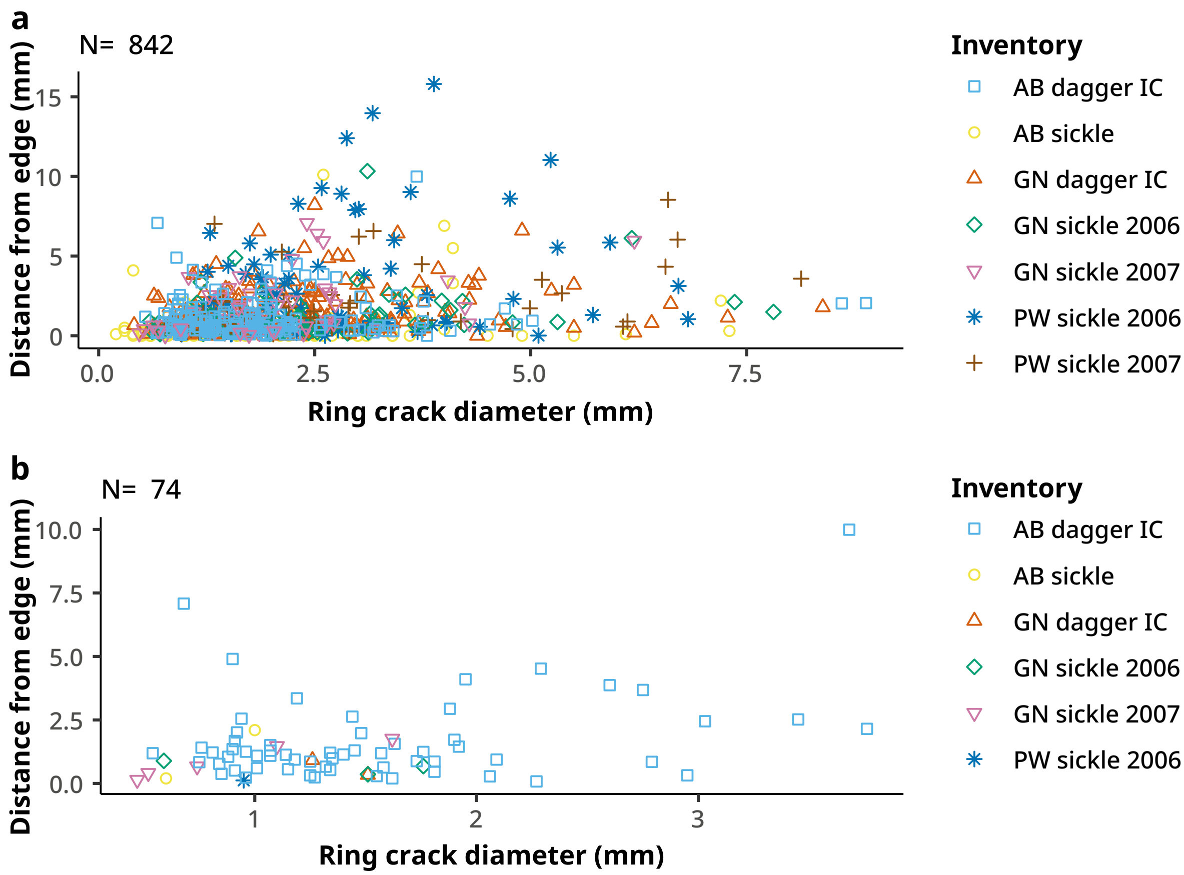


Figure 49. Scatterplot of ring crack diameters in correlation to the distance of the impact point from the edge on the platform remnant of flakes with visible copper traces: a) all ring cracks; b) all ring cracks with visual confirmation of copper. Ring cracks exceeding 10 mm were removed from the data sets.

copper tipped pressure flakers or indirect percussion with copper punch. The use of copper implements makes up just a very little part of the production and compared with the number of flakes with ring cracks (Fig. 49a), it is very likely that most of the small ring cracks close to the edge do not stem from pressure flaking or indirect percussion.

What is also very perceivable in the plots is the low number of flakes with visible copper traces. A. Benke's dagger inventory includes by far the highest number of flakes. Table 22 shows that this is not just a consequence of the general higher number of flakes recorded for the inventory (cf. Table 13), but that a significantly higher number of flakes with ring cracks in his dagger inventory also include visible copper traces. In general, the presence of copper traces is rather low in the inventories. This excludes the possibility that the difference can solely be explained with attention to the traces during the recording. One explanation could be that the copper tips differ between the knappers and some are softer, meaning they are more likely to lose material than others. The implementation of a copper punch by A. Benke could be a second explanation for the variation between the knappers. The punch has a broader tip, which connects to a bigger portion of the platform and more force is applied through the blow than through pressure. Furthermore, a lot of indirect percussion was used on parts of the nodule, where tough spots or knapping accidents hinder the progression. This implies in most cases that more force for the detachment is used. The chance for the copper punch to leave a trace is thereby higher, and it also explains the flakes with impact points farther behind the edge and bigger diameters of the ring cracks.

Knapper and artefact	No trace	Trace	No trace %	Trace %	No RC %	RC %	RC with CB %	Not pres. %	NA %
Benke_Dolch_IC	2660	670	79.9	20.12	84.4	4.83	0.00	10.6	0.18
Benke_Sichel_2018	1462	9	99.4	0.61	64.3	9.79	0.20	22.8	2.86
Blindtest_Callahan	101	0	100.0	0.00	45.5	14.85	2.97	31.7	4.95
Nunn_Dolch-IC	1969	9	99.5	0.46	73.6	14.76	0.15	11.4	0.10
Nunn_Sichel-1.26_2006	970	89	91.6	8.40	75.3	8.03	0.09	16.5	0.00
Nunn_Sichel-3.33_2007	1613	158	91.1	8.92	83.2	3.05	0.06	13.2	0.51
Wiking_Sichel-1.7_2006	910	1	99.9	0.11	69.8	9.22	0.33	19.6	0.99
Wiking_Sichel-2.32_2007	1075	6	99.4	0.56	69.4	5.92	0.00	23.7	1.02

Table 22. Number and percentage of flakes bearing copper traces and ring cracks for each inventory. The difference to Table 20 is due to the including of NA rows to calculate the percentages for the complete inventories. Abbreviations: RC = Ring crack. CB = Conical break.

Some further aspects in the table draw attention. No copper traces in E. Callahan's inventory is far from surprising, as it still is a preform and no pressure flaking was implemented. The use of various tools, including copper, is not expelled from the rough-out stages of bifaces, but rather unusual as it is not strictly needed. A. Benke's early implementation of copper is not so much a technical necessity, but more a personal way to gain more control over the flaking process. This is also displayed in the difference between his sickle and dagger inventory, where the raw material quality was comparable between the artefacts, but the mental goal was different. He really wanted to keep the length of the nodule for the dagger, which led him to pursue a more cautious way of production. Looking only at the presence of ring cracks, E. Callahan's and G. Nunn's inventories stand out. The difference is still explained by the preform, which quite probably has been worked in direct hard percussion for the major part, and raw material. Likewise, the Texas flint used for the dagger by G. Nunn is tougher than the Scandinavian flint, so more force has to be applied. Comparing his dagger to the sickles, the shift is obvious. This also indicates that the formation of ring cracks does not just depend on the utilised tool and tool material, but also on the raw material being worked.

Aside from A. Benke's high amount of copper traces, G. Nunn's sickle inventories also include a quite high number of flakes with traces. American knappers often implement copper pressure flakers in their work, therefore a high count of flakes with traces is not surprising. What is remarkable is the really small amount in the dagger inventory compared to the sickles. It would have been expected to find more traces in the dagger inventory due to the more precise work needed here, as well as for parallel flaking. The only explanation, which can be provided here, is that the difference could stem from the different raw materials. Maybe G. Nunn felt safer using copper while working on not quite familiar raw material. Moreover, the dagger was heat treated after finishing the preform to make parallel flaking possible. This made flaking easier and could also have an effect on the wear of copper tips. Likewise, the almost absence of copper traces in P. Wiking's knapping can be referred back to his personal preference. In 2006 and 2007, he worked with copper pressure flakers, but by his own account, he does not like to work with copper, so he would choose to implement the tool far less often than A. Benke or G. Nunn.

As mentioned already, it should be possible to detect differences in the combination of knapping attributes between the craftsmen, due to their differing choices of knapping implements. From the analyses until now, it can be concluded that there are indeed some significant differences, but in a rather vague way. Thus far, mostly single attributes have been used in the analysis. As these have little significance when treated alone, it is time to take a look at attributes in combination. The first thing to be considered in this respect is a compilation of flakes, which bear expressive attributes for direct percussion with either hard stone, organic billet or soft stone. In general, they are divided by several attributes (see Subchapter 3.2). Direct percussion with the hard hammerstone is connected to marked bulbs, often in combination with conical breaks, no lip formation and frequent éraillure scars and ring cracks. Radial fissures can be present and quite pronounced, but their presence does not indicate directly which knapping implement was used. In contrast, direct percussion with the antler billet is characterised by vague bulbs, lip formation and the absence of ring cracks. Éraillure scars can be present but not significantly. Attributes connected to direct percussion with soft stones are not so easily classified. Used like a hard stone hammer, the attributes resemble percussion with the hard stone and cannot easily be separated from this. It is the second possible way of using a soft stone that will be focused on here. Used more in line with an antler billet in a tangential blow to the edge, soft stones leave slightly different attributes: vague bulbs and lips, which occasionally are present only partially, and small ring cracks. In low frequency, ripples are present on the bulb as well as *esquillement du bulbe*.

The ‘could or could not be present’ possibility of attributes complicates the analysis. For a first attempt, it was decided to concentrate on a distinction based on bulbs and lips to see if patterns arise. The inventories were sorted for flakes, which combined strong bulbs and no lips for the hard percussion, diffuse bulbs (denoted normal in the legend) and normal to strong lips for the organic percussion and vague bulbs with weak and lateral lips for soft stone percussion. A concentration on these two attributes was chosen, as the number of flakes which combine the attributes is already rather low in comparison to the recorded knapping products. Including more attributes would have excluded more flakes making the sample significantly smaller.

Figure 50 shows not only the surprisingly low number of flakes, which combine the chosen attributes remaining for the analysis, but also the unexpected very low impact of organic percussion in the inventories. Mentioned earlier, bifacial reduction is mainly done by direct organic percussion, which is known to have been included in the production of each artefact analysed here. A. Benke works almost exclusively with the antler billet. The impact is in fact greater in general in his inventories, but still, the contribution is far too low. This could, however, be a problem with the coding and the decision between strong and weak characteristics as well as the overlap between soft stone percussion. The impact of soft stone percussion is far too high for A. Benke’s inventories, thus probably a lot of flakes knapped with antler are included in this category.

The impact of hard stone percussion between the inventories seems to be more reliable. Attributes signalling hard hammer percussion are perceivably higher in G. Nunn’s and P. Wiking’s inventories, which was expected. But here, the percental contribution of organic percussion is also far lower than actually observed.

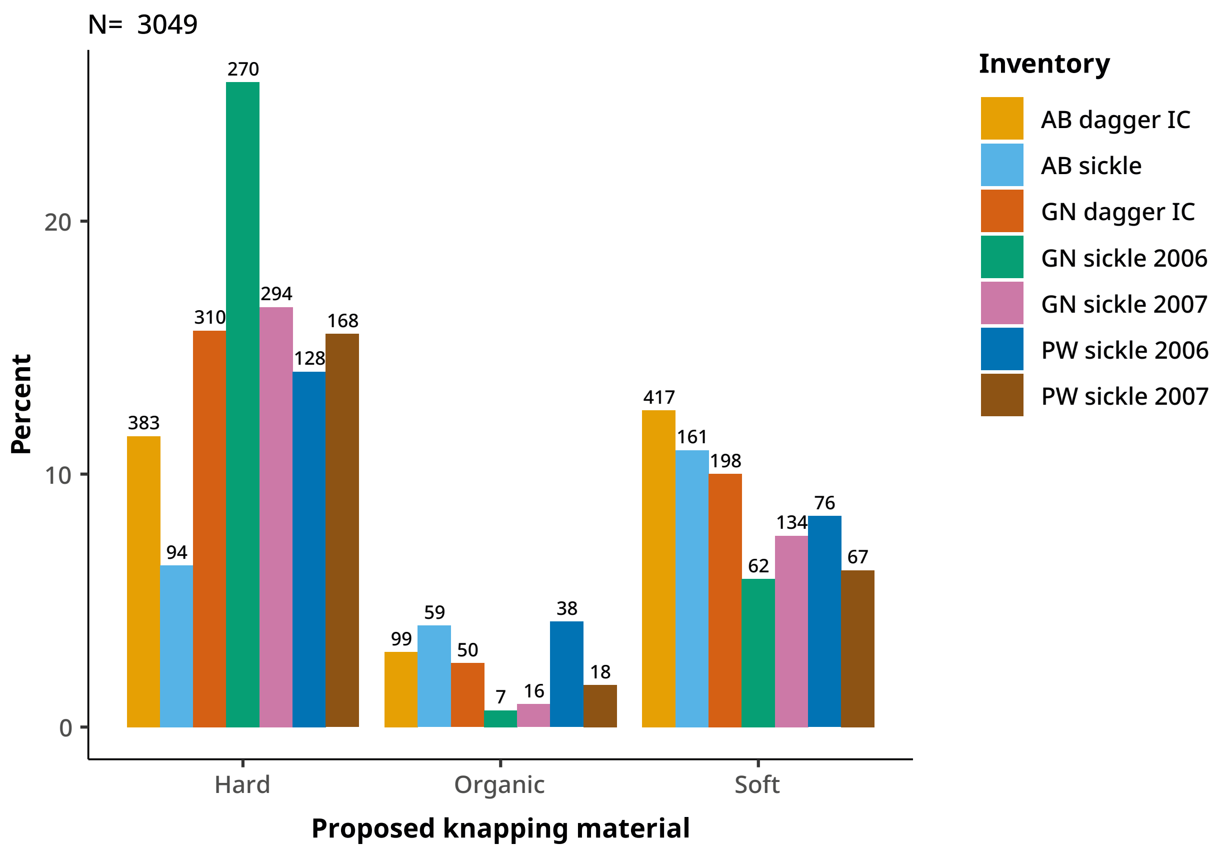


Figure 50. Percental occurrence of attribute combinations which indicate tendencies of the chosen knapping implement. Percentages are compiled for the individual inventories and not based on the total flake count of the graph.

Further tries with plotting several variables by stages and size classes to see if patterns arise were conducted but not included due to the lack of helpful results. There does not seem to be some kind of variation in the attribute form or intensity separated by production stage or flake size, which simultaneously indicates that the separation of production stages based on technical attributes is not possible with the data as recorded here. As mentioned before, the results would probably have been more expressive and significant if the flakes had been recorded based on the aim of the removal. The attempt does show quite impressively, how hard it is to distinguish knapping techniques from attribute characteristics. Form and markedness of an attribute can be influenced by various decisions, which are not altogether consciously made by the knapper. This results in a lot of overlap between the characteristics, which cannot be displayed when assigning fixed groups. This problem has often been discussed in experimental archaeology (see Subchapter 3.2.1), because laboratory experiments do not replicate the real conditions met in the field or during field experiments. Characteristics gained in laboratory experiments explain how the fracture mechanics react to changes and are necessary to understand which variables and attributes are expressive for the identification of the knapping mode, but they cannot truly replicate the real-life work met in the archaeological record. Unlike a machine setup into which custom-made nodules can be fixed, natural nodules are not similar and the human knapper simply cannot perform a strike the same way twice.

Back to the analysis, like for the edge and platform preparation, correspondence analysis was deemed the most reasonable approach to summarise the attributes and look for underlying structures. Again, the data had to be compiled new. Frequency lists per inventory were assembled for bulb formation, scaring and presence of ripples, further radial fissures and lip formation. Rows with missing data were excluded, as well as all rows coded as not preserved. For the bulb, scarring split fractures and combined *esquillement du bulbe* and split fractures were removed as the groups included only 1-2 flakes for very few inventories. Indistinguishable ripples were excluded, as well as lateral lip formation as it acted as an outlier in the first analysis and hindered the interpretation of the graph.

```
##
## Pearson’s Chi-squared test with simulated p-value (based on 2000
## replicates)
##
## data: tec_td[, 2:20]
## X-squared = 979, df = NA, p-value = 0.0005
```

```
##
## Principal inertias (eigenvalues):
##
## dim        value          %    cum%    scree plot
## 1          0.013220      56.2  56.2    **************
## 2          0.003903      16.6  72.8    ****
## 3          0.002517      10.7  83.5    ***
## 4          0.002293       9.7  93.3    **
## 5          0.001191       5.1  98.3    *
## 6          0.000299       1.3  99.6
## 7          0.000092       0.4 100.0
##            --------     -----
## Total:     0.023514     100.0
##
##
## Rows:
##       name   mass qlt inr    k=1 cor ctr    k=2 cor ctr
## 1 |  AB202 |  298 705  85 |  -65 628  95 |   23  76  39 |
## 2 |  AB201 |  122 903 260 | -209 878 406 |   35  25  39 |
## 3 |   ECBT |    8 179  77 |  -98 40    5 | -182 139  64 |
## 4 | GN2005 |  179 615 121 |   95 566 122 |   28  48  35 |
## 5 | GN2006 |   89 724 143 |  118 372  94 | -115 352 302 |
## 6 | GN2007 |  147 919 177 |  150 795 251 |   59 124 132 |
## 7 | PW2006 |   79 753  99 |  -65 141  25 | -135 612 367 |
## 8 | PW2007 |   78 112  38 |   16  21   1 |  -32  91  21 |
##
## Columns:
##      name  mass qlt inr    k=1 cor ctr    k=2 cor ctr
## 1   | B_nn |   2 793  34 | -517 757  46 | -113  36   7 |
## 2   | B_nr | 143 969  30 |  -52 540  29 |   46 429  78 |
## 3   | B_st |  53 972  94 |  160 619 104 | -121 353 200 |
## 4   | B_db |   1  90   7 |   26   4   0 |  121  86   3 |
## 5   | S_nn | 143 761  56 |  -78 658  66 |  -31 103  35 |
## 6   | S_Es |  52 835 184 |  246 729 238 |   94 106 117 |
## 7   | S_EB |   2 482  53 | -467 379  36 | -243 103  33 |
## 8   | S_Sf |   3 361  24 | -270 354  15 |  -38   7   1 |
```

```
## 9  | S_ES |   0 566   7 |  274 111   1 |  554 455  19 |
## 10 | R_nn | 191 425   4 |   14 419   3 |    2   6   0 |
## 11 | R_pr |   9 420  85 | -305 413  62 |  -37   6   3 |
## 12 | F_nn |  36 621  50 |   14   6   1 |  142 616 185 |
## 13 | F_wk | 150 125   9 |  -10  74   1 |   -8  51   3 |
## 14 | F_st |  14 574  74 |   81  52   7 | -258 522 233 |
## 15 | F_bt |   1 441  20 | -185  39   1 | -590 402  49 |
## 16 | L_nn | 118 857  83 |  117 833 123 |  -20  24  12 |
## 17 | L_wk |  65 819  54 | -122 766  74 |   32  53  17 |
## 18 | L_nr |  13 700  66 | -286 691  81 |   32   9   3 |
## 19 | L_st |   3 947  67 | -694 945 112 |  -35   2   1 |
```

Above, the summary of the Chi-squared statistics and CA is printed. The p-value is below the 0.5 threshold of significance, so the association between the rows and columns is given. The first two dimensions explain a high degree of the variation in the data set. The quality of representation by the dimensions is a bit more mixed this time, but still reasonably good for most of the variables and inventories. For the inventories, the major contributor in the first dimension is again A. Benke's dagger inventory, but in the second dimension, the correlation and the contribution are less good. P. Wiking's inventory from 2006 is the only one with a reasonable correlation. For the variables, in the first dimension mainly lip formation (L_nn – none, L_wk – weak, L_nr – normal, L_st – strong) does contribute, but also bulb form (B_nn – none, B_nr – normal, B_st – strong, B_db – double) and to some extent scarring (S_nn – none, S_Es – éraillure scar, S_Eb – *esquillement du bulbe*, S_Sf – split fracture, S_ES – éraillure scar + split fracture). Again, the second dimension is not really well represented by the variables. Radial fissures (F_nn – none, F_wk – weak, F_st – strong, F_bt – both) have the highest impact here. (Not mentioned are the ripples on the bulb: R_nn – none, R_pr – present).

The scree plot in figure 51 shows that the first two dimensions are sufficient for the analysis. The lack of marked groups is visible at first glance in the biplot of the correspondence analysis (Fig. 52). Unlike the preparation (Fig. 33), all the variables and inventories are more or less evenly distributed. It is likewise not easy to interpret what is being represented along the axis of the dimensions. For the first dimension, it could be technique. On the left side, there are strong lips and no bulb as well as *esquillement du bulbe* which are associated with organic and soft stone percussion. Correspondingly, on the right side no lips and strong bulbs are located, but likewise strong radial fissures and éraillure scars that are more likely associated with hard percussion. The positioning of the other variables in between underlines the slow progression from soft to hard percussion techniques. The second dimension seems to be split between radial fissures and bulb scars. From below upwards, the fissures decline in intensity, while the bulb scars are aligned from top down, but not in a really meaningful fashion. The inventories do not form distinctive groups in the plot, but the progression from soft to hard techniques can nonetheless be seen. A. Benke's inventories are positioned farther left, while G. Nunn's inventories are the outmost on the right side. E. Callahan's preform is farther to the left than expected, which could indicate that he worked with a rather soft stone in the reduction. Likewise, here a hierarchical cluster analysis was undertaken to see if clusters of groups were hidden in the data. Chord transformation was applied to the data table again, as it consists of count data.

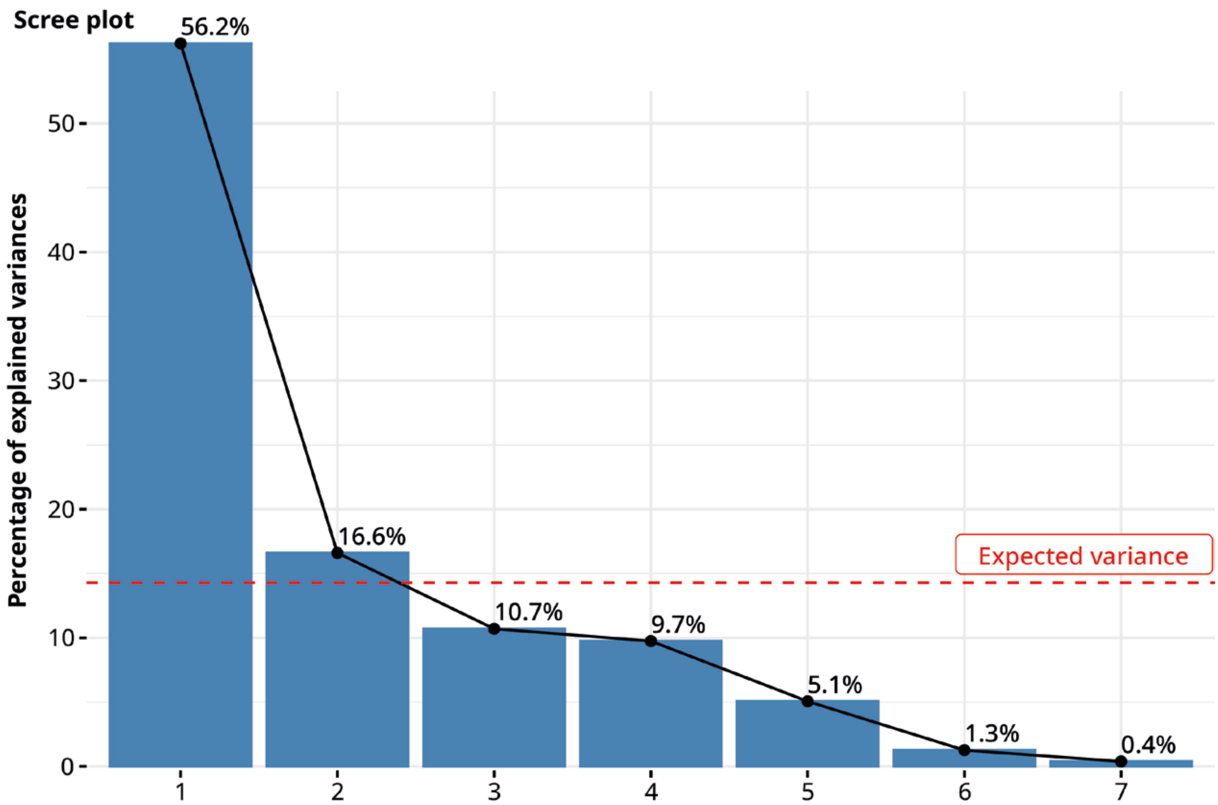


Figure 51. Scree plot for the technical variables.

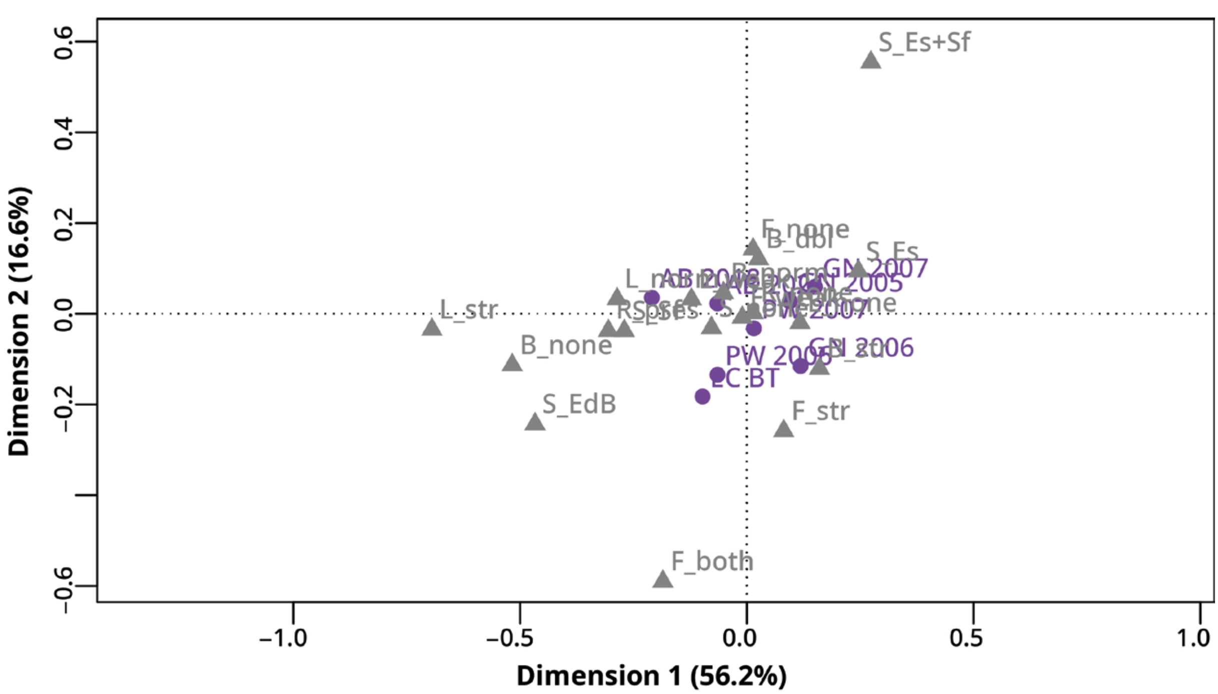


Figure 52. Correspondence analysis of technical variables.

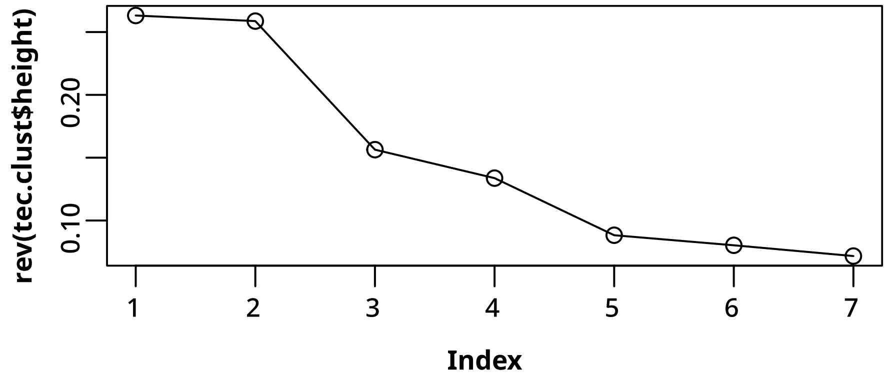


Figure 53. Scree plot of the optimal number of clusters for the data set of technical variables.

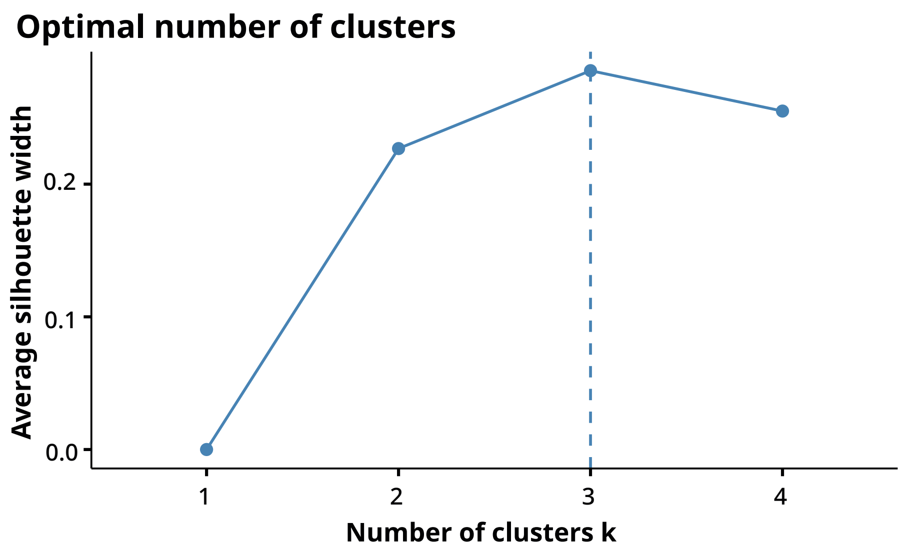


Figure 54. Silhouette plot of the optimal number of clusters for the data set of technical variables.

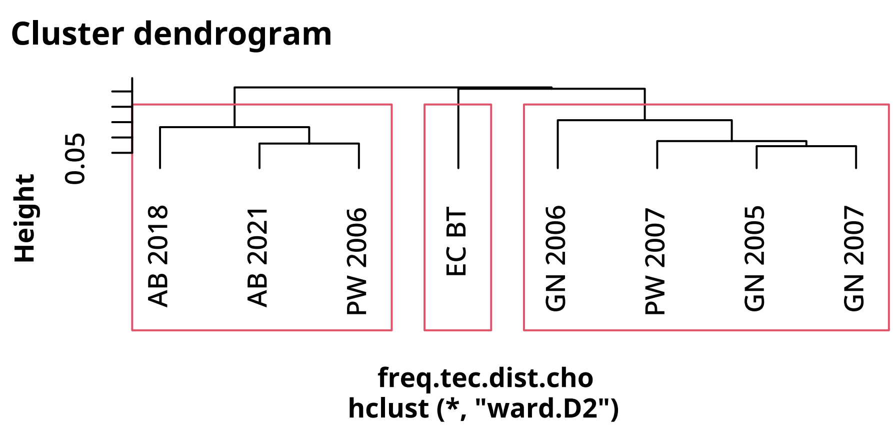


Figure 55. Dendrogram of hierarchical clustering of technical attributes.

The scree plot and the silhouette plot (Fig. 53 and Fig. 54) identify three clusters in the data, which can be seen in the dendrogram (Fig. 55). Despite the lack of grouping in the biplot of the correspondence analysis, quite meaningful groups are generated in the cluster analysis. A. Benke's inventories form a group together with P. Wiking's inventory from 2006. G. Nunn's inventories together with P. Wiking's latter inventory form a second group and E. Callahan's preform makes up the last group. The analysis was repeated without E. Callahan's inventory to see whether it would change the identified clusters. The result was that only two clus-

Figure 56. Silhouette plot of the clusters from the technical attributes.

ters remain, which are not different in their composition as with the three-cluster result. From a technical point of view, the clusters identified here make a lot of sense. In the correspondence analysis, we saw that the major variability is made up of the technical variation in the inventories; and this is biggest between A. Benke and G. Nunn, which are clearly separated in the clustering. P. Wiking was identified as being 'in between' the two other knappers from a working perspective early on, which fits nicely with his inventories being split between the two clusters. Additionally, that his 2006 inventory is more similar to A. Benke and the 2007 inventory is more similar to G. Nunn is an expected result and underlines once more the change in procedure. E. Callahan's inventory forming an own group can be explained by the fact that it is an unfinished piece, not including every production step and by this the whole range of technical choices.

How the inventories are combined in pairs is likewise interesting. The first combination is G. Nunn's inventories from 2005 and 2007, which was not unexpected. G. Nunn's highly structured approach is predestined to create inventories whose technical structures are very much alike. Staying in this cluster, the next connection is P. Wiking's inventory and first after this, G. Nunn's first sickle inventory. It is tempting to interpret the result in terms of experience and knowledge. The bigger distance of the sickle from 2006 to G. Nunn's other inventories could be due to the unfamiliarity with the artefact type and raw material, which could have had an impact on his usual work mode. Likewise, the 2007 inventory would then indicate his familiarisation with the type and material and the return to his used working procedure. P. Wiking's big distance between the inventories could be interpreted as knowledge transfer that happened in between the sessions and changed his technical approach.

The two clusters from the inventories could also be an indication for different production traditions in themselves. In the first cluster, we have European knappers, while the second is made up of (one) American knapper and a knowingly American-influenced inventory. It would be really interesting to include more knappers from both continents to see if the division continues. Likewise, including more knappers, who worked together or were taught by another, would be an intriguing addition to see how the transmission changes and structures the production.

However, the clustering from this analysis must be treated with caution. As the silhouette plot shows, the average width is very low (Fig. 56), which could indicate that no 'natural' clusters were identified (Rousseeuw 1987, 61). With the value of zero, E. Callahan's inventory is exactly in between the clusters, which is not so surprising, as just the first few stages are represented, which are not very different between the knappers, especially when soft hammerstones are used for the decortication, which obscures the difference between hard and organic percussion even more. However, the other two clusters also have an equally low distance, underlining what was already perceived in the correspondence analysis: the clusters are not well separated.

5.5 Summarising the analyses

Summing up the analysis so far, it can be said that the statistical analysis does help in identifying and clarifying patterns seen during the recording of the knapping products and in the documentation of the working procedures. Unfortunately, most of the differences are statistically very weak, regardless if treating single or multiple attributes.

The preparation of the edges and the preparation of the platforms were believed to be the most promising attributes for variability between the knappers early on. The analysis underlined the perceived differences and also showed patterns, which were not expected, even if the significance is restricted. Likewise, the technical signature between the knappers is detectable in the attributes, but statistically not persuasive. The difference was thought to be more distinct, but when dealing with the same technological system and a rather homogeneous production structure, the results are nevertheless encouraging. A surprising discovery was the rather perceptible change in not only the preparation types but also the technical signature in P. Wiking's inventories from 2006 and 2007. As only two inventories were analysed, the results have to be treated cautiously, but it seems possible to detect changing working procedures and through this also the transmission and integration of knowledge between knappers.

The hoped-for positive results in detecting differences between knappers' approaches and the transmission of knowledge were achieved, which leaves the question open how to integrate the findings into archaeological studies. Mixed and incomplete assemblages are the usual state in archaeological contexts, which makes it extremely difficult to mirror the analysis so far. The next section will try to provide some answers to the question.

5.6 Simulating archaeological assemblages

It was not possible to include true archaeological assemblages into the thesis. However, an attempt will still be made to test the applicability in archaeological contexts. For this, random samples based on the flake size classes were drawn from the existing database and anonymised. By no means will this be a template for how patterns look like in real life situations. The goal with this attempt is to see how the patterns, which could be detected so far, behave if an assignment to individual knappers is not possible. Limitations of the approach will also be shown more clearly and can be discussed further.

In the samples, the distinction in sickle and dagger inventories will not be upheld. All flakes will be treated purely as bifacial production without regard to actual artefact production. Each knapper's inventories were assembled in a list and the samples drawn from this population. As the size classes are used to draw samples in a meaningful way, this means that only complete flakes are used in the analyses, which is not a situation which will be met in archaeological assemblages. As the analyses will focus on the platform and the edge of the flakes, and it can be expected that only flakes with proximal preservation would be chosen from real assemblages to pursue these analyses, the choice effects mainly the availability of flakes for the sampling and not the analyses themselves. The decision to rely on the size classes is due to the fact that different sizes of flakes will be differently preserved and recovered during excavation. The bigger flakes can have been used further for tool production, like the thinning flakes, which have often been used to manufacture projectile points, so not all sizes will be present in the archaeological record to the same extent. Likewise, smaller flakes are easier lost or missed during an excavation. Another problem arose due to the strategy. Bigger flakes are more often broken and have therefore not been measured, so that a classification by size was not possible. This has also led to the fact that just a very small number of flakes from the size classes I-III were actually available for sampling. The decision was to include all the available flakes from these classes and sample the other size classes: 100-200 flakes from size class IV, 100-150 from size class V, 100 from size class VI, 50 from size class VII and 10-15 from size class VIII, depending on availability in the selected population. For the mixed samples, a higher number of flakes was chosen from the size classes IV-VI. The more or less fixed number of flakes drawn from the inventories implies varying degrees of representation of the inventories. Smaller inventories, like P. Wiking's, contribute with a bigger proportion of their actual flake count than bigger inventories do. This is not how preservation works in real circumstances, but it was the fastest and easiest way to assemble test inventories for the simulation. It was decided against using a percentage of flakes from each inventory, as that would often have meant only a handful of flakes would have been selected, which would have resulted in very small test assemblages. Furthermore, no control of included size classes would have been possible and the smaller, more unlikely recovered flakes would have dominated.

A few archaeological scenarios will be tested to see how the patterns behave and if it would be possible to detect the observed patterns in mixed states. The focus will be on the multivariate statistics, more precisely the correspondence and cluster analysis, as they are computed more easily and gave the fastest results while including the most information.

As the analysis needs some variable to visualise different groups, the attempts will be run by assuming three distinct features, such as testing separated knapping sites against each other, the fill of pits or houses or chronologically separate features. The test will work with four different possibilities to see how the patterns behave. The first test will look on 'closed' features containing distinct knappers, as in the previous analysis. The second test will look at similar features, but two of the features are mixed, without including the single feature knapper. In the third test, two features are mixed, including flakes from the single-feature knapper. The last test will be to look at a situation where all features contain mixed assemblages, but not all the knappers are present in every feature. All the tests will be run on samples of the complete production process. It has been refrained from looking at solely preform production, due to the very small number of flakes, which could be sampled from the method used here.

5.6.1 Single knapper features

The first three features were selected randomly from each knapper's inventories individually but not sorted for year or artefact. In feature A, 653 flakes were assembled, while feature B and C consist of 618 and 533 flakes, respectively. The first analysis is concerned with the technical variables, including bulb formation, scarring, the presence of ripples on the bulb, as well as radial fissures, and lip formation.

```
##
## Pearson's Chi-squared test with simulated p-value (based on 2000
## replicates)
##
## data: Test_A
## X-squared = 110, df = NA, p-value = 0.0005
```

```
##
## Principal inertias (eigenvalues):
##
## dim        value      %  cum%   scree plot
## 1          0.011946 82.1  82.1  *********************
## 2          0.002613 17.9 100.0  ****
##            -------- -----
## Total:     0.014558 100.0
##
##
## Rows:
##      name  mass  qlt inr    k=1 cor ctr   k=2 cor ctr
## 1  | FtrA | 335 1000 461 | -138 948 533 | -32  52 132 |
## 2  | FtrB | 359 1000 414 |  125 925 467 | -36  75 174 |
## 3  | FtrC | 306 1000 125 |    5   4   1 |  77 996 694 |
##
## Columns:
##      name  mass  qlt inr    k=1 cor ctr    k=2 cor ctr
## 1  | B_nn |   2 1000   9 | -254 993  11 |   22   7   0 |
## 2  | B_nr | 144 1000   8 |  -14 230   2 |  -26 770  36 |
## 3  | B_st |  53 1000  27 |   43 251   8 |   75 749 114 |
## 4  | B_db |   1 1000   9 |  200 419   4 | -235 581  28 |
## 5  | S_nn | 133 1000  79 |  -76 663  64 |   54 337 149 |
## 6  | S_Es |  62 1000 179 |  181 780 170 |  -96 220 220 |
## 7  | S_EB |   2 1000  21 | -218 282   7 | -348 718  86 |
## 8  | S_Sf |   2 1000  13 | -249 743  12 | -146 257  18 |
## 9  | S_ES |   0 1000  17 | -461 334   7 | -651 666  64 |
## 10 | R_nn | 192 1000   3 |   13 823   3 |   -6 177   2 |
## 11 | R_pr |   8 1000  61 | -303 823  61 |  141 177  60 |
## 12 | F_nn |  30 1000  14 |   77 896  15 |   26 104   8 |
## 13 | F_wk | 149 1000   1 |    3 154   0 |   -8 846   3 |
## 14 | F_st |  19 1000  22 | -128 989  26 |   14  11   1 |
## 15 | F_bt |   1 1000   7 | -293 949   9 |   68  51   2 |
## 16 | L_nn | 111 1000 210 |  161 935 240 |   42  65  76 |
## 17 | L_wk |  67 1000 135 | -163 900 148 |  -54 100  76 |
## 18 | L_nr |  17 1000  79 | -243 899  86 |  -81 101  44 |
## 19 | L_st |   5 1000 105 | -560 982 125 |   76  18  10 |
```

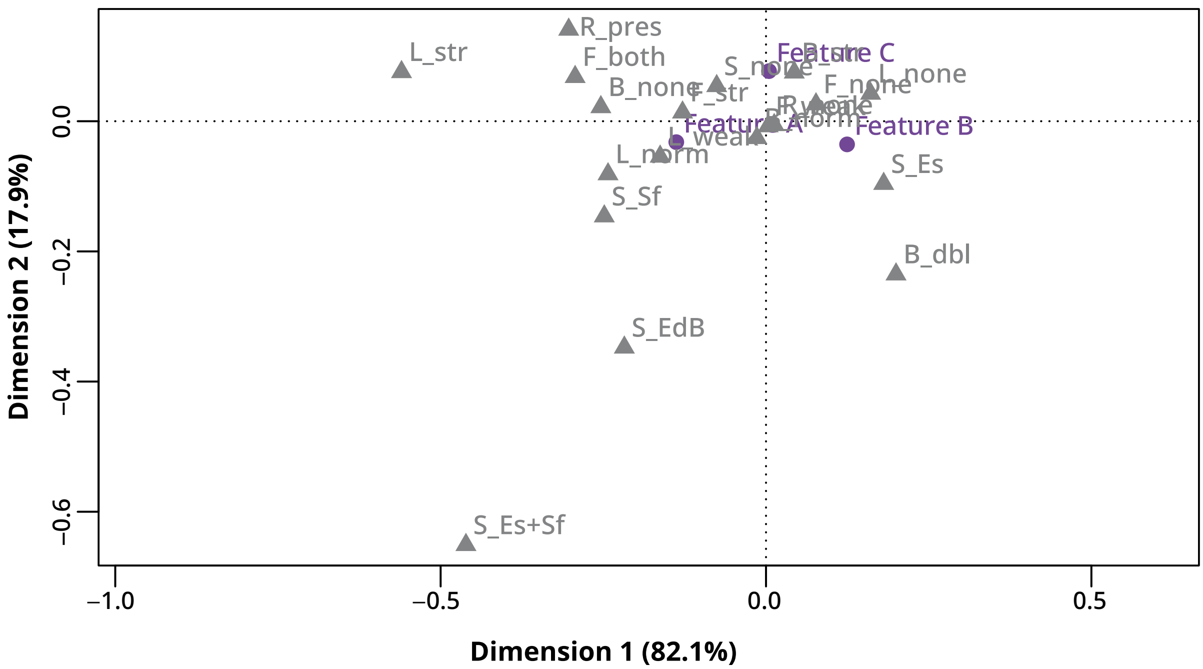


Figure 57. Correspondence analysis of test A.

As we are just comparing three objects with each other, only two dimensions can be present. The Chi-square test shows that there is still a significant difference between the objects, thus the analysis is meaningful. Unlike the earlier analyses, all the rows and columns are represented fully by the dimensions as there are only two possible dimensions. Features A and B contribute more and are represented better by the first dimension, while feature C does this for the second dimension. For the variables, fissures, lips and ripples generally contribute more to the first dimension, while scaring and bulb formation are better represented in the second dimension, with some exceptions. No scree plot was done for the analysis, as it is quite obvious that one dimension would suffice for the analysis, but two dimensions are needed for the visualisation. As there are only two dimensions, no choice can be made about which to show.

Figure 57 shows the biplot of the correspondence analysis. The distribution of the technical variables is similar to the open study (Fig. 52). Along the axis of the first dimension, the progression from soft techniques to hard techniques is hinted. The objects are aligned along the axis in a more or less evenly spaced way. It is not immediately obvious if the objects form groups or are groups by themselves.

With the very few objects looked at here, it is not expected to get a high number of clusters. Figure 58 still suggests the formation of two clusters in the data. Only the silhouette plot's identification of optimal clusters is shown here, as the scree plot forms a straight line between one and two clusters, without a bend which could indicate how many clusters should be expected. Figure 59 shows how the clusters are formed. Feature A is a cluster on its own, while B and C form a cluster together. Nonetheless, the clusters have to be regarded with caution. Figure 60 shows that the clusters are even less separated than in the open analysis.

The same analyses are computed for the preparation types, which gave a bit more reliable results in the open analysis. Edge and platform preparation as well as platform remnant form are fed into the analysis. The summary shows the high representation in the first dimension. Again, this is not totally surprising with

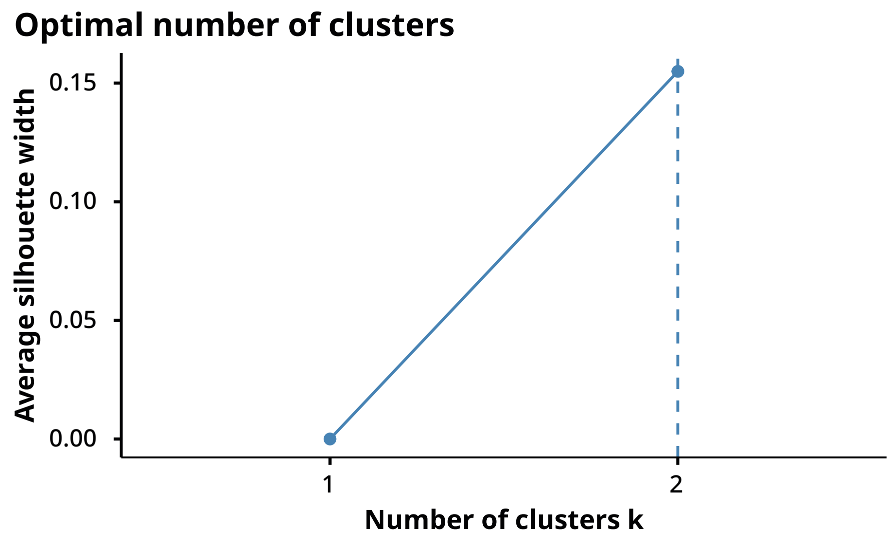


Figure 58. Silhouette plot of the optimal number of clusters in test A for technical variables.

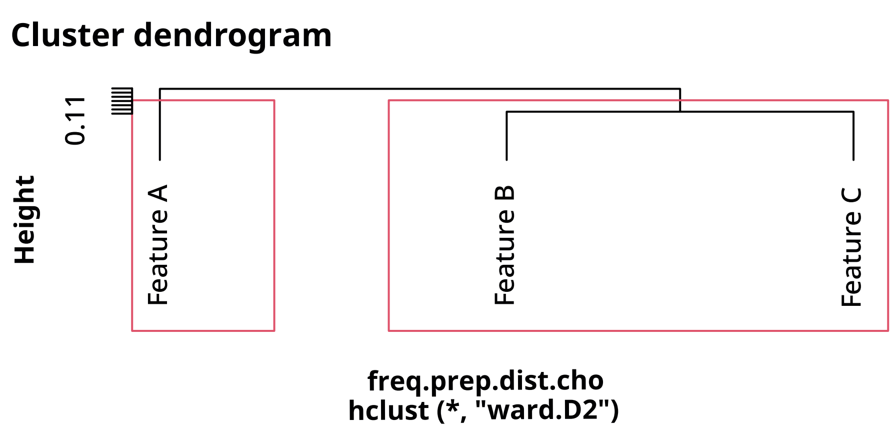


Figure 59. Cluster dendrogram of technical variables of test A.

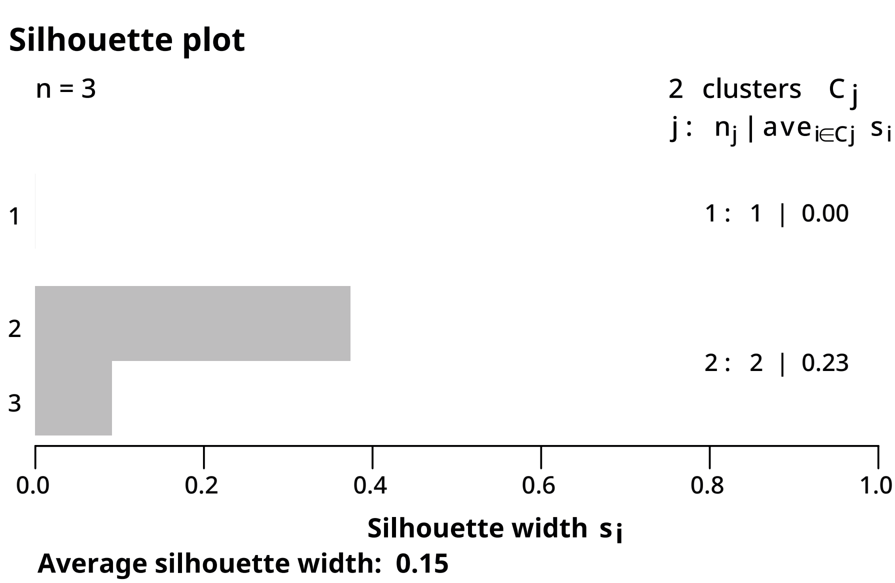


Figure 60. Silhouette plot of technical clusters of test A.

only two dimensions available. Once more, features A and B are represented best and contribute most to the first dimension, while feature C is represented fully by the second dimension. Platform preparation overwhelmingly contributes to the first dimension, while the contributors to the second dimension vary.

```
##
## Pearson’s Chi-squared test with simulated p-value (based on 2000
## replicates)
##
## data: PrepA_all
## X-squared = 197, df = NA, p-value = 0.0005

##
## Principal inertias (eigenvalues):
##
## dim        value     %   cum%  scree plot
## 1          0.035092 77.8  77.8 *******************
## 2          0.010033 22.2 100.0 ******
##            -------- -----
## Total:     0.045125 100.0
##
##
## Rows:
##     name   mass qlt inr    k=1 cor ctr    k=2 cor ctr
## 1 | FtrA | 332 1000 439 | -235 926 522 | -67   74 146 |
## 2 | FtrB | 370 1000 405 |  213 917 478 | -64   83 152 |
## 3 | FtrC | 299 1000 156 |   -3   0   0 | 154 1000 701 |
##
## Columns:
##      name   mass qlt inr    k=1  cor ctr    k=2 cor ctr
## 1  | E_np | 191 1000  16 |   31  258   5 |   53 742  53 |
## 2  | E_br |  81 1000 123 |  112  183  29 | -237 817 451 |
## 3  | E_fn |  37 1000  36 | -176  718  33 |  110 282  45 |
## 4  | E_fa |  15 1000  79 | -472  963  97 |   93  37  13 |
## 5  | E_st |   8 1000  32 | -106   63   3 |  408 937 133 |
## 6  | E_sa |   1 1000   3 | -281  622   3 |  219 378   5 |
## 7  | P_pl | 119 1000 334 | -356 1000 430 |   -2   0   0 |
## 8  | P_fc | 214 1000 186 |  198 1000 239 |    1   0   0 |
## 9  | F_rd |  12 1000  28 | -292  836  30 | -129 164  21 |
## 10 | F_vl | 112 1000  73 | -127  543  51 | -116 457 151 |
## 11 | F_rn |   2 1000   4 |  -53   23   0 | -341 977  19 |
## 12 | F_th | 124 1000  14 |   21   90   2 |   68 910  58 |
## 13 | F_rf |  84 1000  73 |  182  838  79 |   80 162  53 |
```

The visualisation of the correspondence analysis (Fig. 61) again shows a similar picture for the open analysis (Fig. 33). The axis seems to explain the same conditions as in the open analysis, with shape or effort of preparation along the first dimension, but in reverse here, and work load regarding the material along the second. As in the analysis of the technical variables, the features are more or less evenly spaced in relation to another.

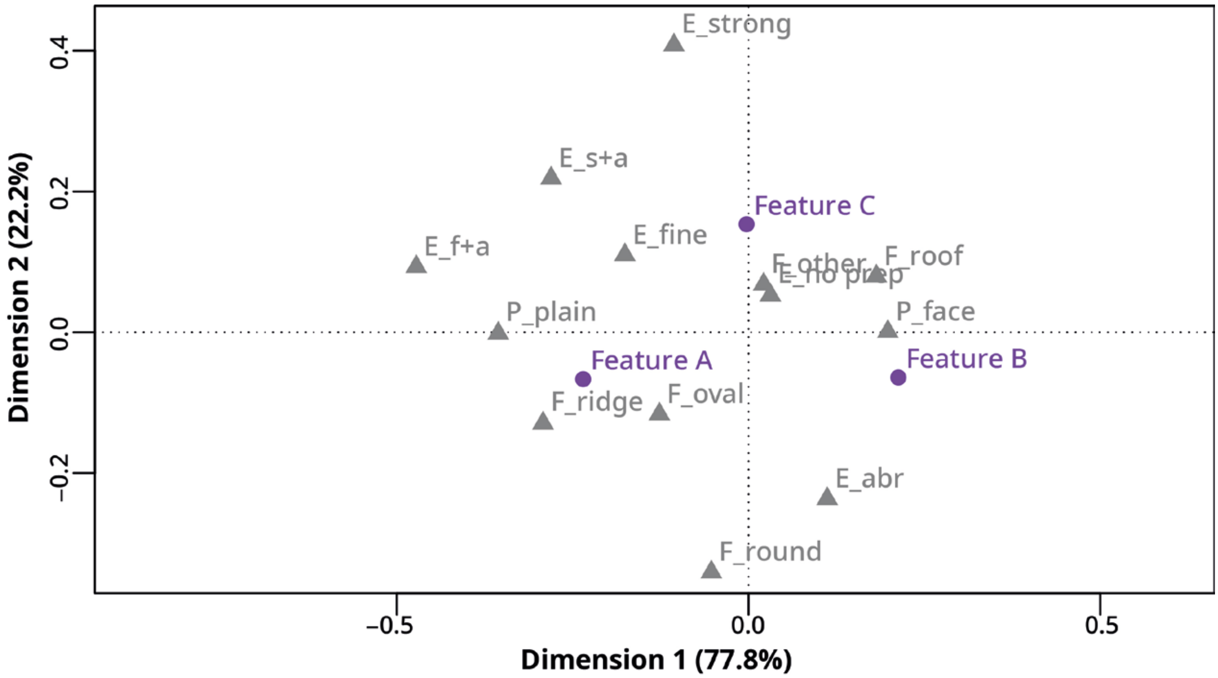


Figure 61. Correspondence analysis of preparation forms for test A.

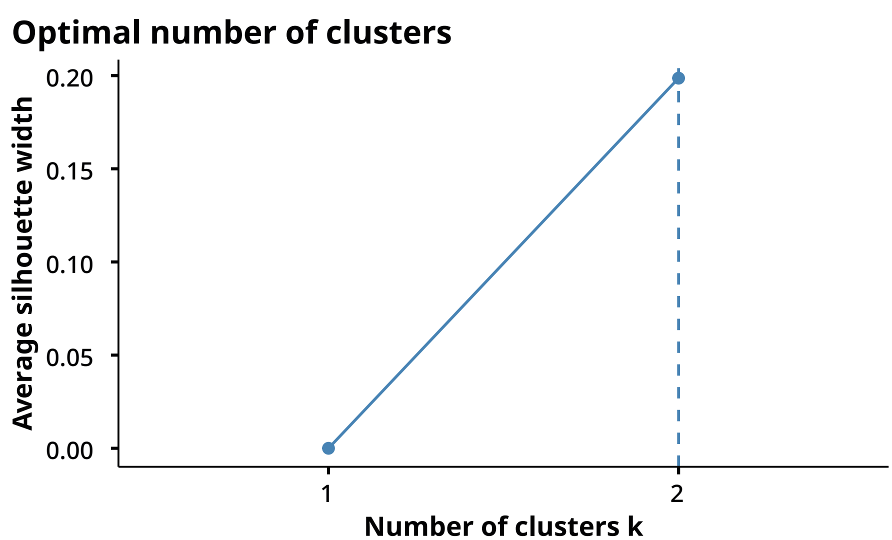


Figure 62. Silhouette plot of the optimal number of clusters in test A for preparation variables.

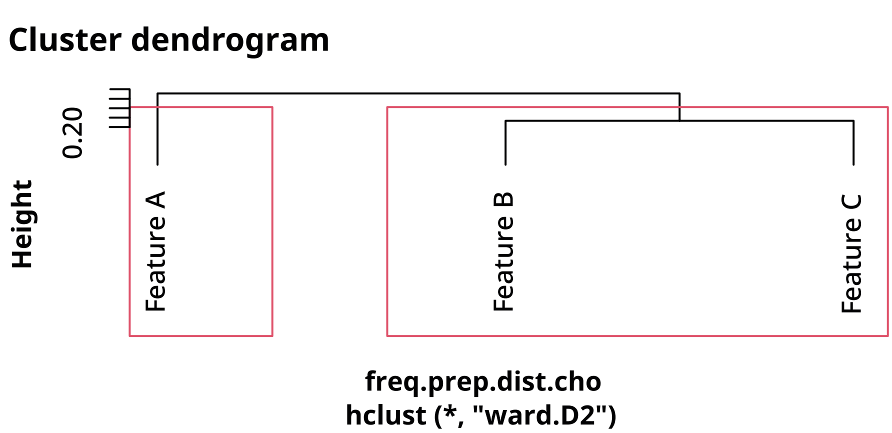


Figure 63. Cluster dendrogram of preparation variables of test A.

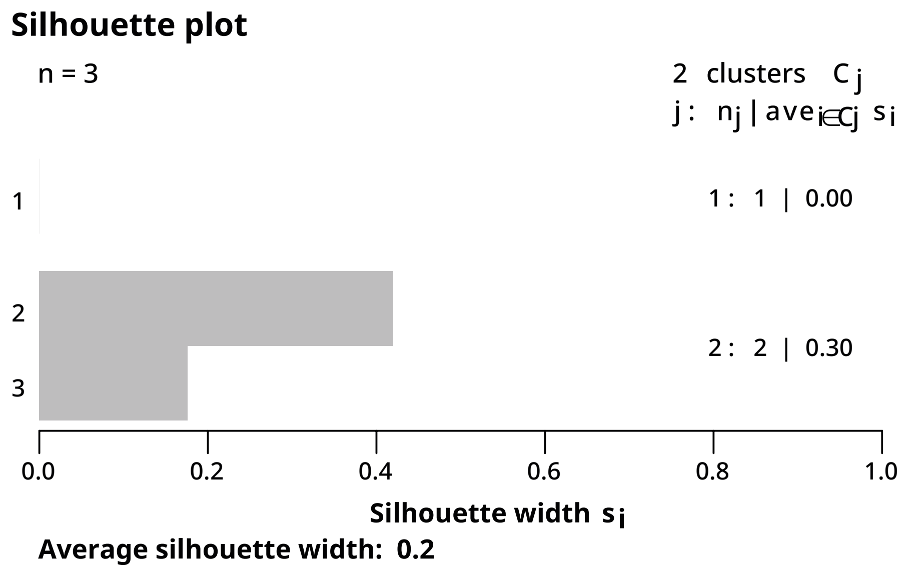


Figure 64. Silhouette plot for clusters of preparation variables from test A.

Once more, two clusters are suggested (Fig. 62) and are comprised of feature A and features B and C (Fig. 63). In contrast to the open analysis, this time the clusters are not separated very well (Fig. 64), but slightly better than for the technical variables.

The results obtained here are not totally meaningless. Feature A consists of flakes from A. Benke, feature B is a sample of G. Nunn's inventories and feature C is made up of P. Wiking's works. It was already seen in the open analysis that G. Nunn's and P. Wiking's inventories are more similar to each other, especially in 2007, while A. Benke's inventories were more distinct. Furthermore, a variation in the application of techniques is still hinted here, with the progression between soft and organic techniques to hard techniques. However, the results show the difficulties arising in mixed inventories, even while still dealing with separate knappers. Looking at several objects and only parts of the inventories seems to be enough to even out the differences that make a distinction between the knappers, which is rather poor especially compared to the results of the preparation types in the open analysis. The perceivable association of features B and C is probably due to knowledge exchange, which was detected in several situations, and still has enough influence to be noticeable. It thus seems possible to prove and explore likenesses and differences between knapping sites, at least when we are dealing with rather homogeneous assemblages, either by individual knappers or knappers who work very similar.

5.6.2 Single knapper against pure mixed features

In the second test, we deal with slightly mixed features. One still includes only one knapper, while the other two features are mixtures of other knappers, not including the single feature knapper. Feature D contains 395 flakes, feature G includes 679 flakes and feature J is comprised of 776 flakes. The variable for combined split fractures and éraillure scars was removed, as none of the assemblages contained flakes with this combination and it hindered the analysis.

A possible scenario could be distinct scatters on a site. For the dagger production, secluded teaching areas have been proposed within an apprenticeship system. It is not hard to imagine situations in such a context, where a teacher demonstrates the production to a circle of attending apprentices, who later (or meanwhile) try to mimic the seen procedure, maybe sitting in groups, talking to another, figuring out how to deal with the production.

```
##
## Pearson’s Chi-squared test with simulated p-value (based on 2000
## replicates)
##
## data: Test_B
## X-squared = 61, df = NA, p-value = 0.003
```

```
##
## Principal inertias (eigenvalues):
##
## dim        value     %   cum%  scree plot
## 1          0.006637 84.3  84.3 *********************
## 2          0.001238 15.7 100.0 ****
##            -------- -----
## Total:     0.007876 100.0
##
##
## Rows:
##     name  mass  qlt inr    k=1 cor ctr   k=2  cor ctr
## 1 | FtrD | 226 1000 536 | -133 950 604 | -31   50 170 |
## 2 | FtrG | 341 1000 375 |   88 889 396 | -31  111 264 |
## 3 | FtrJ | 433 1000  89 |    0   0   0 |  40 1000 567 |
##
## Columns:
##      name  mass  qlt inr    k=1 cor ctr    k=2 cor ctr
## 1  | B_nn |   2 1000   8 |   89 304   3 |  134 696  34 |
## 2  | B_nr | 145 1000   2 |   -9 895   2 |   -3 105   1 |
## 3  | B_st |  52 1000   4 |   25 990   5 |    3  10   0 |
## 4  | B_db |   1 1000  16 | -437 978  19 |  -65  22   2 |
## 5  | S_nn | 139 1000 135 |   86 964 154 |  -17  36  31 |
## 6  | S_Es |  58 1000 325 | -205 950 366 |   47  50 103 |
## 7  | S_EB |   2 1000   8 |  113 347   3 | -154 653  35 |
## 8  | S_Sf |   2 1000   1 |  -48 674   1 |  -33 326   1 |
## 9  | R_nn | 190 1000   6 |  -13 620   5 |  -10 380  15 |
## 10 | R_pr |  10 1000 115 |  235 617  85 |  185 383 281 |
## 11 | F_nn |  35 1000 176 | -183 844 176 |  -79 156 175 |
## 12 | F_wk | 148 1000  21 |   20 381   9 |   26 619  81 |
## 13 | F_st |  16 1000  63 |  170 926  70 |  -48  74  30 |
## 14 | F_bt |   1 1000  51 |  484 761  46 | -271 239  77 |
## 15 | L_nn | 104 1000  13 |  -31 917  15 |   -9  83   7 |
## 16 | L_wk |  73 1000  18 |   33 550  12 |   29 450  51 |
## 17 | L_nr |  19 1000   3 |  -10  88   0 |  -34 912  17 |
## 18 | L_st |   5 1000  36 |  214 742  31 | -126 258  58 |
```

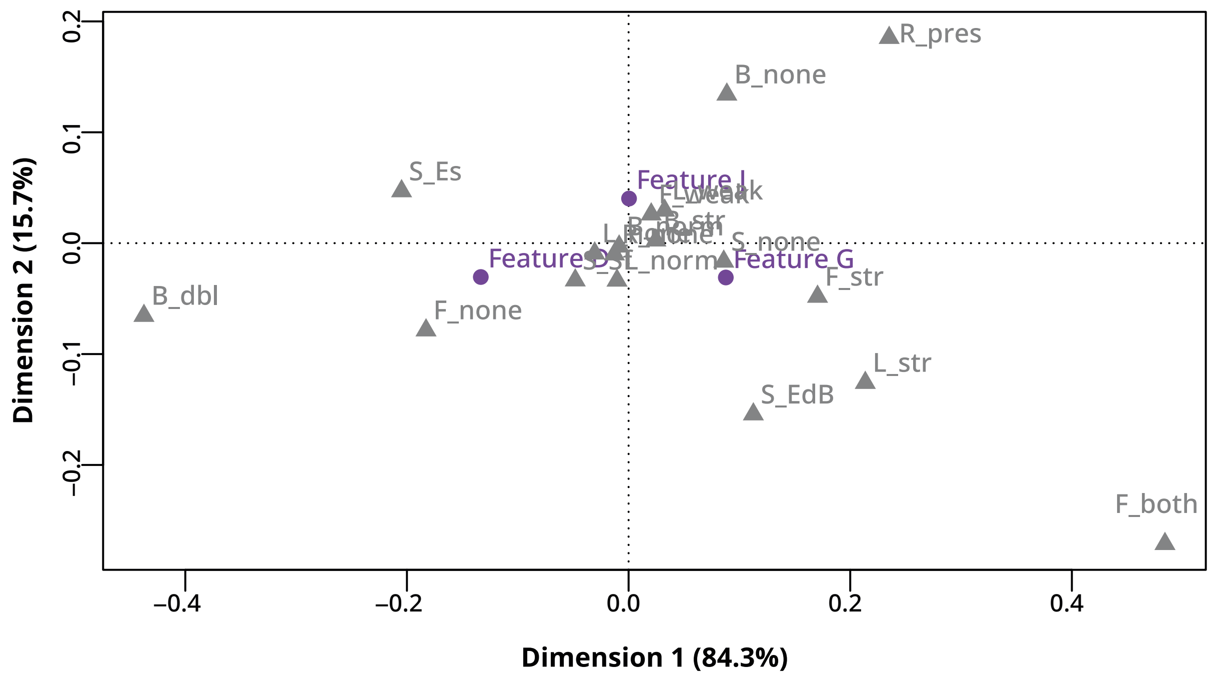


Figure 65. Correspondence analysis of technical variables in test B.

As can be seen, the p-value stays below the 0.5 threshold of significance. Features D and G contribute most to the first dimension, while feature J only contributes and is represented in the second dimension. The variables are mostly best represented in the first dimension, whereas only normal lips, no bulbs, *esquillement du bulbe* and weak fissures contribute more to the second dimension.

The plot of the correspondence analysis (Fig. 65) has changed quite a lot from the prior analysis, and also in contrast to the open analysis (Fig. 52). Normal and strong bulbs cluster together in the middle of the plot, with no and normal lip formation. The other variables are spread without really assembling to meaningful technical units, although it seems that soft stone percussion is distributed more in the lower right section of the plot, whereas strong lips and *esquillement du bulbe* are situated together. There are still some hints for hard technique to the left and soft techniques to the right, but not as clearly as before. From the distribution of the features, it appears that feature D is more dissimilar from the other two and more in line with hard percussion techniques than J and G.

Two clusters are identified (Fig. 66) and the dendrogram confirms the notion from the biplot of the cluster analysis; feature D is indeed dissimilar to the other two features (Fig. 67). But, once again, the silhouette plot shows the very weak separation between the clusters (Fig. 68).

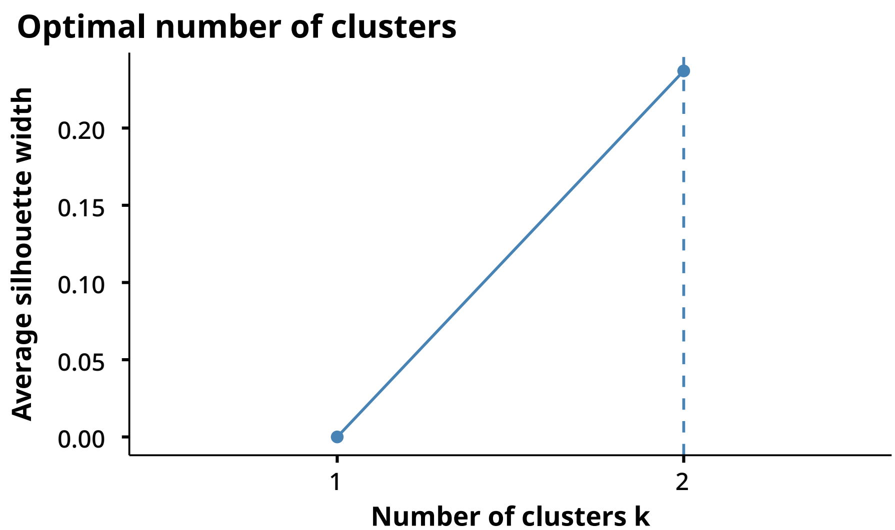


Figure 66. Silhouette plot of the optimal number of clusters for technical variables of test B.

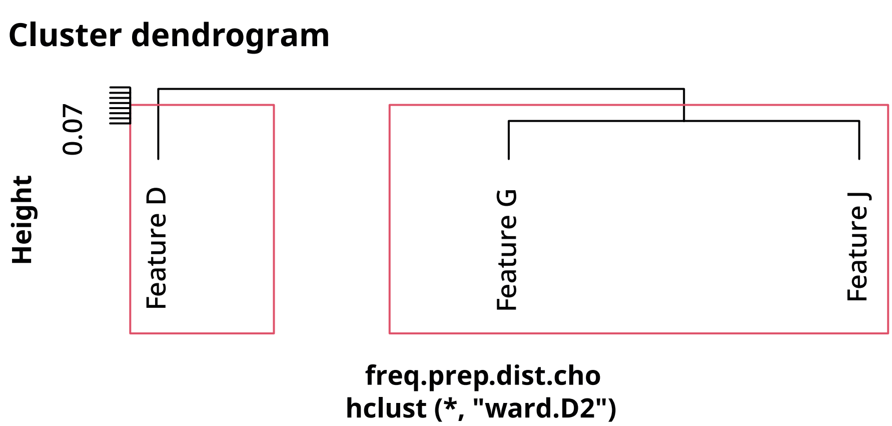


Figure 67. Cluster dendrogram of groups for technical variables of test B.

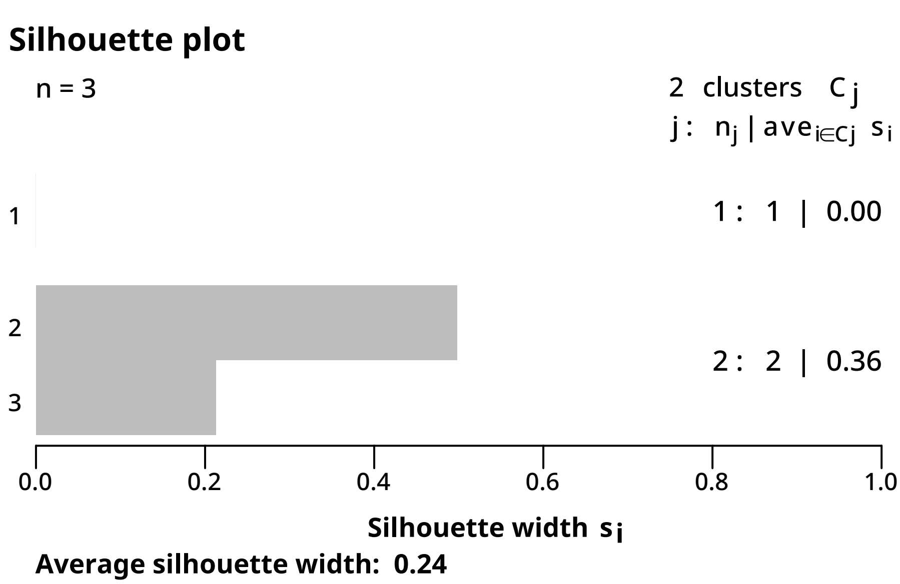


Figure 68. Silhouette plot of clusters from technical variables of test B.

```
##
## Pearson’s Chi-squared test with simulated p-value (based on 2000
## replicates)
##
## data: PrepB_all
## X-squared = 231, df = NA, p-value = 0.0005

##
## Principal inertias (eigenvalues):
##
## dim         value     %   cum%  scree plot
## 1           0.042241 81.2  81.2 ********************
## 2           0.009770 18.8 100.0 *****
##             -------- -----
## Total:      0.052011 100.0
##
##
## Rows:
##     name  mass  qlt inr    k=1 cor ctr   k=2 cor ctr
## 1 | FtrD | 242 1000 543 | -335 960 641 | -69  40 117 |
## 2 | FtrG | 343 1000 344 |  209 834 354 | -93 166 304 |
## 3 | FtrJ | 415 1000 113 |   23  36   5 | 117 964 580 |
##
## Columns:
##      name  mass  qlt inr    k=1 cor ctr    k=2 cor ctr
## 1  | E_np | 191 1000  29 |  -36 171   6 |   80 829 126 |
## 2  | E_br |  74 1000 105 | -215 629  81 | -165 371 206 |
## 3  | E_fn |  40 1000 102 |  338 851 107 |  141 149  81 |
## 4  | E_fa |  16 1000  63 |  392 773  60 | -213 227  76 |
## 5  | E_st |  10 1000  48 |  244 248  15 | -426 752 192 |
## 6  | E_sa |   2 1000   9 |  227 231   2 | -414 769  36 |
## 7  | P_pl | 126 1000 297 |  350 997 365 |  -18   3   4 |
## 8  | P_fc | 207 1000 181 | -213 997 222 |   11   3   3 |
## 9  | F_rd |  11 1000  17 |  249 788  16 |  129 212  19 |
## 10 | F_vl | 123 1000  23 |   25  65   2 |  -95 935 114 |
## 11 | F_rn |   1 1000  25 | 1016 538  17 | -941 462  61 |
## 12 | F_th | 118 1000  33 |   90 552  22 |   81 448  79 |
## 13 | F_rf |  81 1000  70 | -211 993  85 |   17   7   2 |
```

Analysing the preparation attributes, the contribution to the dimensions by the objects is similar to the technical variables. Feature J is again the only object contributing significantly to the second dimension. Moreover, the variables do contribute mainly to the first dimension, with the exception of oval platforms and no edge preparation. Strong preparation and abrasion combined with strong preparation also contribute some more to the second dimension. As in the analysis of the technical variables, the first dimension explains more than 80% of the variation.

The biplot of the preparation attributes is not so dissimilar to the other plots for this part of the analysis (Fig. 69). Along the axis of the first dimension, remnant form or preparation effort still seems to be the guiding factor. The round platform

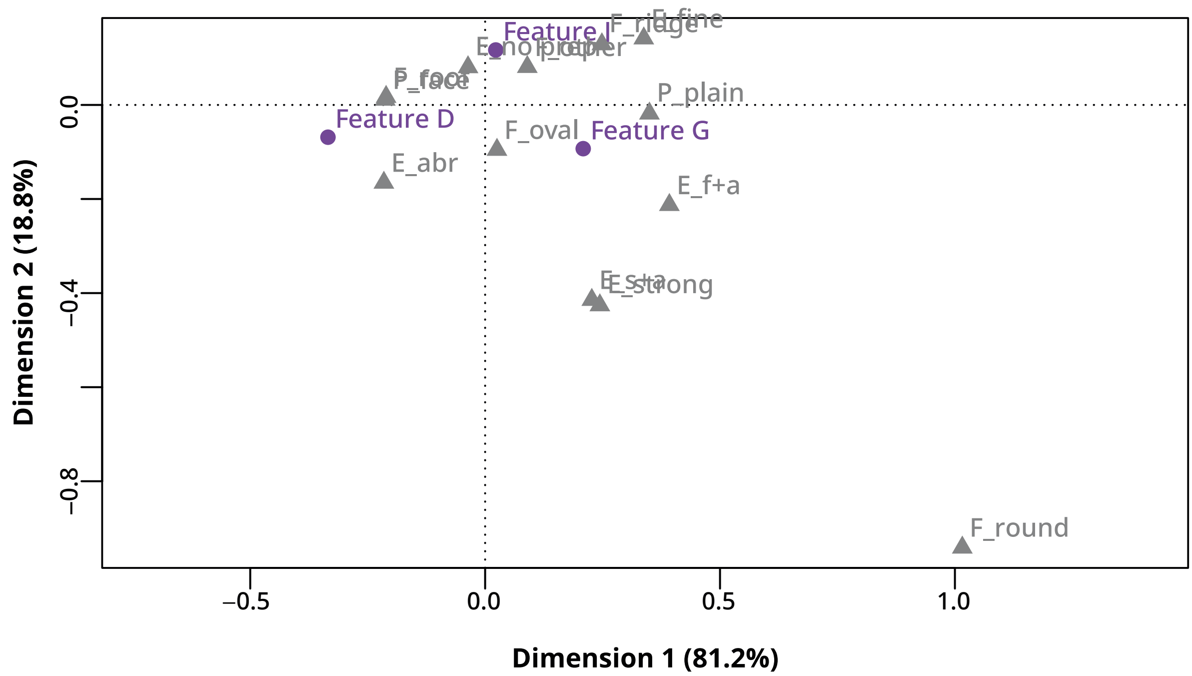


Figure 69. Correspondence analysis of preparation variables of test B.

remnants act as an outlier here probably due to the really small number included. The second dimension again progresses from material intensive preparation to less intensive, but this time from top to bottom of the plot. Once again, feature D seems to be more off than the other two inventories, although the spacing seems to be more even.

Unsurprisingly, the optimal number of clusters for the data is two (Fig. 70). Here too, the perceived difference between feature D and the other two is repeated (Fig. 71), but also once more, the separation of the clusters is very weak, although a bit better than for the technical variables (Fig. 72).

Surprisingly, the significance, the explained variability and the separation of the clusters become slightly better when dealing with the mixed assemblages, compared to the earlier single knapper features. We are still dealing with rather limited mixing, and the contrast between the mixed assemblages was also attempted to be as high as possible. Feature D is a sample of flakes from G. Nunn's dagger inventory, feature G is comprised of flakes from P. Wiking's sickle from 2006 and A. Benke's sickle from 2018, while feature J is made up of P. Wiking's 2007 sickle and A. Benke's dagger. The selection was chosen with the thought in mind that no flake can be present twice in the analysis, which would have happened if the samples had been drawn from populations only split for knappers. Feature G was chosen in this constellation, as these works were the most dissimilar to G. Nunn's dagger, while feature J includes works, which are to some extent influenced by him. A possible outcome could have been that features D and J would have formed a cluster together. That G and J are still more similar to each other than to D, slightly underlines the personal preferences, which have been previously explored. Although the influence of G. Nunn is present in both inventories, it seems that personal adaption and the way of using techniques are still present. Quite likely, A. Benke's approach is also dissimilar enough from G. Nunn's that the similarity of P. Wiking's inventory is levelled to some extent. Another factor favouring the distinction is quite likely the different raw material, which also has an influence on the chosen techniques.

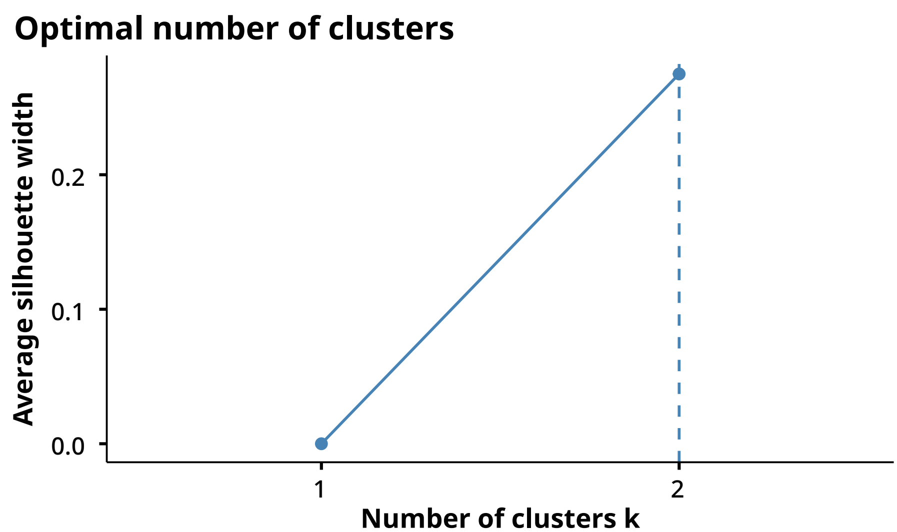


Figure 70. Silhouette plot of the optimal number of clusters for the preparation variables of test B.

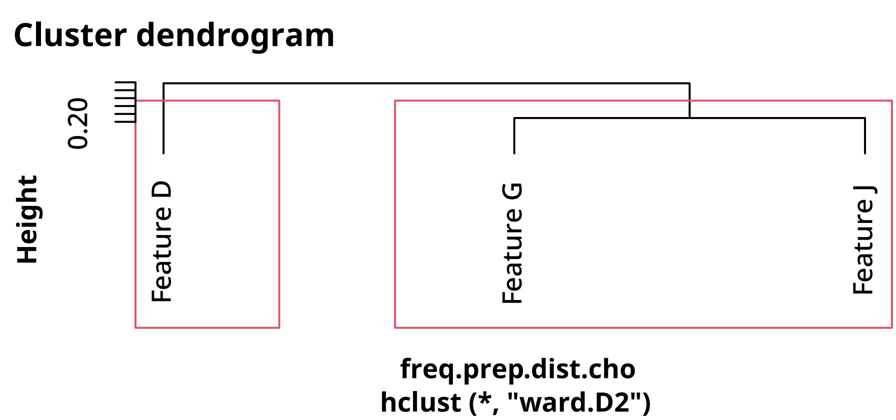


Figure 71. Cluster dendrogram of groups from preparation variables of test B.

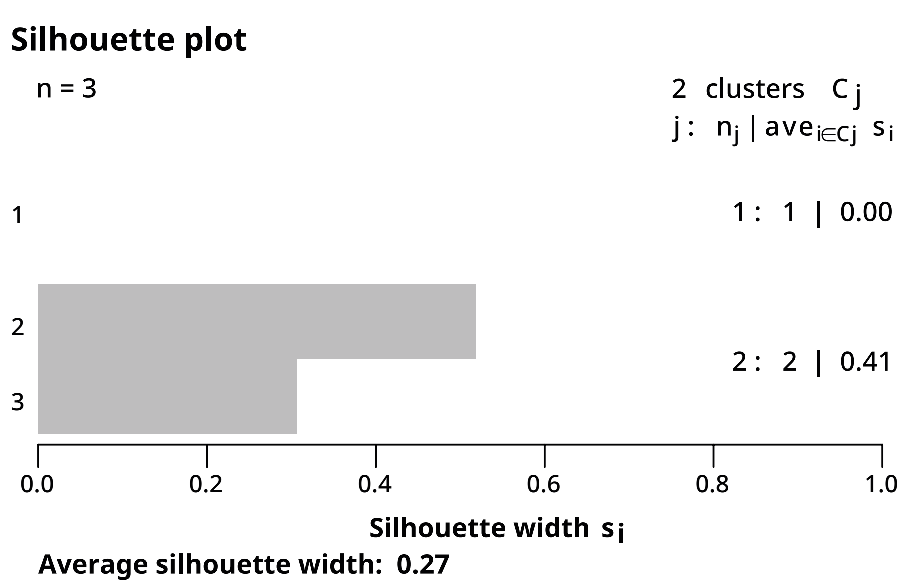


Figure 72. Silhouette plot of clusters from preparation variables of test B.

5.6.3 Single knapper against 'messy' mixed features

In the third test, the mixing changed slightly. This time, one single feature is again tested against mixed assemblages, but each of the mixed features includes the knapper of the single feature. Feature D is the same as in the second test, feature E includes 610 flakes and feature H includes 907 flakes.

```
##
## Pearson's Chi-squared test with simulated p-value (based on 2000
## replicates)
##
## data: Test_C
## X-squared = 2560, df = NA, p-value = 0.0005
```

```
##
## Principal inertias (eigenvalues):
##
## dim        value     %   cum%  scree plot
## 1          0.324454 98.1  98.1 *************************
## 2          0.006377  1.9 100.0
##            -------- -----
## Total:     0.330831 100.0
##
##
## Rows:
##     name  mass  qlt inr     k=1  cor ctr    k=2 cor ctr
## 1 | FtrD | 223 1000 761 | -1061 1000 775 |    6   0   1 |
## 2 | FtrE | 288 1000  78 |   274  840  67 | -120 160 645 |
## 3 | FtrH | 488 1000 162 |   324  958 158 |   68  42 354 |
##
## Columns:
##      name  mass  qlt inr      k=1 cor ctr    k=2 cor ctr
## 1  | B_nn |   2 1000   0 |   -26   13   0 | -232 987  14 |
## 2  | B_nr | 141 1000   0 |   -26  677   0 |  -18 323   7 |
## 3  | B_st |  56 1000   1 |    60  471   1 |   63 529  35 |
## 4  | B_db |   1 1000   1 |    38    6   0 | -479 994  46 |
## 5  | S_nn | 133 1000   2 |    45  520   1 |  -43 480  39 |
## 6  | S_Es |  63 1000   4 |  -100  444   2 |  112 556 124 |
## 7  | S_EB |   3 1000   1 |   179  183   0 | -378 817  61 |
## 8  | S_Sf |   1 1000   1 |  -196  270   0 | -322 730  21 |
## 9  | S_ES |   0 1000   0 |   569  309   0 |  851 691  15 |
## 10 | R_nn | 148 1000 128 |   534  997 130 |  -29   3  20 |
## 11 | R_pr |  51 1000 355 | -1512  997 361 |   84   3  56 |
## 12 | F_nn |  32 1000  29 |   470  746  22 |  274 254 382 |
## 13 | F_wk | 125 1000  42 |   328  967  41 |  -61  33  73 |
## 14 | F_st |  41 1000 210 | -1304  999 214 |  -29   1   6 |
## 15 | F_bt |   3 1000  27 | -1757 1000  27 |   -1   0   0 |
## 16 | L_nn |  98 1000  86 |   536  990  87 |   54  10  45 |
## 17 | L_wk |  70 1000  20 |  -308  987  21 |  -36  13  14 |
## 18 | L_nr |  25 1000  63 |  -904  988  63 | -100  12  39 |
## 19 | L_st |   6 1000  29 | -1280  998  29 |  -52   2   2 |
```

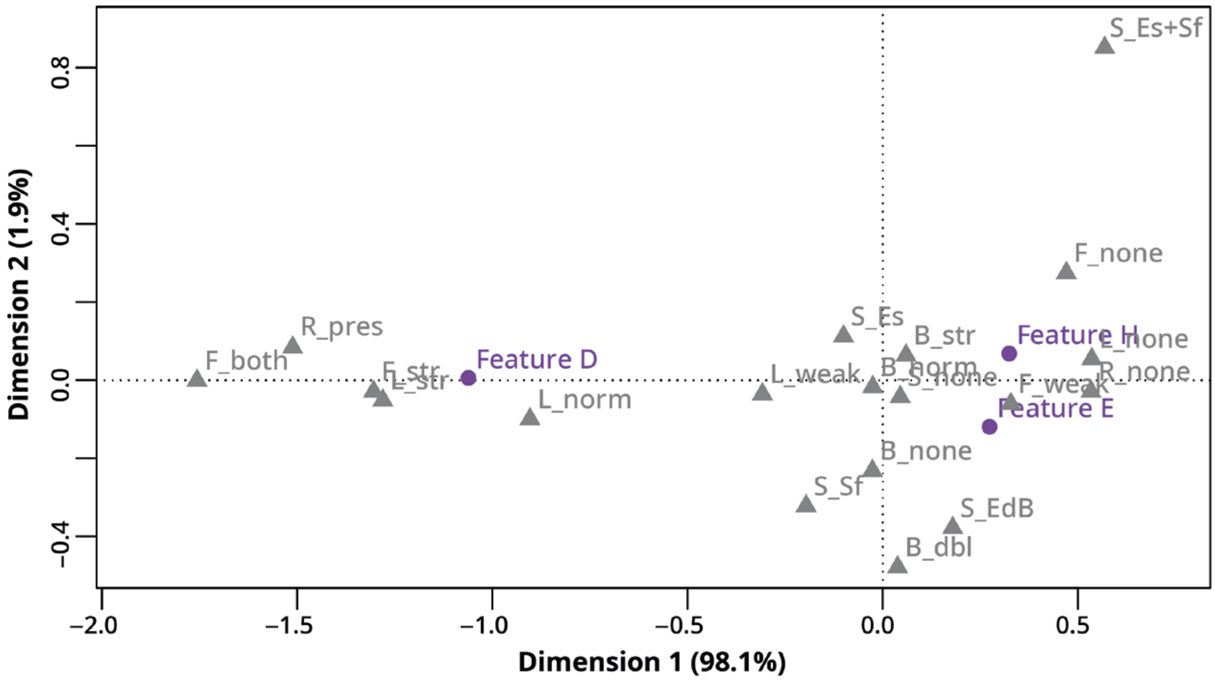


Figure 73. Correspondence analysis of technical variables of test C.

The variability in this test is nearly completely explained by the first dimension, where all three objects also contribute most and are represented best. For the variables, again the lips, fissures and ripples are best represented in the first dimension, while bulbs and bulb scarring fit better in the second dimension.

The biplot is more difficult to interpret this time (Fig. 73). Along the first dimension, a progression from strong to no lips can be seen, but the bulbs do not match the distribution. The choice of technique does not seem to be the expressed variability this time. It appears that the intensity of attributes is described more, with strong forms on the left and weak or not present forms on the right. The bulb formation and the scarring align with the axis of the second dimension, which was already seen in the analysis summary, although there is no real pattern to the alignment. The objects are clearly separated by distance this time, feature D being quite off of the other two. If we assume force being the represented variation along the first dimension, this implies that feature D has been worked with more forceful blows than features H and E.

The identified clusters sum up to feature D being a single cluster and E and H forming a group together (Fig. 74 and Fig. 75). Surprisingly, the separation of the groups is really good (Fig. 76). In the cluster formed by features E and H, the average silhouette width is very high, suggesting that the objects in the cluster are very much similar to each other and less to feature D. The average silhouette width is somewhat lower due to the value of the cluster with feature D, but still quite good in comparison to the values obtained so far.

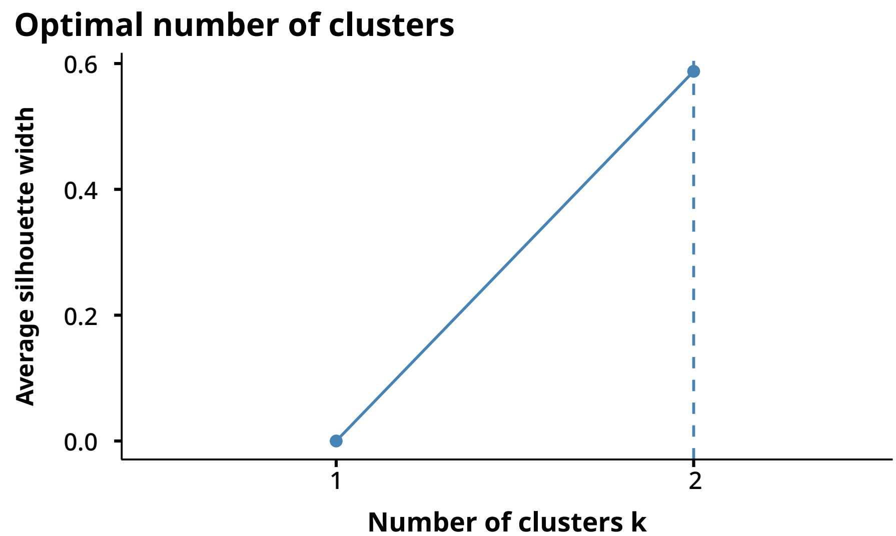


Figure 74. Silhouette plot of the optimal number of clusters for the technical variables of test C.

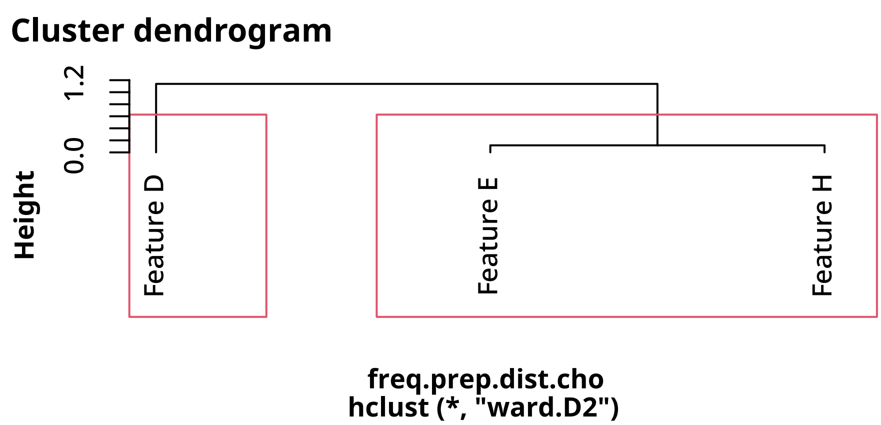


Figure 75. Cluster dendrogram of groups formed by technical variables of test C.

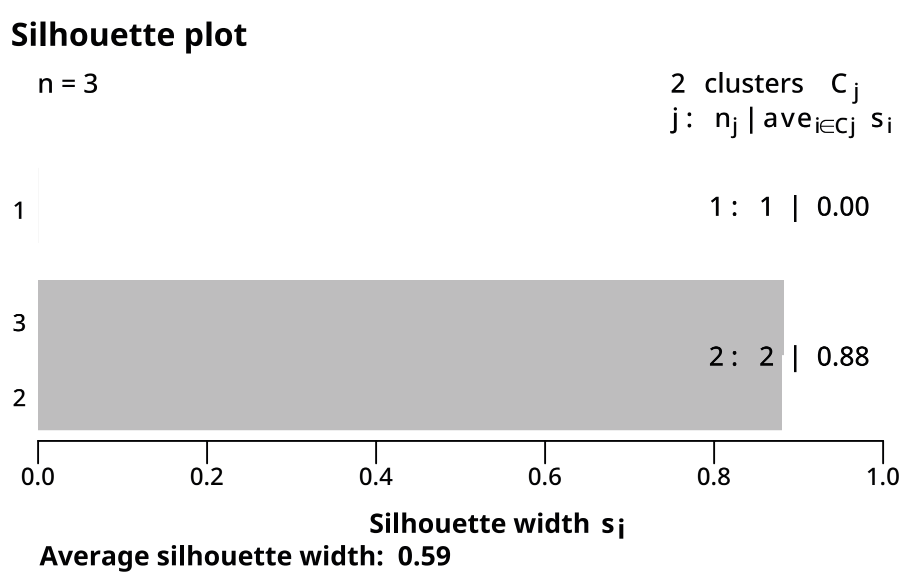


Figure 76. Silhouette plot of group separation of technical variables of test C.

```
## Pearson’s Chi-squared test with simulated p-value (based on 2000
## replicates)
##
## data: PrepC_all
## X-squared = 222, df = NA, p-value = 0.0005

##
## Principal inertias (eigenvalues):
##
## dim        value      %   cum%  scree plot
## 1          0.031144  61.9  61.9 ***************
## 2          0.019161  38.1 100.0 **********
##            -------- -----
## Total:     0.050305 100.0
##
##
## Rows:
##     name  mass  qlt inr    k=1 cor ctr    k=2 cor ctr
## 1 | FtrD | 243 1000 351 | -184 466 264 | -197 534 493 |
## 2 | FtrE | 297 1000 424 |  263 960 658 |  -54  40  45 |
## 3 | FtrH | 460 1000 224 |  -72 214  78 |  139 786 463 |
##
## Columns:
##      name  mass  qlt inr    k=1 cor ctr    k=2  cor ctr
## 1  | E_np | 177 1000  35 |  -99 980  56 |   14   20   2 |
## 2  | E_br |  91 1000  44 |   27  29   2 | -154  971 112 |
## 3  | E_fn |  44 1000 130 |  199 266  56 |  331  734 250 |
## 4  | E_fa |  13 1000  52 |  441 976  82 |  -69   24   3 |
## 5  | E_st |   7 1000   7 |   -2   0   0 | -229 1000  19 |
## 6  | E_sa |   2 1000   8 |  381 618   8 | -299  382   8 |
## 7  | P_pl |  99 1000 244 |  348 979 385 |   51   21  14 |
## 8  | P_fc | 234 1000 103 | -147 979 163 |  -22   21   6 |
## 9  | F_rd |  12 1000  23 |  127 168   6 |  282  832  50 |
## 10 | F_vl | 109 1000 178 |  167 339  97 | -233  661 308 |
## 11 | F_rn |   1 1000  19 | 1014 998  30 |  -40    2   0 |
## 12 | F_th | 124 1000  88 |  -25  17   2 |  187  983 227 |
## 13 | F_rf |  88 1000  70 | -199 995 112 |  -14    5   1 |
```

Compared to the analysis of the technical variables, the explained variability of preparation types by the first dimension is significantly lower. The contribution to the dimension also changes. Feature E contributes mostly to the first dimension, while H is better represented in the second dimension, and feature D is nearly evenly split between the dimensions. The correlation of the variables does not favour one type above the other in the dimensions, and there is a nearly even split in the number of variables represented best for the dimensions.

In figure 77, the biplot of the preparation forms again resembles the distribution of the open analysis (Fig. 33), only mirrored. The objects are spread evenly, without the big offset seen in the technical variables. Feature E seems to include less effort for preparation than D and H.

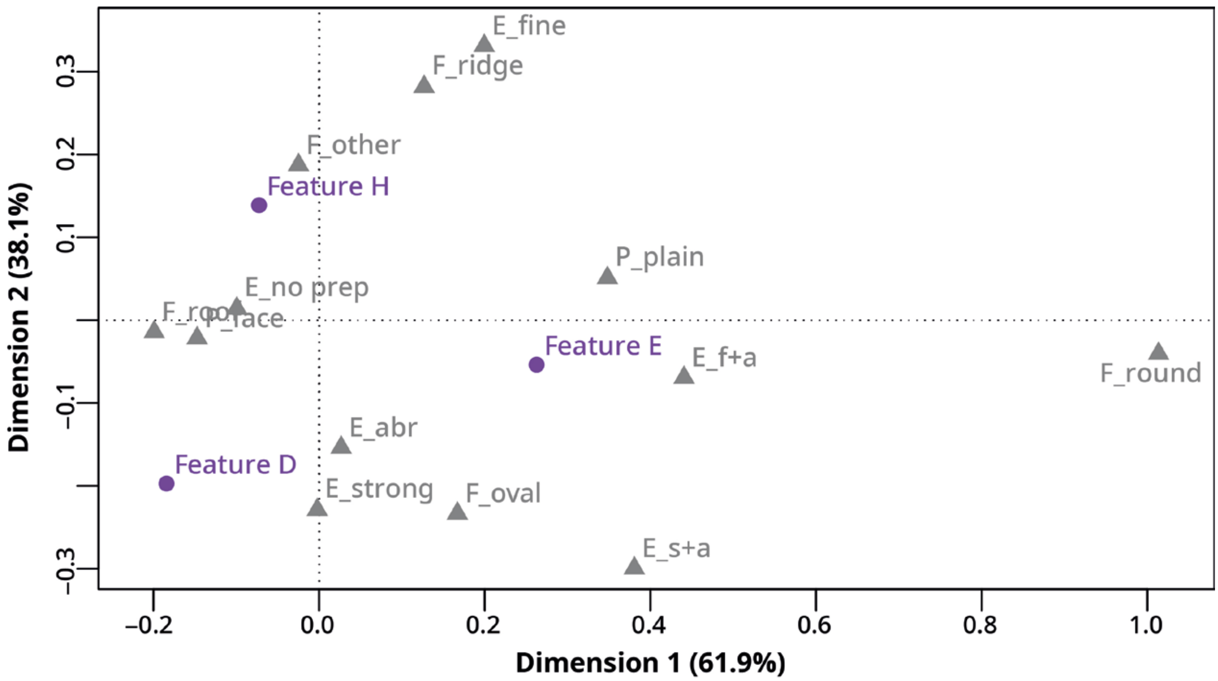


Figure 77. Correspondence analysis of preparation variables of test C.

The clusters have changed from the technical analysis. Now, features D and H form a cluster, as well as feature E singly (Fig. 78 and Fig. 79). The separation of the clusters is worse than for the technical variables, and with an average of 0.19 technically non-existent (Fig. 80).

The results in this analysis were surprising and at least for the technical variables very different from the expected result. Feature D is still G. Nunn's dagger inventory. As he is the only knapper included with three inventories, no other combination would have been possible, although another inventory could have been chosen as a sample for the single feature. Feature E is a mix of G. Nunn's sickle from 2006 and A. Benke's sickle, while feature H consists of G. Nunn's and P. Wiking's sickles from 2007. Again, there was some consideration to the mixing with these inventories. In Feature E, inventories most dissimilar to each other were assembled, while in feature H inventories, those which were most like each other were chosen. As G. Nunn's knapping products are part of every assemblage, it was expected to see even less separation of the clusters, if there had been clusters at all. The clear separation of the assemblage with the dagger knapping products from the later work was not expected. In particular, the difference to feature H was not expected due to the approximation of P. Wiking's work to G. Nunn's. In contrast, when comparing the result with the raw material, the clustering does make sense. It seemed that more force was applied to feature D in the biplot. Knowing that feature D is G. Nunn's dagger inventory, this makes some sense. In contrast to the other features, which are all comprised of Hillerslev flint, the dagger was made of Texas flint. As stated earlier, this variety is tougher than Scandinavian flint and does indeed need more force to remove similar flakes. The result from the analysis of preparation variables did show the expected result: G. Nunn and P. Wiking's assemblages form a cluster, whereby the assemblage including A. Benke's knapping products differs more from them. This also makes sense compared to the results of the technical variables: G. Nunn may have used more force to remove flakes on the Texas flint nodule, but his general approach to reduction was not influenced by the material.

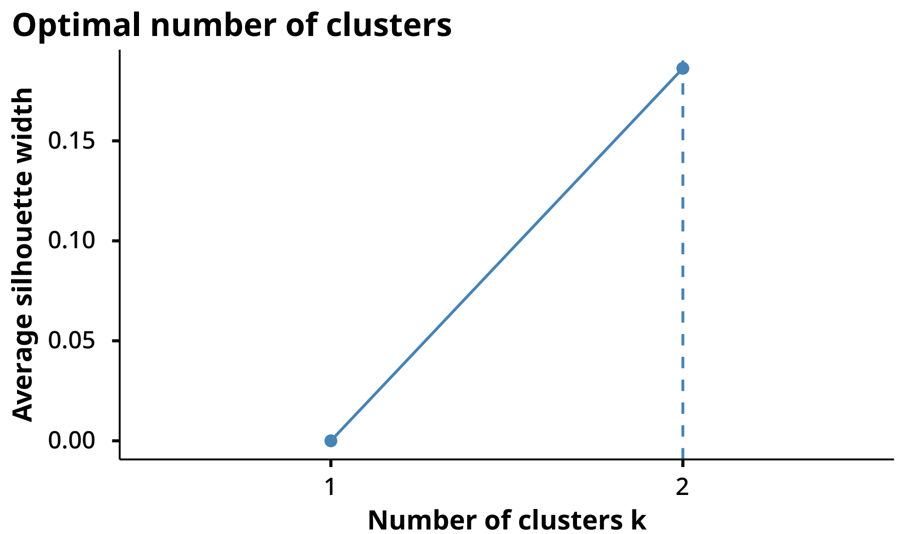


Figure 78. Silhouette plot of the optimal number of clusters for the preparation variables of test C.

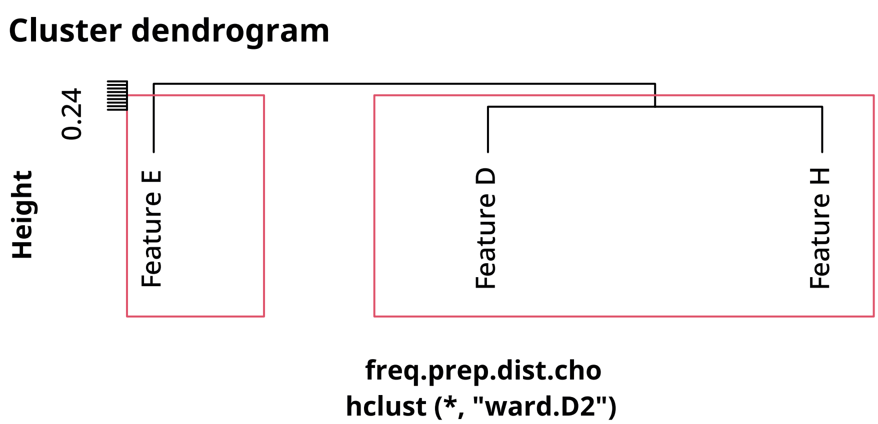


Figure 79. Cluster dendrogram of groups formed by preparation variables of test C.

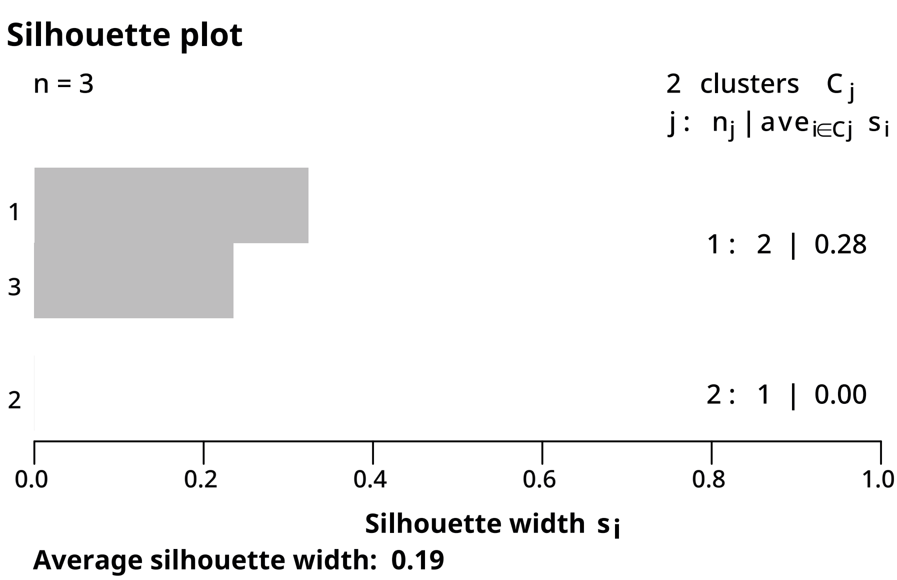


Figure 80. Silhouette plot of group separation by preparation variables of test C.

This analysis shows impressively that the results and interpretations can become very disorderly when dealing with mixed assemblages. It also shows that similarity in technical matters does not imply similarity in the preparation for the strike, especially when differing raw materials or raw material qualities are involved. Furthermore, it has demonstrated that raw material can have a very strong influence on the analysis and hinder the identification of knappers or approaches. This was also the first time that the preparation is less capable of explaining and differentiating between the knappers and features than the technical variables. But again, it did not seem that the choice of applied techniques was the factor for variability, but that raw material characteristics were important and by this the force applied during reduction.

5.6.4 Mixed features

The last test deals with the mixing of all knappers present in the record, but not with everyone in all features together. The total number of flakes in the assemblages is 679 for feature G, 907 for feature H and 722 for feature I.

```
##
## Pearson's Chi-squared test with simulated p-value (based on 2000
## replicates)
##
## data: Test_D
## X-squared = 128, df = NA, p-value = 0.0005
```

```
##
## Principal inertias (eigenvalues):
##
## dim        value      %   cum%  scree plot
## 1          0.010760  80.0  80.0 ********************
## 2          0.002691  20.0 100.0 *****
##            -------- -----
## Total:     0.013451 100.0
##
##
## Rows:
##     name  mass  qlt inr    k=1 cor ctr   k=2 cor ctr
## 1 | FtrG | 274 1000 346 | -115 774 335 | -62 226 391 |
## 2 | FtrH | 396 1000 465 |  125 987 574 | -14  13  30 |
## 3 | FtrI | 330 1000 189 |  -55 386  91 |  69 614 579 |
##
## Columns:
##      name  mass  qlt inr    k=1 cor ctr    k=2 cor ctr
## 1  | B_nn |   2 1000  16 | -267 714  14 |  169 286  22 |
## 2  | B_nr | 141 1000   6 |  -23 957   7 |    5  43   1 |
## 3  | B_st |  56 1000  22 |   69 882  24 |  -25 118  13 |
## 4  | B_db |   1 1000  11 |   51  15   0 |  409 985  52 |
## 5  | S_nn | 137 1000  57 |  -46 382  27 |  -59 618 176 |
## 6  | S_Es |  60 1000 134 |  111 408  68 |  134 592 397 |
## 7  | S_EB |   2 1000   3 |   20  18   0 | -145 982  16 |
```

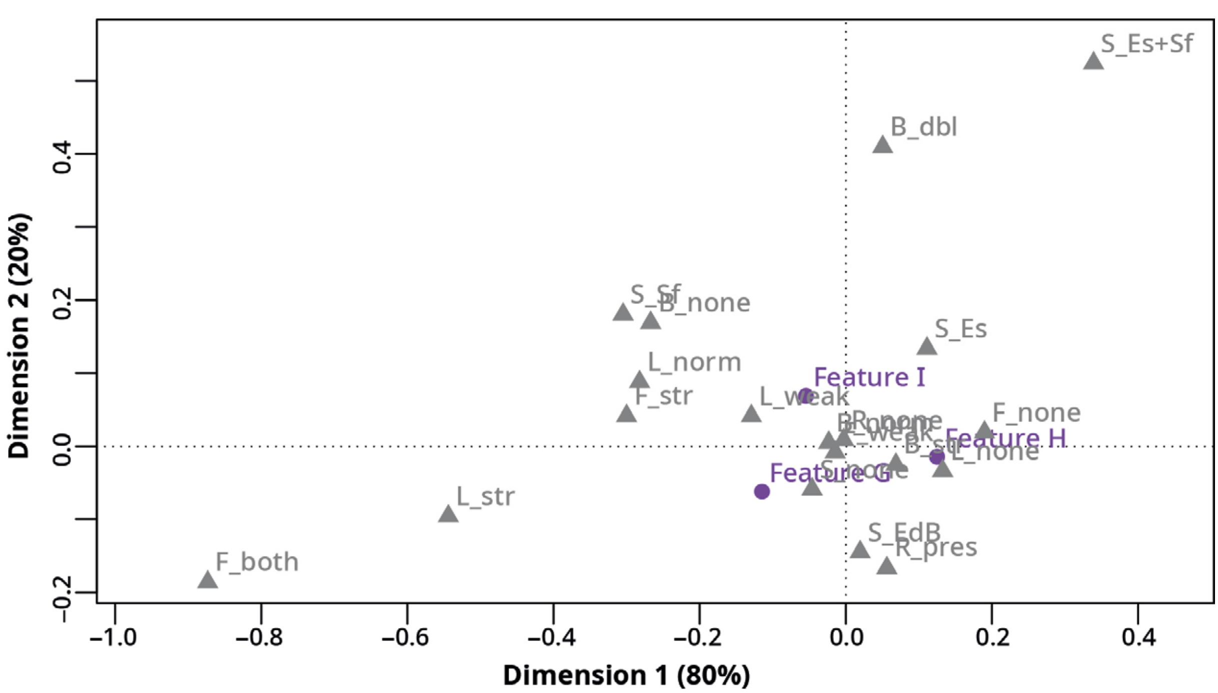
```
## 8  | S_Sf |   1 1000  13 | -305 741  12 |  180 259  16 |
## 9  | S_ES |   0 1000   6 |  339 295   2 |  524 705  21 |
## 10 | R_nn | 190 1000   1 |   -3 102   0 |    9 898   5 |
## 11 | R_pr |  10 1000  22 |   56 102   3 | -167 898 100 |
## 12 | F_nn |  40 1000 108 |  190 990 133 |   19  10   5 |
## 13 | F_wk | 144 1000   3 |  -14 753   3 |   -8 247   4 |
## 14 | F_st |  15 1000 104 | -300 981 127 |   41  19  10 |
## 15 | F_bt |   1 1000  62 | -873 957  74 | -186  43  13 |
## 16 | L_nn | 114 1000 158 |  133 940 186 |  -34  60  48 |
## 17 | L_wk |  67 1000  92 | -129 907 104 |   41  93  43 |
## 18 | L_nr |  16 1000 103 | -282 911 117 |   88  89  45 |
## 19 | L_st |   4 1000  81 | -544 970  98 |  -96  30  12 |
```

The explained variability of the first dimension is in good accordance with the other tests so far. It is a bit lower than before, but not significantly. Feature H and to a minor extent also G are represented best in the first dimension, and Feature I in the second dimension. The variables are mostly best represented in the first dimension. With the exception of double bulbs, most of the bulb scarring and ripple formation are better represented in the second dimension.

The distribution of the variables along the axis is again different from that of the open analysis (Fig. 81) and is more similar to the analysis in test C. Following the interpretation of the analysis before, the distribution of the features suggests that features G and I are worked using more force than feature H, which seems to be more distant to the others.

Here, two clusters are also indicated (Fig. 82). The identified clusters contain feature H alone and features G and I (Fig. 83), but the separation of the clusters is poor, quite unlike test C (Fig. 84).

Figure 81. Correspondence analysis of technical variables in test D.



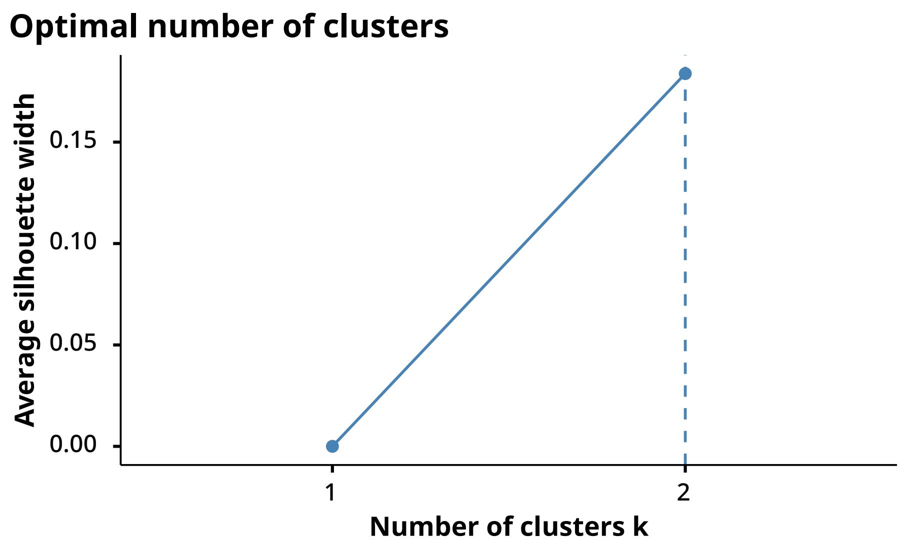


Figure 82. Silhouette plot of the optimal number of clusters for technical variables of test D.

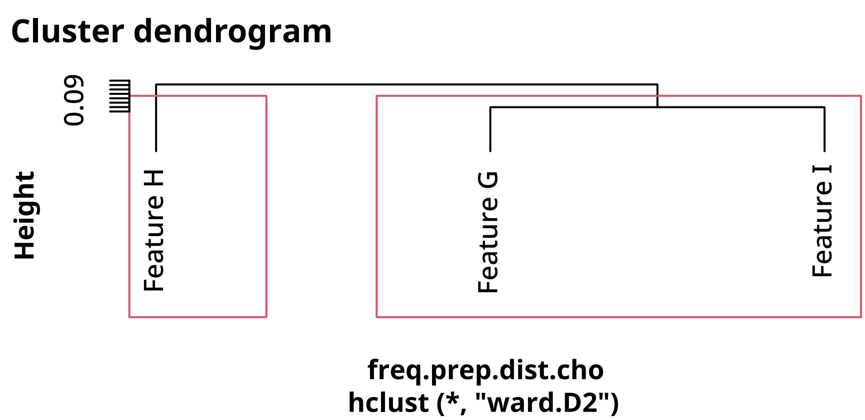


Figure 83. Cluster dendrogram of groups in the technical variables of test D.

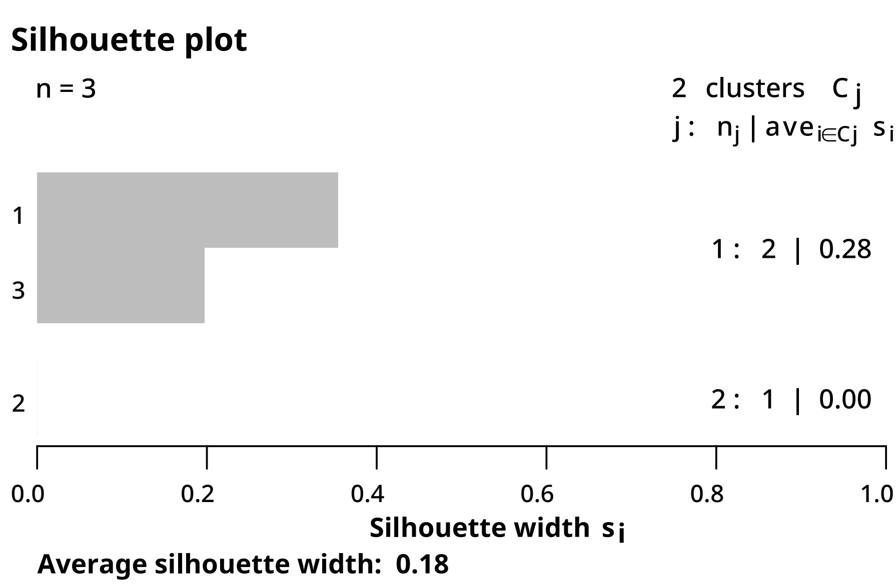


Figure 84. Silhouette plot of group separation from the technical variables of test D.

```
##
## Pearson’s Chi-squared test with simulated p-value (based on 2000
## replicates)
##
## data: PrepD_all
## X-squared = 210, df = NA, p-value = 0.0005

##
## Principal inertias (eigenvalues):
##
## dim        value      %   cum%  scree plot
## 1          0.030341  78.4  78.4 *******************
## 2          0.008367  21.6 100.0 *****
##            -------- -----
## Total:     0.038708 100.0
##
##
## Rows:
##     name  mass  qlt inr    k=1 cor ctr   k=2 cor ctr
## 1 | FtrG | 280 1000 532 | -268 977 662 | -42  23  58 |
## 2 | FtrH | 374 1000 315 |  160 787 316 | -83 213 310 |
## 3 | FtrI | 346 1000 154 |   44 111  22 | 124 889 633 |
##
## Columns:
##      name  mass  qlt inr    k=1 cor ctr    k=2 cor ctr
## 1   | E_np | 190 1000  37 |   50 333  16 |   71 667 113 |
## 2   | E_br |  74 1000   4 |   40 790   4 |   21 210   4 |
## 3   | E_fn |  43 1000  90 |    9   1   0 | -284 999 415 |
## 4   | E_fa |  15 1000  96 | -486 929 113 | -135  71  32 |
## 5   | E_st |   9 1000  66 | -517 988  83 |  -56  12   4 |
## 6   | E_sa |   2 1000  16 | -595 937  19 | -154  63   5 |
## 7   | P_pl | 120 1000 251 | -284 998 319 |  -13   2   2 |
## 8   | P_fc | 214 1000 141 |  159 998 179 |    7   2   1 |
## 9   | F_rd |  12 1000  22 |   29  12   0 | -269 988 101 |
## 10 | F_vl | 107 1000 157 | -212 792 158 |  108 208 151 |
## 11 | F_rn |   1 1000  12 | -689 934  14 | -184  66   4 |
## 12 | F_th | 128 1000  49 |   73 363  23 |  -97 637 145 |
## 13 | F_rf |  85 1000  61 |  159 914  71 |   49  86  24 |
```

For the preparation variables, the explained variability is quite good and, once more, the features’ correlation with the dimensions show two, G and H, that are better represented in the first dimension and feature I in the second dimension. Only two variables are really represented in the second dimension: fine edge preparation and ridge-like platform remnants.

The biplot is still very similar to the open analysis, but reversed (Fig. 85). Feature G seems to need less input to the platform preparation than I and H, while I seems to invest less work into the edge preparation than G and H. This time, G appears to be more dissimilar to the other features.

Two groups are identified and, like in test C, the clusters differ from those identified in the analysis of the technical variables (Fig. 86 and Fig. 87). The sep-

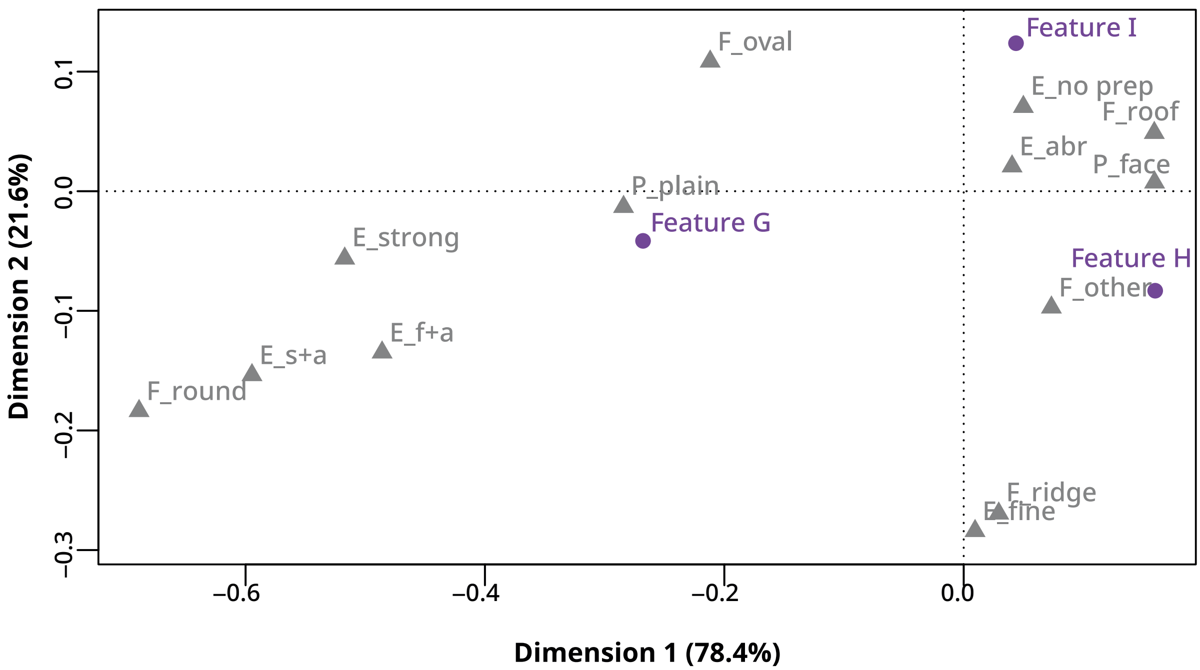


Figure 85. Correspondence analysis of the preparation variables of test D.

aration of the clusters is not very good, but it is the best result encountered so far during the analysis of preparation types (Fig. 88).

The results were again somewhat surprising. Starting with the technical variables, it appeared again that force is the driving variability along the axis, but the features forming a group here do not fully support that hypothesis. Feature G contains knapping products from P. Wiking's 2006 sickle and A. Benke's sickle, while feature I includes both dagger inventories.

While the more forceful approach is probably true for G. Nunn's dagger, it is not for A. Benke's, which is probably why the assemblage aligns as less forceful than feature G. Neither raw material nor material quality seem to be the only factors this time. Probably, technical choice plays out more strongly here, as the features including A. Benke's assemblages are positioned more in line with attributes associated with soft techniques. It is also surprising that the features including A. Benke are clustered this time, excluding the feature containing P. Wiking and G. Nunn, who are both represented in either of the other features, too. This could indicate that although A. Benke had the highest variability in the open analysis, the signature of the not changing technical choices this time is stronger than the similar approach but with more variable application.

The result of the analysis of preparation types is more in line with what was expected, and differs from the clustering of the technical variables. Here, the assemblages of the daggers and P. Wiking's and G. Nunn's combined assemblage from 2007 are more alike, showing that the investment into the preparation probably is higher in A. Benke's dagger inventory, than in the sickle inventory. This could have levelled out P. Wiking's investment into the preparation to some extent. Or, it is also likely that G. Nunn invests so much time and labour into the preparation during the dagger production that it overrides the effect of A. Benke's approach.

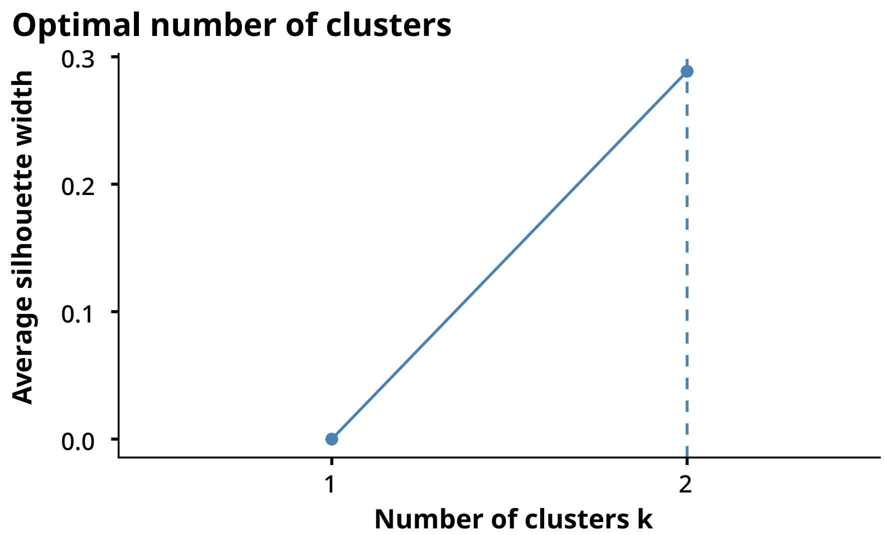


Figure 86. Silhouette plot of the optimal number of clusters for the preparation variables of test D.

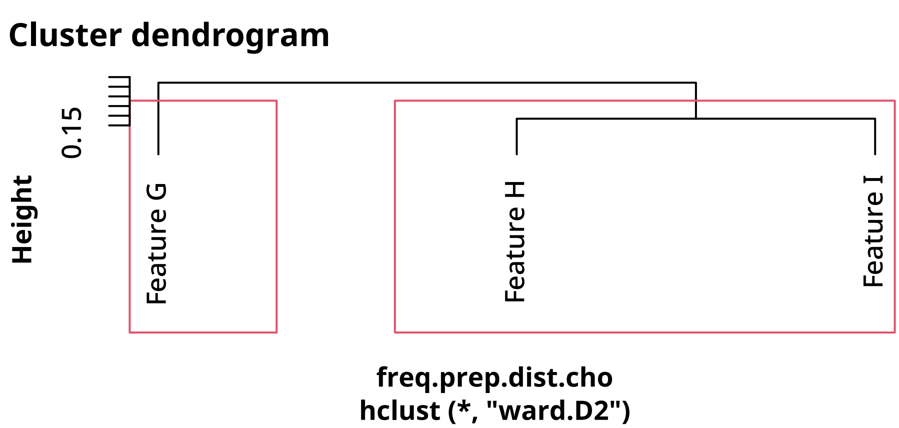


Figure 87. Cluster dendrogram of groups from the preparation variables of test D.

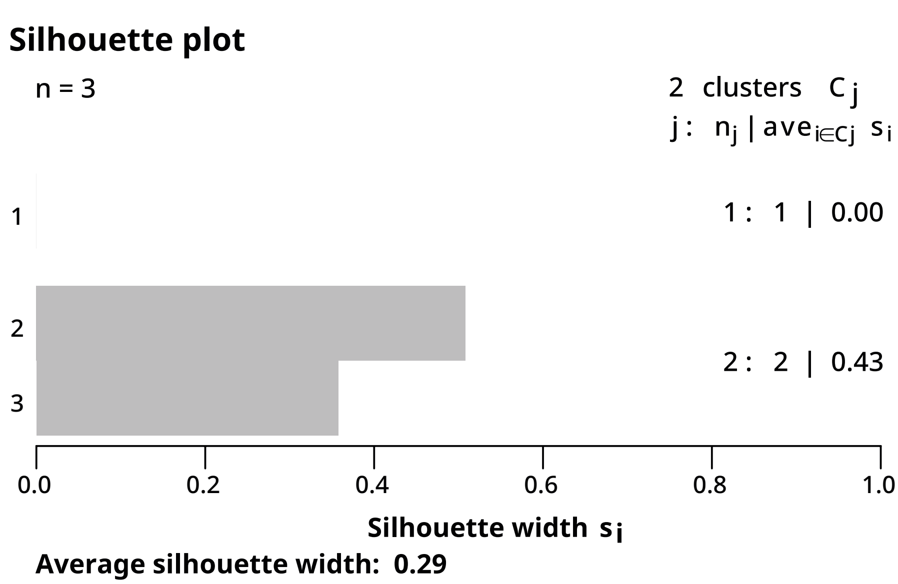


Figure 88. Silhouette plot of group separation for the preparation variables of test D.

5.7 Summing up the results

Starting with the descriptive statistics at the beginning of the chapter, the analysis of the recorded inventories provided some mixed results. The separation of flakes into production stages based on metrics or cortex coverage did not yield reliable results. Similarly, trying to detect stages based on the changing application of techniques by differences in the platform thickness was not successful. The overlap in flake sizes between the stages is too big, and also the techniques are not exclusive enough in between stages to determine the change in application. The results would probably have been more expressive, if the individual flakes had been collected either based on the tool they were removed with, or by goal of the removal. The latter version would be the more interesting one, as the differences not only between knapping tools but also between the application of tools during differing aims of reduction could be explored. But, collecting knapping products in this way would create major disturbances in the reduction process itself. Basically, every few strikes, the reduction would have to be stopped to collect the produced flakes, and to record the aim and the utilised tool. As the aim of this study was not primarily to detect the differences in tool application, but rather the differences between individual knappers' approaches to the reduction sequence, the least possible disturbance to their way of working was attempted. This also included the choice in the implementation of techniques, especially the implementation of copper tipped pressure flakers. It is still up to debate, whether copper was available as a flaking instrument in the Late Neolithic and whether it was part of sickle production. Again, no restrictions were given so the knappers could react and work how they deemed necessary and with what they were comfortable with.

The analysis of preparation differences during production was slightly more successful. The preparation of the edge and the platform as well as the platform shape are associated with the knappers, but with a very weak statistical significance. Cramér's V test for the strength of the relationship yielded values of: 0.12, 0.2 and 0.14 for the edge preparation, platform preparation and platform shape, respectively.

Following up on the individual treatment of the preparation attributes, multivariate statistics were applied. Based on the form of the data, correspondence analysis and hierarchical cluster analysis were used. The correspondence analysis suggested the effort of preparation to be the force of variation between the inventories. Along the axis of the first dimension, preparation of the platform progressed from highly to less prepared from left to right. In the second dimension, material consumption seems to be the ordering force. The inventory's distribution is in accordance with the observed patterns from the documentation; G. Nunn's inventories are positioned farthest to the left, showing more input to the preparation before removal, and A. Benke's inventories being more on the right or lower part of the biplot, showing less input to the preparation of the edge and platforms. P. Wiking's inventories range between these two. Positively surprising was the visible approximation of G. Nunn's and P. Wiking's inventories from 2007, which suggest that transfer of knowledge and changing ways of working between craftspeople is detectable. Due to the restricted number of inventories included in the analysis, the results have to be treated with caution. The change can also have other reasons unrelated to transmission or change on a personal level. Comparing several other inventories in addition could reveal how expressive the observed pattern is, which unfortunately was beyond the scope of this study.

Cluster analysis was undertaken to see if and how the inventories relate to another. The result did not mirror the groups seen in the biplot, only two clusters were detected. The first comprised of all inventories by G. Nunn and P. Wiking as well as A. Benke's dagger inventory, while the second included A. Benke's sickle and E. Callahan's dagger preform. The result still underlines the tendencies noticed in the documentation. G. Nunn's and P. Wiking's inventories from 2007 are more similar, but also quite like P. Wiking's 2006 and A. Benke's dagger inventories. This is not totally surprising, as P. Wiking was perceived as 'in between' G. Nunn and A. Benke from the start. A. Benke had a more careful approach during the production of the dagger and taught himself how to work IC types using the video of G. Nunn. The first cluster is made of inventories with a higher workload and to some extent more care to the production process than the second cluster presents. This is also not surprising, as the preform reduction stages need less preparation to be successful and A. Benke has a seemingly more intuitive approach to the material and more often uses chances offered by the material than investing time into a careful preparation. The separation of the groups is not overwhelming, but quite good and statistically reliable.

The next step in the analysis was to compare the patterns of the technical attributes between the knapper's inventories. Differences between the knappers were highly expected, as varying application of tools was perceived early on in the recording process. While A. Benke works almost exclusively with the antler billet, G. Nunn and P. Wiking vary between organic and stone percussion during production. The differences were slightly perceivable during the analysis of the single variables.

The comparison of the exterior edge angle yielded some very weak results. The range of angles in A. Benke's inventories seems a bit more restricted than for the other two knappers. Analysis by flake size classes yielded again no difference, which could be attributed to changing techniques in early or late reduction stages. But in A. Benke's dagger inventory, the final pressure technique did show an offset from the angles of the other stages. It showed that the pressure retouch is a rather clearly to distinguish production step. An analysis of variance was made to see if possible groups could be distinguished based on the angles. The significance was there, but no clear groups could be seen. One point obscuring the picture could be that the ideal angles for removal between the techniques are rather similar. Another factor possibly concealing differences is the influence of other, not registered variables. The exterior edge angle is not an attribute, which can be controlled completely during the reduction, and how the knapping implement hits the platform is influenced by a lot of conscious and unconscious choices and movements during the strike. Likewise, the measuring process is not always easy and can lead to incorrect measurements. Although no statements about changing techniques during the stages could be made, it is possible to detect differences in tool application during the reduction. A restricted toolkit, like A. Benke's focus on antler billets, is hinted in a narrower distribution of possible exterior angles.

Thickness of platform remnants was the next attribute tested for differences. The hypothesis was that a differing application of techniques should be detectable, as stone percussion is more prone to leave thicker remnants by connecting farther behind the edges organic percussion would. While no differences for stages could be detected, the analysis of variance showed significant differences and summed up to meaningful groups to some extent. A. Benke's inventories formed a group, as well as G. Nunn's dagger inventory. His sickle inventories made up a group with P. Wiking's sickle from 2007, while the sickle from 2006 made up a last group. This result did not only underline the perceived differences between A. Benke and the other two knappers, but showed again, how P. Wiking's work became seemingly more similar to G. Nunn in 2007. Having G. Nunn's dagger inventory as a single group suggests further that raw material also has an influence on the thickness, which is not altogether surprising.

Differences in technical applications could also be detected by the occurrence of ring cracks, which are associated with hard hammer percussion and copper pressure. The results here suggest that ring cracks are more likely in earlier stages of production and more likely associated with indirect technique. In the context of bifacial production, ring cracks seem not to be reliable markers for the application of copper tipped pressure flakers. For parallel flaking and final pressure retouch, no ring cracks were recorded, which is quite likely due to the rather low force needed for the removal of the associated flakes. The analysis of variance detected significant differences between the inventories and occurrence of ring cracks, but the groups made no sense from a technical point of view. Quite likely, the raw material quality is the grouping force here. Another test was to see if the ring crack diameters in correlation to the impact behind the edge could tell something about the technique it originated from. Bigger ring cracks seem to be associated with stone percussion and positioned farther behind the edge, while ring cracks with visible copper traces are more often positioned rather close to the edge and have smaller diameters. The majority of copper traces was identified in A. Benke's dagger inventory, which suggests that traces and ring cracks are more likely to occur if copper punches are used during indirect percussion, as only a minor part of the reduction was done with a stone hammer.

How hard a distinction for applied techniques based on even several attributes can be, was visible in the attempt to combine attribute markedness to distinguish between organic, soft and hard stone percussion. The first problem was the very small number of flakes remaining in the analysis while sorting for flakes with common occurrence of the attribute characteristics. In the end, the test was run only on attributes of bulb and lip formation and yielded unexpected results. The impact of organic percussion in the inventories seemed rather low, while hard hammer percussion was overwhelmingly present. A problem could be the coding, not relying on metric classes to decide how marked an attribute was. Another factor that conceals the organic percussion is probably the implementation of the soft stone, which can resemble organic percussion quite a lot, so some of the flakes attributed to soft stone percussion in the analysis were quite likely knapped with antler hammers. No further attempts at analysing combined attributes in this fashion were made. Instead, correspondence analysis and hierarchical clustering were applied to the technical variables.

Bulb characteristics, scarring and presence of ripples, radial fissures and lip formation were assembled to a table of counts for the inventories. Rows with not available as well as not preserved data were excluded. Furthermore, from the blub scarring, split fractures and the combination of *esquillement du bulbe* with split fractures were excluded due to their low presence. The same was done for indifferent ripples on the bulb. Lateral lip formation was removed from the analysis, as it acted as an outlier in the visualisation and hindered the interpretation. Like for the preparation variables, the first two dimensions explained the most variation. The representation by the dimensions was good, but a bit lower than in the preparation analysis. No groups were distinguishable from the biplot. The first dimension seems to explain technical variation, displaying attributes for organic and soft stone percussion to the left and hard stone percussion to the right. The second dimension is a bit unclear; intensity of the radial fissures progresses from the bottom of the plot to slightly above the first dimension's axis, while bulb scarring is distributed from slightly below the first dimension's axis to the top of the plot, but without obvious arrangement. The inventories align by technique along the first axis as expected. A. Benke's inventories are positioned farther left, while G. Nunn's are found farthest to the right.

The cluster analysis identified three clusters, which also follows the expected results. A. Benke's inventories formed a cluster with P. Wiking's sickle from 2006, while G. Nunn's inventories and P. Wiking's sickle from 2007 made up a second cluster. The third cluster was E. Callahan's dagger preform. Based on the application of techniques, the clusters made sense and the result again underlined the approximation of P. Wiking's and G. Nunn's production strategy. The clusters could also indicate regional – or here more likely national – manufacturing traditions, distinguishing a European way of bifacial reduction and an American one. More inventories, including more knappers from either continent, would have to be analysed to see if this pattern holds true. Unlike the analysis of preparation attributes, the clusters based on the technical attributes are rather vaguely separated and have to be treated carefully. This shows that the technical work, and by this the characteristics of attributes, is influenced more strongly by different factors than personal choices and preferences.

The results were not as strong or significant as hoped for, but still perceivable and encouragingly useful. The next step would have been to look for similar patterns in archaeological inventories, without knowing who or how many knappers are represented. As this was not possible, an alternative way to at least test the applicability to archaeological contexts was attempted. For this, more or less random samples, based on the availability of flakes, were drawn from the existing data base and anonymised. The sample size varies between the generated data sets, as the inventories varied in the number of flakes available for the sampling. This was due to the fact that the samples were drawn based on flake size classes in order to generate sample sets more likely met in archaeological contexts. This implied that only completely preserved flakes were included in the sampling, which restricted the availability of flakes quite massively for some size classes. As no flake was meant to be included twice in the analysis, this further restricted the possible combinations and tests. In the end, four different scenarios were tested with nine distinct samples. As the correspondence analysis and the hierarchical clustering yielded the best results, only these were used in the test analyses.

In test A, the constructed features included only single knappers. The inventories of the three knappers were sampled together, not split according to artefacts. The analysis of the technical attributes yielded similar results to the open analysis. The first dimension shows the distinction between hard and soft techniques and the features range between softer and harder application, although no groups seem to form. The cluster analysis identified two groups, feature A alone and features B and C clustered together. The separation of the clusters is, however, very vague.

The analysis of the preparation attributes was also rather similar to the open analysis, without showing clear groupings. Again, features A and B + C were identified as clusters, slightly better separated than for the technical variables. Dissolving the anonymisation, the results are in line with the open analysis. Feature A was a sample of A. Benke's work, feature B of G. Nunn and feature C included

P. Wiking's inventories. In undisturbed contexts, it should be possible to identify similarities and dissimilarities between knappers, but with the statistically weak results, it will probably not be possible to identify individual knappers. More likely, the distinction can be made between very similar operation modes and contrasting different contexts.

Test B dealt with one feature by a single knapper and two features of two mixed knappers not including the single feature knapper. The result of the technical attributes was slightly different from the analyses so far. The progression between techniques was not so clear as before, although still perceivable. Feature D seemed to have a bigger distance to the other two features. The cluster analysis underlined the difference, identifying D as a single cluster and G and J as a second cluster. The separation was again rather low. The analysis of preparation attributes was similar to the open analyses and the same clusters as with the technical variables were generated, with a slightly better separation of the clusters.

Feature D is a sample of G. Nunn's dagger inventory, feature G of P. Wiking's sickle from 2006 and A. Benke's sickle, while feature J includes P. Wiking's sickle from 2007 and A. Benke's dagger inventory. The result was not totally anticipated. For the preparation attributes, it could also have been possible that D and J would form a cluster, grouping together the inventories with the most input for preparation. The personal touch is still present, but it is also perceivable that raw material has some influence on the results.

This becomes even more notable in test C. Again, a single knapper feature is tested against two mixed features, but this time the single feature knapper is present in all features. For the technical attributes, the correspondence analysis does not fit the analyses thus far. This time it seems to be force during reduction which explains the variability. D is perceivably different from features E and H, which are also identified by the cluster analysis. The separation is unexpectedly good.

The changing picture of the dimensions is not repeated in the analysis of the preparation. The clusters are also formed differently than in the technical analysis, leaving E as a single cluster and grouping D and H together. From the interpretation of the distribution of the variables on the biplot, it seems that feature E invests less work into preparation than D and H. The separation of the clusters is again, as expected, rather low.

Feature D is the same as in test B, feature E includes G. Nunn's sickle from 2006 and A. Benke's sickle, and feature H includes G. Nunn's and P. Wiking's sickles from 2007. As all samples include G. Nunn's work, no clear distinction was expected in the results. The technical analysis makes sense, when looking at the raw material, which is distinguishably different for G. Nunn's dagger and also explains the differentiation in force during reduction. Texas flint is tougher than Scandinavian flint and more force is needed to remove similar flakes. This will influence the technical decisions to some extent, but the raw material constraints seem to have a bigger influence on the results here than the technical decisions. The latter has less influence on the preparation, which yielded expected results. G. Nunn invests more time and labour, which is evened out a bit when the other two knappers contribute to the mix.

In the last test, D, all features were mixed, but not every knapper was present in every feature. The analysis of the technical variables was again different from the open analysis and more in line with the results from test C. Application of force seems to be the driving force of variation in the first dimension. Features G and I form a cluster and seem to have been worked with more force than feature H, but the separation is rather low.

The analysis of the preparation variables does not differ from the former analyses. More work in general seems to be invested in the preparation in Feature G, while for feature I, more work appears to be invested in the preparation of the edge. The cluster analysis groups together feature G and features I + H. The change in clusters between the variables is again different from the open analysis but resembles the results in test C. The separation of the clusters is better than for the technical variables but not very good.

Feature G is comprised of flakes from P. Wiking's 2006 sickle and A. Benke's sickle, feature I of G. Nunn's and A. Benke's dagger inventories and feature H is made up of P. Wiking's and G. Nunn's sickles from 2007. The distribution of the features along the axes in the biplot for the technical variables is not immediately identifiable. Neither application of force, nor raw material constraints seem to be the guiding factors. Probably, the choice of technique is the underlying force again, as the features including A. Benke's inventories are positioned more on the side with variables for soft percussion than the other features.

For the preparation variables, the results are in accordance with the analysis so far. In mixed inventories, G. Nunn's and P. Wiking's investment into the preparation also sets them apart from A. Benke's inventories, but his more careful approach on the dagger can also be seen.

The statistical analysis was not as significant as hoped for, but it still yielded promising results. Tendencies of differences between the knappers could be detected, which underlined the perceived differences during the recording and in some cases surprising patterns could be detected. The sole exception to the low significance is the analysis of technical variables in the mixed test C, which seems to explain more about raw material qualities than techniques. A general trend seems to be that the preparation variables provide more significant and reliable results and explain more about personal preferences and differences in production than the technical variables. These seem to be influenced by a high amount of other and more complex processes, such as raw material properties. The results so far have also shown that a lot of the recorded attributes are not very expressive and could have been excluded, which was also part of the study. Similarly, some attributes would have yielded better results, if recorded in a different manner or knappers with more marked differences in skill were included. If recording continued with the same goals, a focus would be directed towards preparation and technical variables, excluding the other attributes in favour of a less time-consuming method. As the size classes likewise did not really help the interpretation, it would not be necessary to continue including them. They made the recording and assessing of the inventories more convenient, but four to five classes would suffice.

Another important consideration is the structure of the experiments. Collecting the knapping products individually by aim of the removal and the utilised tool could improve the identification of the tendencies observed in the study so far and help to identify differences between production stages. The disruption in the production process would probably have a major influence on the procedure of the knapper(s), for example, the unconscious choice to work as long as possible with the same tool on the same goal to prevent disruptions or reconsiderations of the progress, due to more time to decide on removals, which would to some extent cover the personal approach looked for here (cf. Carr and Bradbury 2010, 81). The more reasonable approach would certainly be to conduct experiments with individual collections of flakes as a separate study. The results can help to assign production stages to collections of knapping products, which can aid the identification of the technical choices during production.

A further possibility would be the use of extensive refittings. It would allow the subsequent division by stage of flakes without disrupting the production and, in case of archaeological assemblages, would be the only way of assessing the aim of a flake. Refittings are very time-consuming as already mentioned (see Subchapter 5.2), but they offer a lot of detailed information, once completed. Decisions to rely on refittings would have to be assessed for each project individually, but more implementation of the practice (and subsequent availability of the data) would benefit more than one research project.

The applicability of the study to archaeological assemblages is not fully resolved. The mixed tests indicate that differences should be detectable, if not on personal level then at least on the level of a technological tradition; assuming that people learning from one another work more similar to each other. The answer to the initial questions for this project is by this: yes! It is possible to detect individual preferences in knapping products, which at least can help to identify schools of learning and/or technical traditions in the archaeological record, provided they were in existence. The analysis of this study offers a hypothesis for the interpretation of patterns, which will be detectable in archaeological contexts. The approach is based on more than personal intimate technological knowledge. It thus helps to explain the differences which lead to the interpretation of different craftspeople or changing technological traditions without it being absolutely necessary for the researcher to accumulate practical knowledge of the craft.

Chapter 6: Summary and perspective of the results

The identification of individual knappers in prehistoric contexts is no new agenda to archaeology (*e.g.* Pigeot 1990; Callahan 2006; Clausen and Schaaf 2015). It is, however, not often very clear for non-flint experts, how the differences should be interpreted to conclude a specific number of present craftspeople. Regrettably, differentiation is often subjective and not comprehensible for those who are not familiar with flint knapping themselves (*e.g.* Andraschko and Schmidt 1991, 74-75; Paardekooper 2008, 1346; Bradley *et al.* 2009; Petersson and Narmo 2011; Currie 2022). A point, which makes the problem even more severe: often the experts themselves cannot fully explain, why they know there is a difference (Johansson 1983, 81-82; Petty 2019), which has been stated quite remarkably by F. Bordes:

> "[...] *most of the time I can tell whether a stone has been worked by Crabtree, Tixier, or myself. Our styles are different, but do not ask me to say what the differences are! I feel them more than I see them. I suspect that flint-knapping will have to become a necessary part of the training of any archaeologist interested in prehistory." (Behm et al. 1978, 359)*

The aim of this study was to get a more secure basis for an interpretation of individual craftspeople in flint knapping assemblages, without having to become an expert in knapping oneself. The most promising way perceived was the combination of the *chaîne opératoire* approach with technical attribute analysis so that individual knapper's technical fingerprints during reduction could be detected and described. Such an approach does not demand for the researcher to be an expert in flint knapping, although a thorough understanding of the flaking process is necessary. As fracture mechanics is a constant property, guided by physical laws, it is justifiable to resort to modern knappers work in lieu of prehistoric craftspeople. This has the advantage that there is no doubt about who did what in what way, which makes the identification of individual differences within the same technological system and applied method so much easier.

Using technical fingerprints to distinguish craftspeople from another has a further advantage to approaches using skill levels. Various craftspeople can have the same level of skill and mimic each other in their works, which would make it hard to distinguish how many people were involved. Using technical subtleties during the production process, in contrast, would dispel the likeness between objects made on the same level of skill, provided that there are subtle differences in the production which can be traced. This is what this project set out to explore. The major questions guiding the analysis were: is it possible to trace individual differences in technical knapping attributes? And which attributes and attribute combinations do we have to look for in the archaeological record?

The first step in answering the questions was to look at the production process in detail. Three knappers from different backgrounds and with different learning trajectories were compared with each other. The bifacial method, and especially the manufacturing process for the Scandinavian flint daggers, had to be re-invented by modern knappers through experimentation and today, most knappers who want to learn to manufacture bifaces follow the proposed process, which technically creates a technological tradition of knapping bifaces in our modern times. For the three knappers involved in this study, this can be seen in the connections that all three have, despite different backgrounds. G. Nunn has learnt a lot about parallel edge-to-edge pressure flaking and dagger production from E. Callahan, and while A. Benke and P. Wiking are mostly self-taught in bifacial method, A. Benke used G. Nunn's film about dagger production to learn how to make type IC daggers. Likewise, P. Wiking spend time in the U.S. with G. Nunn, also met E. Callahan, and had the opportunity to observe and learn more about the bifacial method. In a way, all three are connected 'traditionally' in their work, and still work perceivably different from one another.

For all their general similarity, their production sequences – or recipes of action during work – show technical differences and preferences which have a high possibility of being detectable in attribute analysis and could be translated to means to distinguish between individuals. In Chapter 4, these differences were presented in detail, but the gist of the chapter was that there are indeed personal preferences in the choice of techniques during reduction, for example, G. Nunn having a high variety of knapping implements in varying weights and forms to choose between, A. Benke being more comfortable with antler as a knapping implement and not shy to use copper and its advantages in the reduction process, while P. Wiking rather uses indirect technique and refrains from using copper implements. Some of the technical choices during reduction are made on the basis of the raw material, but still differ between knappers, which makes the choices not dependent on material qualities, but influenced to a greater extent by the individual's need of control and experience. For example, when encountering tough inclusions, there are a variety of choices available, for example, switching to a hammerstone instead of the antler billet, or using a heavier stone. Exchanging direct percussion for pressure or indirect technique and a change to copper instead of organic materials are further possible ways to cope with the problem. Likewise, the problematic zone could be left all together and be pursued from a different angle at a later time. The final decision is up to the knapper and what they feel most comfortable with at the moment. Like each knapper has a preferred scheme of action to follow, they also have preferred and proved schemes for trouble shooting during reduction, which makes them distinguishable from each other.

The summary of the production sequences suggested a high likelihood of differentiation by chosen techniques during the reduction, more pronounced between some than others. During the recording of the knapping products, another distinguishing factor was encountered, which likewise holds a high possibility to separate craftspeople's work from each other: the preparation of platforms and the exterior edge. Flint knapping is highly reliant on preparation and maintenance of the knapping edge, not less so in the bifacial method. How the preparation is conducted, however, is again a personal choice, mostly not depending on the raw material which is worked on. To some extent, the chosen reduction technique influences which kind of preparation is most appropriate, like abrasion being the most likely choice when working with antler billets, so that the sharpness of the stones edge is lessened and the billet surface is not damaged. A point which is very much a personal choice or sign of individual preference beside the chosen form is the intensity of the preparation. It is guided by material necessities, as both too little and too extensive preparation can end in failed removals, but there is a range in between, which can be chosen according to what the knapper feels is necessary and comfortable with. Likewise, the extent of the preparation is very much guided by personal decisions. During the documentation and evaluation of knapping sessions, all three knappers constantly worked on the maintenance of the edge and the preparation for the strikes, but the picture obtained from the knapping products differed greatly between the knappers, more than expected. This implied that the individual knappers could be distinguished from each other during the recording, based on the general trend in the preparation of the edge and the platform remnant. Furthermore, changes in their approach could likewise be detected. This raised expectations that markers and combinations of preparation attributes in the statistical analysis could be identified so that a firmer base for interpretation could be established. Being able to distinguish between knappers and determining reasons for the differences from a technical perspective was a first positive step, but it still requires that one is intimately familiar with the material and that a lot of knapping products are looked at in order to get a feel for the knapper's mannerisms.

A problem, which was feared to be encountered in the statistical analysis, is related to the simplifications needed to reach interpretable results. A too detailed recording of attributes would only have resulted in having differences everywhere, while no groups could form. Therefore, the recording had to be more generalised in order for technical aspects to be formed into groups together. A lot of the differences seen on the flakes were, however, gradations of differences in the same attribute between the knappers, which is very strong support for the dual approach here. The descriptions and observations can be used in the end to guide the statistical analysis and help to get a better interpretation of the results.

A general trend in the statistical analysis was the low significance of results, although the association between variables and knappers was given. The analysis of single attributes did show tendencies between the knappers, but the best results were obtained with correspondence and cluster analysis while looking at attributes for technical choices and preparation. The distinguishing factor in the analysis of preparation attributes was the investment of work. At least in the biplot of the correspondence analysis, the progression between knappers from higher to lower investment fitted the observations from the documentation and the knapping products. This seems to be a very stable factor for the preparation attributes, as the results were very similar in the simulation of archaeological inventories, where the data sets were mixed. Moreover, very perceivable was also the approximation of G. Nunn's and P. Wiking's approaches in 2007.

The technical attributes were mostly harder to interpret and not so consistent. In the correspondence analysis, the factor of variation seemed to be the general implementation of techniques, ranging from hard direct to organic percussion. The cluster analysis results produced groups, which made more sense, and showed again the approximation of P. Wiking and G. Nunn. The results in the simulation indicated clearly that the technical attributes are influenced by more factors than the personal approach. At least in two cases, the factor of variation seems to be the force applied during the removals, which indicates that raw material and quality of the raw material have a strong influence on the markedness of technical attributes. This is not entirely surprising, as the raw material quality has an influence on which technique can or should be used during reduction. In tougher or more problematic material, the choice would more often include hard techniques and tools as well as more forceful dealt strikes.

Even though extensive documentation on the working processes was available, it was not possible to re-assign flakes to a production stage. The overlaps in measurements were too big and trials to split stages based on technical traits were also not successful. The identified differences in applied techniques during production steps were not as expressive as hoped for. This is possibly due to the fact that the bifacial method, for all its theoretical structuring into production steps, is still a continuous process. Clearly marking a transition from one step to the next is often not possible, even when the knapper follows a very structured mental approach. Furthermore, the differences in technique have often only accounted for a few removals, which become obliterate in the vast majority of similar removals. The imprint of the main technique used during the reduction is far more perceivable and some results indicate that it is possible to differentiate between inventories with a high variety of techniques and tools involved and inventories done with a more restricted tool kit. Adjustments to the recording system could help to refine the identification of tendencies in the choice of technique. Likewise, further experiments concentrating on the identification of distinguishing markers between techniques of differing production aims could help to develop means to re-assign flakes to stages of the production process.

Another point from the documentation, which could not be detected in the statistical analysis, was the general approach to the raw material and mental templates. Based on the documentation and observations on the knapping products, classifications of knapper types were proposed. But the statistical analysis did not show indications for a possible distinguishability of how structured or accurate work was conducted. To answer questions on this topic, we cannot rely on statistical attribute analysis alone. Descriptions of the inventories are necessary to reach the full potential of distinguishing traits. Further potential to discover differences in gestures and handling of an artefact during the manufacturing process lies in these descriptions. P. Wiking's inventories had a slightly careless feel to them at times, which probably relates to him working much faster and in a pragmatic manner as well as his handling of the nodules differently during the reduction. The free handling of nodules is by no way a worse or false approach, but it seems to compel additional strikes before flakes detach more often. This seems to be perceivable in more frequent occurrences of ring cracks not related to the strike actually detaching the flake. Such indications of recurring blows without success were the main reason for the impression of carelessness in his inventories.

Despite some drawbacks, the statistical analysis proved that it is possible to detect differences between knappers. The results are not overly significant in a strictly statistical sense, but both differing technical choices as well as personal preferences can be deducted from the results. Far better, the differences are still perceivable when dealing with mixed inventories. The results for technical attributes, which highlighted raw material differences, would probably not be so marked and are not as likely to be encountered, when dealing with archaeological inventories of the same region. It was notable here, as one of the inventories was made from a significantly tougher material than the others. It has to be kept in mind that variation in technical attributes could also be due to raw material differences, which override the personal notes in technical choices. But in archaeological settings where the raw material is homogeneous, it will have little influence on the results.

In combination with the descriptions, the results are very positive. Although it was not possible to re-assign flakes to production stages and thus to be able to get a more detailed picture of changing techniques throughout production, the general fingerprint left by the implemented techniques was strong enough to distinguish the varying production schemes. In archaeological inventories, it should at least be possible to distinguish differing traditions from one another. Better results could probably be obtained by further experiments, where the focus is placed on the differentiation of flakes to production goals. If it is possible to detect general outlines in measurements and probable platform remnant forms corresponding to the aim of removal, it will be possible to reassign flakes to production steps and thus reach a higher resolution to detect changing choices of technique during reduction.

Another point, which could be proven in the analysis, was the detectability of knowledge transmission. Based on the backgrounds of the knappers and the documentation, different types of transmission and also biases could be specified. Depending on how exclusive a generation is defined, the transmission between G. Nunn and the other two knappers can be either horizontal (between peers) or oblique (from older to younger generation) transmission. The situations encountered here can all be classified more or less as teaching, although not all with verbal assistance. Both P. Wiking and G. Nunn described their 'learning' situation as being observational, with G. Nunn working on a biface and P. Wiking observing. But P. Wiking also participated in a knapping school, carried out by G. Nunn, where he was not the only 'pupil' and G. Nunn did more explaining. Likewise, A. Benke relied on the knapping video by G. Nunn, where a lot of explaining is provided beside the visual progression. In addition to the imitation of G. Nunn's approach, trial-and-error learning was also present, for example, indicated in P. Wiking's statement that he manufactured a dagger solely in indirect technique once, just to see if it is possible. Or A. Benke's statement that he used G. Nunn's video as a template, but changed some steps in the process to adapt it to his preferred way of work. Biases at work during the transmission are especially contextual, as all knappers were already rather set in their way of working and had developed preferences based on their own experience. Another factor limiting transmission was the language barrier. There is always loss of information in an exchange, as transmitters have to translate knowledge into words and receivers have to make the effort to understand what the information is. This can be hard on both sides while talking the same language. However, the loss is bound to be more severe, when the first language of the transmitter and the receiver differs and both have to find a common ground of communication. Observations can help a lot in overcoming communication difficulties. Likewise, when the topic is familiar to both, transmitter and receiver, it is easier to get the essentials of the message, even if language complicates precise understanding.

The results do also emphasise the difficulty in keeping knowledge exclusive, especially in populations, where knowledge of the basic principles is widespread. In flint technology, if the basics have been mastered and the person is sufficiently talented, it is indeed possible to learn new techniques and ways of production solely by observation or, as E. Callahan demonstrated, by close examination of the finished products. This stresses the need to analyse the complete production process if we want to answer questions about the structure and development not only of the technological system, but also of the transmission of knowledge.

While no changes were perceived in the documentation and observation of the production sequences, the attributes on the flakes did show differences between the 2006 and the 2007 inventory made by P. Wiking, which was detectable in the statistical analysis. At some point, he modified his approach and assumed an approach more similar to G. Nunn's operating sequence. The most likely explanation for this change was the known contact and teaching situation. Even the more trial-and-error approach by A. Benke left traces identifiable in the analysis. His dagger inventory was also more similar to G. Nunn's work, but kept its personal fingerprint. More surprising was that G. Nunn's work also showed some changes, which were seen during the recording and were expressive enough to appear in the statistical analysis. By his own account, he did not think he took much information from working together with P. Wiking, but some things must have stuck, even if only subconsciously.

The results should be treated with care, as a rather limited set of inventories was included. Some differences in the sequence can be accounted to P. Wiking being less familiar with the bifacial method in 2006 and by this less secure with the production sequence. Likewise, all knappers were unfamiliar with Bronze Age bifacial sickles included in the first inventory, so some differences could be accounted to not only trying to cope with a new form but also unfamiliar flint and thus different properties during the reduction process. More inventories would reveal if the obtained patterns are stable or if further factors influence the differences. Similarly, it would have been interesting to include inventories from the 2022 session by P. Wiking to see if further changes in his approach had taken place and maybe rendered his inventories more dissimilar to G. Nunn's work, while the personal fingerprint became stronger again. In general, it would be interesting to include more inventories and also more knappers from different backgrounds, but also those with known close connections, to see if 'traditional' lineages could be established. Perhaps, a geographical differentiation of manufacturing traditions could also be traced. This was beyond the scope of this study, but further analysis of modern flint knappers would support interpretation in prehistoric contexts and highlight structures and components important to the identification of transmission and development of knowledge and technologies.

The results from the analysis provide an opportunity to pursue questions about technical traditions of manufacture within the same technological system, even while dealing with the same production method. This can be used to obtain a better understanding about the development of technological systems and help to identify innovations in the production process and the introduction of new techniques as well as losses of knowledge and techniques. It can also help us to gain a better understanding of the structure of production in a society. As mentioned in Chapter 2, dagger production in Late Neolithic and Early Bronze Age Scandinavia has been proposed to have been organised in secluded workshops to guard the knowledge. Contradictory opinions were also voiced, but a final solution to the question is still pending. With more recent excavations of settlements (*e.g.* Bech 2004; Sarauw 2006; Bech *et al.* 2018), the opportunity to pursue questions concerning manufacturing structures is increasing. Beside uncovering where and to what extent production took place, the identification of technical fingerprints can help to define the structure further and also show if and how the production changed through time.

Following the more probable hypothesis that production and knowledge were not severely restricted during the Late Neolithic could lead to three likely scenarios in the technical structure of production. The first case would be a highly homogeneous knapping tradition throughout the region. Second, there could be regional differences in technical application. In the third case, a high diversity, which can neither be attributed to regional traditions nor to a fixed and strict tradition inside of the society, would show a high flexibility in the production process. To see which case is most likely, we have to analyse the production more closely, as carried out in this investigation. Likewise, if we want to conclude how dagger manufacture was treated in society, we have to compare the results to the other aspects of flint technology and see if there are differences in the production of other tool types.

This study is a positive start for the identification of differing technical applications. The next step would be a refinement of the recording system and the application of the method to archaeological contexts.

Chapter 7: Summary in German / Deutsche Zusammenfassung

Die deutsche Zusammenfassung folgt der Kapitelaufteilung der englischsprachigen Arbeit. Im Folgenden werden die Kapitel kurz zusammengefasst und die wichtigsten Punkte zum Verständnis herausgearbeitet.

7.1 Einleitung

Die vorliegende Arbeit entstand im Rahmen eines Dissertationsprojekts, dessen ursprüngliche Planung vorsah, sich mit dem Wandel technologischen Wissens während des Spätneolithikums und der Bronzezeit Skandinaviens zu beschäftigen. Der Fokus sollte auf den bifaziellen Geräten liegen, wobei die Entwicklung der Methode zur Herstellung dieser Artefakte von den Anfängen über den Höhepunkt bis zum langsamen Verschwinden dieses Wissens abgebildet werden sollte. Mit Blick auf die vorgesehene Projektlaufzeit wurden früh Anpassungen hinsichtlich zeitlicher und geografischer Ausdehnung vorgenommen. Mit Ausbruch der Corona-Pandemie wurde das Projekt schließlich gänzlich umstrukturiert. Um trotz Reisebeschränkungen und Lockdowns weiterarbeiten zu können, wurde der Fokus auf die Identifizierung von technischen Fingerabdrücken in Flintabschlagsinventaren gelegt, die Hinweise auf individuelle Bearbeiter oder technologische Traditionen liefern können. Hierfür wurden Inventare experimenteller Replikationen bifazieller Geräte von unterschiedlichen Bearbeitern ausgewertet. Der Ansatz war dabei, detaillierte Beschreibungen der Herangehensweisen mit statistischen Analysen der technischen Merkmale zu verschränken und somit zu aussagekräftigeren Ergebnissen zu gelangen.

7.2 Forschungsgeschichte

7.2.1 Generelle Entwicklung der Forschung zur Flinttechnologie

Die Bearbeitung von Flint ist schon fast so lange ein Interessenschwerpunkt archäologischer Forschung, wie die Archäologie als Fach existiert. Die frühe Forschung war dabei vor allem daran interessiert, natürliche von menschengemachten Abschlägen zu trennen sowie die zum Abbau genutzten Geräte zu identifizieren. Mit der steigenden Verfügbarkeit von Computern und Softwareprogrammen waren zunehmend auch große Abschlagsinventare von Interesse für die Rekonstruktion technologischer Systeme.

Ein erster Versuch, eine methodische Grundlage für experimentelle Herangehensweisen auszuformulieren und diese auf archäologische Befunde anzuwenden, ist die *chaîne opératoire*, die von A. Leroi-Gourhan basierend auf M. Mauss in den 1940er Jahren ausgearbeitet wurde. Im angloamerikanischen Raum orientierte sich die Archäologie derweil methodisch näher an den Naturwissenschaften. Zur selben Zeit änderte sich die generelle Fragestellung an Flintinventare: Nicht mehr die Geräte selbst und deren Aufgaben standen im Fokus, sondern Fragen nach der exakten Herstellung der Artefakte rückten insbesondere in Frankreich ins Zentrum der Forschung. Damit wurde das Verständnis der Bruchmechanik eines der zentralen Themen der Forschung, das insbesondere in den Vereinigten Staaten auf streng wissenschaftliche Weise experimentell untersucht wurde und wird.

Kritik an der naturwissenschaftlichen Ausrichtung der Forschung wurde ab den 1980er Jahren laut, während die Forschung einen weiteren Paradigmenwechsel durchlief: Naturwissenschaftliche Herangehensweisen ließen keine Rückschlüsse auf tatsächliches Verhalten zu, und eine Re-Orientierung der Forschung zu mehr praxisnahen Versuchen sei notwendig. Selbst heute ist die Kluft zwischen den beiden Ansätzen noch nicht gänzlich überwunden und die Forschung häufig in zwei Lager aufgeteilt. Die vorliegende Studie versucht, die beiden Ansätze näher zusammen zu bringen. Denn die Aufnahme und technische Analyse der Inventare erfolgt basierend auf vermeintlich objektiven mathematischen und physikalischen Regeln, wird aber durch detaillierte Beschreibungen und Beobachtungen der unkontrollierten Experimente ergänzt. Dadurch bekommen die statistischen Analysen mehr Kontext, und gleichzeitig kann eine Bewertung der Aussagekraft und Nützlichkeit der Merkmale vorgenommen werden.

7.2.2 Forschung zu spätneolithischen bifaziellen Geräten

Das Hauptaugenmerk der Forschung zur Flinttechnologie bifazieller Geräte des Spätneolithikums und der frühen Bronzezeit in Skandinavien lag lange Zeit auf den bekannten Flintdolchen. Diese sind allerdings weder die ersten, noch die einzigen bifaziellen Geräte dieser Zeit. Aus mittelneolithischen Trichterbecherkontexten sind die ersten bifaziellen Spitzen bekannt, die häufig als Dolchstäbe interpretiert werden. Dolche, wenn auch nicht unbedingt in bifazieller Ausführung, treten in Europa schon wesentlich früher auf. Die bekanntesten Beispiele sind hierbei die zentralfranzösischen Grand-Pressigny-Dolche, die auch im südlichen Skandinavien unter Verwendung lokalen Rohmaterials kopiert werden.

Aus technologischer Sicht lässt sich dafür argumentieren, dass die Entwicklung der skandinavischen bifaziellen Dolche mindestens seit dem Mittelneolithikum kontinuierlich vonstattenging. Das nötige Wissen sowie die erforderlichen Techniken waren zu diesem Zeitpunkt vorhanden bzw. entwickelt, zudem lassen sich technische Eigenheiten der Dolche auf frühere lokale Bearbeitungstraditionen zurückführen. So haben Studien gezeigt, dass sich zum Beispiel die Ziernaht der späteren bronzezeitlichen Dolchtypen auf die Herstellung vierseitiger Äxte zurückführen lässt.

Die Anforderungen an Können und Wissen zur Herstellung von Flintdolchen werden aus moderner Perspektive häufig überschätzt. So wurde unter anderem postuliert, dass die Produktion der Dolche in abgelegenen Zentren stattgefunden sowie Spezialisten und Vollzeithandwerker benötigt habe. Werden alle Funde zusammen betrachtet, fällt jedoch auf, dass die Anzahl an technisch hochkomplexen und außergewöhnlich gut gearbeiteten Objekten eher gering ist. Der Hauptteil der Funde zeigt, dass ein breites Spektrum an Können und Wissen vorhanden war. Zumindest für das Spätneolithikum ist es wahrscheinlicher, dass ein Großteil der Bevölkerung über das nötige Wissen und Können verfügte, einen Dolch zum Alltagsgebrauch herzustellen. Ein offensichtlicher Rückgang im Wissensschatz und die Konzentration des Wissens auf weniger Personen lässt sich dafür in der Bronzezeit fassen, was sich unter anderem an den bifaziellen Sicheln ablesen lässt. Während die Herstellung oft auf einem technisch hohen Niveau liegt, weisen Nachbearbeitung und Reparatur häufig Defizite auf.

Die wahrnehmbare Trennung in kunstfertig gearbeitete Prestigedolche und weniger komplexe Alltagsgeräte wurde auch als Zeichen für den Einsatz einiger weniger Handwerker gewertet, die die Grenzen des verfügbaren Wissens ihrer Zeit bewusst überschritten und erweiterten. Eine weitere offene Frage der Forschung betrifft die Nutzung der Dolche. Vermutlich wird es sich im überwiegenden Teil der Fälle um Allzweckgeräte gehandelt haben. Forschung zu den bifaziellen Sicheln ist dagegen eher rar gesät und hat sich meist auf die Anwendungsbereiche der Geräte beschränkt, wobei die Verwendung als Erntegerät heute nicht mehr in Frage gestellt wird.

Studien zur Technologie haben sich in den häufigsten Fällen auf die Endprodukte und den Vergleich der Niveaus des Könnens während der Produktion konzentriert. Dieser Fokus schränkt die Aussagekraft der Resultate auf die letzten wenigen Arbeitsschritte ein, die auf den Objekten noch sichtbar sind. Für die Dolche wurde ein Lehrlingssystem vorgeschlagen, in dem Bearbeitende verschiedener Lernstufen gemeinsam an den Stücken arbeiten und jeweils die Arbeitsschritte übernehmen, die ihrem Lernstand entsprechen. Da die letzte, flächige Bearbeitung aber ein höheres Maß an Können verlangt, lassen sich durch die Analyse der fertigen Produkte keine belastbaren Beweise für die Existenz eines solchen Systems finden. Wenn stattdessen der gesamte Produktionsprozess analysiert wird und der Fokus auf den Abschlagsprodukten liegt, ließen sich Unterschiede in Können und Herangehensweise während der Produktion leichter herausarbeiten. Diese könnten dann die Hypothese entweder unterstützen oder widerlegen.

Ferner ließen sich durch Unterschiede im Herstellungsprozess auch regionale Unterschiede in der Bearbeitung feststellen, die auf lokale Bearbeitungstraditionen hindeuten können. Um Fragen dieser Art zu beantworten, schien die *chaîne opératoire* in Kombination mit technischer Attributanalyse die geeignetste Herangehensweise zu sein.

7.3 Theorie, Methode und Terminologie

7.3.1 Theoretischer Hintergrund

7.3.1.1 Technik und Technologie

Technologie wird häufig synonym für das Verwenden von Geräten und technischen Hilfsmitteln verwendet. Dabei bezeichnet der Begriff im Kern ein viel weiteres, viel weniger definiertes Feld. Technologien sind besser als strukturierende Rahmen zu verstehen, die Handlungen bestimmen. In diesem Sinne betreffen sie auch nicht ausschließlich technische Prozeduren, sondern umfassen jede Handlung des Alltagslebens. Implizit in der Definition enthalten ist auch das Verständnis, dass nicht nur *eine* Technologie das Verhalten einer gegebenen Gesellschaft bestimmt, sondern eine Vielzahl von Technologien zu jeder Zeit am Werk sind. Sie werden durch die Bedürfnisse und Traditionen sozialer Strukturen beeinflusst und beeinflussen diese gleichzeitig auch selbst. Technologien sind strukturierte Systeme, bestehend aus Artefakten, Verhalten und Wissen, das über Generationen weitergegeben und tradiert wird.

Techniken sind Bestandteile von Technologien und somit auch durch Traditionen geprägt. Verschiedene Techniken sind zu bedeutungsvollen Handlungssystemen zusammengefasst, die bestimmen, wie innerhalb eines gegebenen technologischen Systems vorgegangen wird. Obwohl unterschiedliche Techniken denselben Zweck erfüllen können, ist die Wahl der Technik nicht völlig frei. Die Struktur der Handlungsweise, auch Operationssequenz oder *chaîne opératoire* genannt, bestimmt die korrekte Auswahl möglicher Techniken für den Hergang. Dabei umfassen Techniken nicht nur die Auswahl konkreter Geräte und Materialien, sondern auch Gesten und Positionen, sowohl des Körpers als auch der Geräte.

Die *chaîne opératoire* wurde definiert als Übergang von Rohmaterialien aus einem natürlichen in einen Fertigungszustand durch eine Reihe von Handlungsabläufen. Im Prinzip umfasst sie aber jegliche Veränderung eines Materials, des menschlichen Körpers eingeschlossen. Basierend auf M. Mauss' Arbeiten entwickelte A. Leroi-Gourhan dieses Konzept zur Anwendung in der Archäologie weiter. P. Lemonnier fügte eine weitere Dimension hinzu, indem er unterschiedliche Typen von Ereignissen innerhalb von Handlungen definierte. In jeder Handlungsabfolge gibt es Ereignisse, die variabel und flexibel sind, technische Varianten, deren Änderung keinen nennenswerten Einfluss auf das Resultat hat. Des Weiteren existieren stabile und fixe Ereignisse, strategische Operationen oder Momente, die nicht verändert oder ausgelassen werden können, ohne das Resultat zu ändern oder zu gefährden. Durch die *chaîne opératoire* können die Ereignisse voneinander getrennt und gesellschaftliche Eigenheiten der technischen Varianten herauskristallisiert werden. Indem gesellschaftliche Entscheidungsprozesse in technologischen Handlungen herausgearbeitet werden, bietet sich die Möglichkeit, Aussagen zur sozialen Organisation und zu Umwelteinflüssen zu treffen.

In der französischen Forschung wird viel Wert auf die Unterscheidung von Techniken anhand von Merkmalen auf den Abschlagsprodukten gelegt. Dies passiert hauptsächlich durch experimentelle Arbeit. Dabei darf nicht vergessen werden, dass technische Attribute keine eindeutigen Aussagen zulassen. Die Überlappungsbereiche zwischen den Merkmalen sind sehr groß und können immer nur eine Tendenz aufzeigen.

Wissen ist ein wichtiger Bestandteil von Technologien. Ohne das Wissen, welche Handlungen durchzuführen sind, woher Roh- und Arbeitsmaterial zu beziehen sind, aber auch, wie Probleme behoben werden und das Produkt angewandt wird, würde eine Technologie und auch ein Herstellungsprozess wenig Sinn ergeben. Das Wissen, welches die richtige Wahl und Herangehensweise ist, ist dabei abhängig vom sozialen Umfeld. Konzepte, wie Wissen arrangiert ist und weitergegeben wird, gibt es etliche; ein paar wenige werden hier zusammengefasst.

Bei Schiffer und Skibo (1987) wird technologisches Wissen in drei Kategorien unterteilt: Aktionspläne (*recipes of action*), Lehrrahmen (*teaching frameworks*) und Technikwissenschaft (*techno-science*), wobei letzteres in der Regel nur innerhalb der Naturwissenschaften aufgedeckt wird. Wie die *chaîne opératoire* umfassen Aktionspläne das Wissen über gesellschaftliche Regeln eines Produktionsprozesses, während Lehrrahmen die Weitergabe des Wissens strukturieren. Pelegrin (1990; 2000) unterteilt in Wissen (*connaissance*) und Know-how (*savoir-faire*), wobei ersteres das bewusste und vermittelbare Wissen ist, während Know-how aus unterbewussten, auf Erfahrung basierenden Erinnerungen besteht, die kaum vermittelbar sind, sondern erlangt werden müssen. Die bifazielle Methode ist ein eindrucksvolles Beispiel für diese Unterteilung, da die Produktionssequenz an sich recht einfach erklärt und beschrieben werden kann. Die tatsächliche Umsetzung und Durchführung der Arbeiten ist aber nur mit ausreichend Übung möglich, da einige der Produktionsschritte intuitives Wissen benötigen, das nicht erklärt oder kontrolliert werden kann.

Wissen wird fast ausschließlich über Techniken des sozialen Lernens vermittelt, will heißen: was wir wissen, wird uns von anderen Menschen beigebracht. Dadurch entsteht ein System sozialer Tradition, das über die Generationen hinaus Wissen erhalten kann. Die Weitergabe ist dabei kein stabiler Prozess, da es immer noch eine Entscheidung der Akteure ist, ob und welches Wissen sie übernehmen und anwenden. Das Tradieren von Wissen, aber auch die Veränderung und der Verlust von Wissen, lassen sich durch die Analyse der *chaîne opératoire* nachverfolgen und vergleichen.

Um regionale und chronologische Unterschiede in Herstellungsprozessen zu analysieren, muss die generelle Herstellungssequenz erst einmal bekannt sein, und die fixen Ereignisse müssen von den variablen getrennt werden. Um dies in archäologischen Inventaren bifazieller Geräte tun zu können, wurden die Unterschiede in der Herangehensweise moderner Bearbeiter untersucht. Dabei wurde nicht ausschließlich auf die einfach zu identifizierenden Abschläge bestimmter Bearbeitungsphasen zurückgegriffen, weil diese in der Regel die strategischen Momente in der Sequenz darstellen, die nicht anders hätten bewerkstelligt werden können. Die zu erwartenden Unterschiede, die eine Rekonstruktion regionaler Herangehensweisen und einer sich wandelnden Technologie zulassen, werden aber in den technischen Varianten zu finden sein, weswegen das gesamte Abschlagsmaterial der Herstellung für die Analyse betrachtet wurde.

7.3.1.2 Wissensvermittlung

Die Weitergabe von Wissen wird häufig mit der biologischen Vererbung verglichen. Der Vergleich ist allerdings nicht vollkommen zutreffend. Zum einen kann Wissen wesentlich schneller verändert werden als Gene es können. Auch ist Wissen nicht im selben Maße determiniert. Ob ein Aspekt des Wissens übernommen wird oder nicht, ist auch eine bewusste Entscheidung, die in der Auswahl der Gene nicht getroffen werden kann. Auch deswegen gilt nicht in jedem Fall eine Selektion für die erfolgreichsten Aspekte. In den seltensten Fällen sind Bevölkerungsgruppen vom Aussterben bedroht, weil ihnen ein bestimmtes Wissen fehlt. Dieser Umstand macht es möglich, dass Traditionen bestehen bleiben, die einen klaren negativen Charakter haben und das Potential einer Gesellschaft einschränken.

Die Arten der Weitergabe werden dennoch mit den biologischen Termini bezeichnet: Überlieferung (*transmission*) von Informationen zwischen Personen, Veränderung (*mutation*) von Informationen, Selektion aus dem zur Verfügung stehenden Wissenspool und Abweichung (*drift*), die durch keine der anderen Arten beeinflusst wurde.

In Zusammenhang mit sozialem Lernen wird häufig die Überlieferung als Weitergabemechanismus behandelt. Unterschieden wird hier zwischen vertikaler (Eltern zu Kindern), horizontaler (zwischen Generationsgenossen) und schräger Weitergabe (von Älteren zu Jüngeren ohne Einbeziehung biologischer Verwandter). Ebenso wie die Art der Weitergabe Einfluss auf das Vermittelte hat, hat auch die Lernumgebung Einfluss. Wird das Wissen von vielen an einzelne Personen weitergegeben, schafft dies stabileres Wissen, als wenn Einzelne Wissen an Viele weitergeben. Letztere Form kann die Verbreitung von Wissen aber um ein Vielfaches beschleunigen. Mechanismen der Wissensvermittlung sind neben Unterrichten (*teaching*) auch Verstärkung durch Anreize (*stimulus enhancement*), Nachahmung (*emulation*) und Imitation, wobei nur das Unterrichten die aktive Teilnahme des Lehrenden fordert, allerdings nicht notwendigerweise verbal. In den meisten Lernsituationen wird nicht nur ein Mechanismus zum Tragen kommen und nicht jede Vermittlung basiert auf sozialem Lernen. Individuelles Lernen, auch Versuch-und-Irrtum (*trial-and-error*) genannt, kann ebenfalls Teil des Vermittlungsprozesses sein.

Soziales Lernen bindet kulturelle Entwicklung zu einer beschreibbaren Kette zusammen. Keine Idee kommt aus dem Nichts, Innovationen und Entwicklungen basieren immer auf schon existierendem Wissen und müssen mit diesem kompatibel sein, um übernommen zu werden. Durch die Beschreibung und Analyse der *chaîne opératoire* technologischer Prozesse können diese Ketten verfolgt und verstanden werden.

7.3.2 Methodischer Hintergrund

7.3.2.1 Experimente in der Archäologie

Da alle bearbeiteten Inventare dieser Studie experimentelle Replikationen von spätneolithischen und frühbronzezeitlichen bifaziellen Geräten darstellen, soll eine kurze Einordnung und Bewertung von Experimenten im Kontext archäologischer Forschung folgen.

Obwohl Experimente seit Anbeginn der Archäologie als Wissenschaft Teil des Forschungskanons sind, ist die Definition und Anwendung immer noch heftig umstritten. Der kleinste gemeinsame Nenner ist das Vorhaben, eine im Voraus geplante Handlung zu beobachten, um eine Hypothese oder Frage zu testen. Die Kontroverse betrifft dabei den Aufbau und zum Teil die Durchführung der Handlung. Auf der einen Seite stehen dabei Verfechtende strikt wissenschaftlicher, kontrollierter Laborexperimente, bei denen alle Variablen bis auf eine konstant gehalten werden. Durch das Verändern der einen, nicht konstanten Variable werden dann Rückschlüsse auf die Zusammenhänge der anderen gezogen. Dem gegenüber stehen die unkontrollierten Experimente, häufig auch Feld-, Erlebnis- oder kontextuelle Experimente genannt, in denen es oft eher darum geht, herauszufinden, ob eine spezifische Handlung oder ein Aufbau funktioniert. Da diese meist außerhalb von Laboren stattfinden, ist die Möglichkeit, Variablen zu kontrollieren, geringer, was die exakte Wiederholung der Versuche meist unmöglich macht und den Experimenten dadurch einen schlechten Ruf beschert. Im Gegenzug stehen kontrollierte Experimente in der Kritik, sich fernab der Realität zu bewegen und damit nicht geeignet zu sein, Alltagssituationen zu erklären.

Der Kerngedanke hinter Experimenten stammt aus den Naturwissenschaften und nimmt an, dass sich Gesetzmäßigkeiten in Phänomenen aufdecken lassen, die auf ähnliche Situationen angewendet werden können. Im Falle der Archäologie steckte in den 1960er und 1970er Jahren vor allem die Hoffnung dahinter, Gesetzmäßigkeiten menschlichen Verhaltens zu entdecken und dadurch Kulturentwicklung unabhängig von chronologischer Gliederung untersuchen zu können. Die Grundannahme in experimentellen Studien zur Flinttechnologie ist, dass die Bruchmechanik unabhängig von zeitlichem und menschlichem Einfluss reagiert. Die Regeln der Bruchmechanik lassen sich somit entschlüsseln und damit das Verhalten während der Bearbeitung in der Vergangenheit rekonstruieren.

Ein Problem, das häufig ignoriert wird, ist, dass Hypothesen nie wirklich bewiesen werden können und eine tatsächliche und eindeutige Wahrheit auch in den Naturwissenschaften nicht existiert. Eine Hypothese steht immer nur so lange als wahr da, bis sie widerlegt werden kann. Dementsprechend ist ein Resultat, das durch Experimente erlangt wird, auch nie als einzig mögliche Wahrheit zu betrachten. Es ist eine mögliche Lösung, die Analogien für die Interpretation archäologischer Kontexte liefern kann. Vor allem bieten Experimente aber die Möglichkeit, unwahrscheinliche und falsche Hypothesen auszusortieren und neue Interpretationen und Fragen aufzuwerfen. Dabei können Experimente nicht für sich selbst stehen. Sie lassen sich besser als hermeneutischer Zirkel denken, der seinen Anfang und sein ‚Ende' im archäologischen Kontext hat. Jede Frage oder Hypothese, die getestet werden soll, muss aus diesem Kontext stammen und auch wieder in Zusammenhang damit bewertet werden, um als sinnhafte Methode in die Forschung eingebunden werden zu können.

Um Kritik und Fehlern entgegenzuwirken und die Experimente selbst belastbarer und vergleichbarer zu gestalten, wurden von unterschiedlichen Autoren Regeln für die Einbindung von Experimenten in die Forschung aufgestellt, die hier kurz zusammengefasst sind:

1. eine klare und relevante Forschungsfrage
2. detaillierte Beschreibungen von Materialien und Methoden
3. Verwendung von authentischen und relevanten Materialien und Geräten
4. Einbinden von Personen mit den nötigen Fähigkeiten zur Durchführung des Experiments, sofern nicht durch Forschende abgedeckt
5. professionelle Planung und Durchführung
6. Testen verschiedener möglicher Szenarien
7. (Rück-)Vergleich zum archäologischen Kontext
8. Publikation der Resultate

Vor allem die letzten beiden Punkte werden in der Forschung leider häufig vergessen, was die Relevanz und Nützlichkeit vieler Experimente stark einschränkt. Dieser Kritik muss sich auch die vorliegende Studie stellen. Aufgrund der zeitlichen Vorgabe und der Einschränkungen durch die Corona-Pandemie war ein Vergleich zu archäologischen Kontexten nicht möglich. Die Resultate sind deshalb eher als eine Pilotstudie zu verstehen, deren Bewertung im Feld noch aussteht.

Weil sich diese Studie mit der persönlichen, individuellen Herangehensweise während der Flintbearbeitung befasst, wäre die Durchführung kontrollierter Experimente nicht der geeignete Weg gewesen, da bei diesen ja gerade die Individualität aus der Analyse entfernt werden soll. Die Kontrolle während der Experimente wurde daher minimal gehalten, sodass die Bearbeiter völlig freie Entscheidungsmöglichkeiten hatten, abgesehen von Rohmaterial, Artefakttyp und kleineren Einschränkungen im Gerätespektrum.

Die Experimente wurden als nötig empfunden, da die beste Annäherung an prähistorisches Flinthandwerk, die wir erreichen können, Beobachtungen an seinem modernen Gegenpart sind. Wie schon festgestellt wurde, sind Technologien und Traditionen sehr fest miteinander verwoben, weshalb die gezogenen Analogien ein großes ‚Aber' enthalten. Diese Studie beschäftigt sich mit persönlichen Vorlieben und Herangehensweisen, die ebenso durch Tradition geprägt sind. Somit ist die Ausgangslage für prähistorische und moderne Bearbeitende nicht gleich. Der soziale Hintergrund unterscheidet sich stark, vor allem beeinflusst ist die ‚Tradition der Flintbearbeitung'. Personen in der Prähistorie wuchsen von klein auf in ihren (mehr oder weniger festen) Traditionen auf und erlernten das Bearbeiten von Flint. Interessierte Personen heute sind meist um einiges älter, ehe sie mit der Flintbearbeitung in Kontakt kommen, und erlernen das Handwerk häufig selbst. Darüber hinaus sind sie nicht an chronologisch separierte Traditionen gebunden, sondern beherrschen meist eine Vielzahl von Bearbeitungstechniken und Methoden, quer durch die Zeit. Dies bedeutet, dass das Repertoire möglicher Handlungswege für moderne Bearbeitende um einiges breiter ist, als es für ihre prähistorischen Vorbilder zutrifft. Da es hier aber nicht um die eine korrekte Rekonstruktion der Produktionsweise geht, sondern darum, die persönlichen Entscheidungen individueller Handwerker innerhalb ihres Methodenspektrums zu identifizieren, ist der Vergleich immer noch hilfreich dabei, Merkmale und Merkmalskombinationen zu entdecken, die auch in der Prähistorie unterschiedliche Herangehensweisen erkennbar werden lassen.

Ein weiterer Grund für die Einbindung von Experimenten war, dass archäologische Inventare selten fein säuberlich getrennt sind, weder chronologisch noch nach Bearbeitenden. Eine Identifizierung individueller Herangehensweisen ist somit schwer bis unmöglich.

7.3.2.2 Das Aufnahmesystem

Zunächst sollen einige weitere, spezifische Begrifflichkeiten und Zusammenhänge erklärt werden. Einige der Merkmale sind in Abb. 2 und 3 dargestellt. Um eine Lesbarkeit auch für die deutschsprachige Zusammenfassung zu gewährleisten, wird im Folgenden der verwendete englische Terminus in Klammern hinter die deutsche Bezeichnung gesetzt. In der Studie wird der französischen Terminologie gefolgt.

Neben Technologie und Technik ist ein weiteres Konzept für Flintbearbeitungsstudien von Bedeutung, die Methode (Abb. 1). Als Methode werden Sequenzen miteinander in Verbindung stehender Handlungen bezeichnet, die zur Herstellung eines vorgegebenen Produkts führen. Flintbearbeitungstechnologien können mehrere Methoden umfassen, die unterschiedlichste Techniken beinhalten. In der französischen Forschung wird die Definition recht restriktiv genutzt, sodass nur wenige Methoden existieren, darunter die bifazielle Formgebung (*shaping*) von Flint. Formgebung bezeichnet eine Sequenz von Handlungen mit dem Ziel, ein einzelnes Objekt in eine gewünschte Form zu bringen. Die bifazielle Methode wird hier als Teil der Flintbearbeitungstechnologie im spätneolithischen und frühbronzezeitlichen Skandinavien behandelt.

Die erste Unterscheidung von Bearbeitungstechniken wird zwischen direktem und indirektem Schlag gezogen. Der direkte Schlag trifft dabei direkt auf die Fläche des Flints, während bei einem indirekten Schlag ein Zwischenstück zwischen Oberfläche und Schlägel vorhanden ist. Der direkte Schlag wird darüber hinaus in harten und weichen Schlag getrennt, wobei der direkte harte Schlag mit einem Stein die älteste bekannte Technik der Flintbearbeitung ist. In den letzten Jahrzehnten wurde eine weitere direkte Technik aufgedeckt. Neben dem Schlag mit dem harten Stein und dem mit organischem Material, wie Geweih, Holz oder Knochen, lässt sich anhand der Schlagmerkmale auch die Bearbeitung mit weichen Steinen, wie Sandstein, unterscheiden.

Die Unterscheidung zwischen hartem und weichem Schlag ist dabei vor allem durch die unterschiedliche Art des Bruches gegeben. Während der direkte, harte Schlag zum charakteristischen muscheligen Bruch führt, löst das Schlagen mit weichen, organischen Materialien einen Biegebruch aus. Beide unterscheiden sich durch eine Reihe von Merkmalen und deren Ausprägungen. Während ersteres zu ausgeprägten Bulben (*bulb of percussion*), Schlagaugen (*ring crack*), auch in Kombination mit Konusbrüchen (*conical break*), Schlagnarben (*éraillure scar*), großen Schlagflächenresten (*platform remnant*), ausgeprägten Wallnerlinien (*ripples*) und Radialstrahlen (*radial fissures*) führen kann, zeichnet letztere Technik sich eher durch die Bildung von Schlaglippen (*lip*), schwachen Bulben und kleineren Schlagflächenresten aus.

Im Unterschied zu den beiden Techniken besitzt der Schlag mit dem weichen Stein zwei Ausprägungen. Zum einen kann der weiche Stein eingesetzt werden wie ein harter Stein und ist in dem Fall kaum anhand der Merkmale von diesem zu unterscheiden. In seiner zweiten Anwendung weisen die Abschläge Charakteristika des weichen Schlags mit organischen Materialien auf, können aber auch unterscheidende Eigentümlichkeiten aufweisen. Neben der Lippenbildung und diffusen Bulben treten auch zertrümmerte Schlagflächenreste auf. Schlagaugen können ebenfalls vorhanden sein, ebenso Konusbrüche, auch in Kombination mit Schlaglippen. Wallnerlinien auf den ersten Zentimetern des Bulbus, ebenso wie *esquillement du bulbe,* scheinen eine weitere Eigentümlichkeit dieser Technik zu sein.

Eine weitere Technik, die direkt angewendet, aber als eigenständige Technik behandelt wird, ist die Drucktechnik. Dabei wird die Spitze eines Bearbeitungsgeräts direkt auf die Kante des Werkstücks gesetzt und Druck ausgeübt, der das Abspringen eines Abschlags auslöst. Auch hier kann in eine harte und eine weiche Variante unterschieden werden, bei denen entweder mit Kupferspitzen oder organischen Materialien gearbeitet wird. Die resultierenden Merkmale sind in der Regel recht kleine Schlagflächenreste, die kaum die Größe der Spitze des Druckwerkzeugs überschreiten. Dabei gilt: je härter das Material der Spitze, desto kleiner die Kontaktfläche und der Schlagflächenrest. Der Bulbus ist häufig klein und prägnant und sitzt sehr hoch auf der ventralen Fläche. Außerdem können Schlagaugen bei der Verwendung von Kupferspitzen entstehen.

Die letzte unterschiedene Technik ist der indirekte Schlag. Ähnlich wie bei der Drucktechnik ist die Kontrolle während des Schlags höher als bei freien Schlägen. Das Zwischenstück wird als Punch bezeichnet und besteht meist aus Geweih oder Kupfer, kann aber auch aus anderen Materialien gefertigt sein. Merkmale der indirekten Technik sind diffuse, langgezogene Bulben und markante Lippen. Wallnerlinien fehlen meist, aber Schlagnarben können vorkommen. Je nach Material des Punches können auch Schlagaugen auftreten. Die Größe der Schlagflächenreste hängt auch hier von der Größe der Kontaktfläche zwischen Werkstück und Punch ab, ist in der Regel aber größer als bei der Drucktechnik. J. Pelegrin merkt zudem an, dass große und konkave Schlagflächenreste nur bei indirekter Technik entstehen können, da ihre Größe nicht durch Spitzen von Druckretuscheuren zu erreichen sei und die konkave Form keinen erfolgreichen Abbau in direkter Technik erlaube.

Darauf aufbauend wurde ein Aufnahmesystem entworfen (Tab. 3), das unterschiedliche Charakteristika von Abschlägen und technischen Merkmalen samt Ausprägung umfasst. Durch die Auswertung der gesammelten Daten können somit sowohl eine Bewertung der angewendeten Techniken vorgenommen als auch persönliche Vorlieben der Bearbeiter herausgearbeitet werden. Erschwert wird die Arbeit durch die Tatsache, dass die technischen Merkmale keineswegs ausschließliche Marker sind. Die Ausprägung kann in den meisten Fällen eher als eine Skala angesehen werden, denn die Überlappungsbereiche zwischen den Techniken sind sehr groß. Dazu kommt die nötige Simplifizierung der Ausprägungen, um eine statistische Analyse möglich zu machen, ohne sich in zu vielen Details und Unterschieden zu verlieren. Die Merkmale stellen somit eher Tendenzen als eindeutige Aussagen dar, können aber nichtsdestoweniger dabei helfen, individuelle Vorlieben in der Flintbearbeitung zu identifizieren.

Neben den bereits erläuterten technischen Merkmalen wurden auch verschiedene generelle Charakteristika von Abschlägen in die Aufnahme eingebunden. Das dafür verwendete System wurde ursprünglich entwickelt, um auch archäologische Inventare aufnehmen zu können, die keine unterteilbaren Bearbeitungseinheiten darstellen. Die Charakteristika der Abschläge sollten in diesem Fall dazu dienen, die Bearbeitung von bifaziellen Geräten besser von ‚einfacher' Flintbearbeitung zu unterscheiden und weitere Einblicke in das Können und die Erfahrung der Bearbeitenden zu ermöglichen. Insgesamt wurden 32 Merkmale mit unterschiedlichen Formen und Ausprägungen im Aufnahmesystem zusammengestellt. Nicht alle wurden schlussendlich in der Analyse verwendet, weil sich die Datengrundlage durch die Umstrukturierungen des Projekts im Zusammenhang mit der Corona-Pandemie verändert hatte und die Auswertung nun etwas andere Ziele verfolgte als ursprünglich geplant. Des Weiteren war die Aufnahme bewusst groß gehalten, um eine Bewertung der Aussagekraft bestimmter Merkmale vornehmen zu können.

Es wurden für diese Analyse nur Inventare moderner Handwerker aufgenommen, die die vollständige Produktionssequenz umfassten. Dabei wurden alle Abschläge mit einer Länge von mindestens 0,5 cm betrachtet.

7.3.2.3 Statistische Grundlagen der Analyse

Ähnlich wie die Nutzung von Experimenten hat auch die Mathematik, speziell die Statistik, eine lange Tradition in der archäologischen Forschung. Gerade während der 1960er und 1970er Jahre wuchs das Interesse an scheinbar objektiven

Methoden zur Identifikation von Regelmäßigkeiten im menschlichen Verhalten. Die teils aufwendigen Rechenoperationen hatten eine umfassende Einbindung in die Forschung vorher wenig praktikabel erscheinen lassen. Die steigende Anzahl von leistungsfähigen Computern und die Zugänglichkeit von geeigneten Softwareprogrammen eröffneten jedoch rasant neue Möglichkeiten. Die Reorientierung der Forschungsschwerpunkte, von Generalisierungen hin zu dynamischen und situationsbedingten Erklärungen für Verhaltensmuster, löste wenig später eine Trennung von quantitativen und qualitativen Methoden in Studien aus. Heute ist vor allem die angloamerikanische Forschung noch stark von quantitativen und statistischen Methoden geprägt, während die europäische Forschung häufiger auf qualitative und beschreibende Methoden setzt. Überschneidungen existieren, sind aber rar gesät.

Der Standpunkt dieser Studie ist, dass es nicht den einen, richtigen Weg gibt, Forschung zu betreiben. Die Auswahl der Methoden ist stark abhängig von der Fragestellung und der Datengrundlage. In vielen Fällen kann es hilfreich sein, beide Methoden zu verwenden, wie es hier getan wird. Die statistische Auswertung von Daten ist ein Hilfsmittel, das vor allem bei großen und komplexen Datensätzen hilft, Strukturen zu erkennen und Information zusammenzufassen. Gerade multivariate Methoden können hier einen einfachen und guten Überblick verschaffen und helfen, Fragen zielgerichteter zu verfolgen. Es darf aber nicht vergessen werden, dass Resultate statistischer Verfahren keineswegs eine Wahrheit darstellen. Die Resultate sind nicht nur von den Daten abhängig, sondern werden auch vom gewählten Verfahren sowie den gesetzten Annahmen und der Auswahl von Variablen, Algorithmen und Methoden beeinflusst und verändert. Am Ende ist es immer die Entscheidung des Forschenden, welches Resultat Sinn ergibt und damit als richtig verstanden wird. Hier kann es hilfreich sein, nicht-statistische Methoden heranzuziehen, um die Validität und Sinnhaftigkeit von Resultaten zu bewerten.

Aufgrund dessen wurde hier eine Herangehensweise gewählt, die statistische und nicht-statistische Verfahren kombiniert. Die detaillierten Beschreibungen der Arbeitsabläufe der Handwerker, basierend auf Beobachtungen und Gesprächen während der Experimente, dienen dazu, erste Unterschiede und erfolgversprechende Ansätze zu erarbeiten, die dann in der statistischen Analyse daraufhin untersucht werden, wie sinnvoll und aussagekräftig sie sind. Weiterhin können die statistischen Analysen auch Muster aufdecken, die aus den Beobachtungen nicht herauszuarbeiten waren, aber durch die genauen Beschreibungen in Kontext gesetzt werden können.

Neben simplen, beschreibenden statistischen Analysen einzelner Merkmale werden einige multivariate Verfahren zum Einsatz kommen. Abhängig von den verfügbaren Daten und ihrer Eignung für die jeweilige Analyseart werden Varianzanalyse (ANOVA), Hauptkomponentenanalyse (PCA), Korrespondenzanalyse (CA) und hierarchische Clusteranalyse eingesetzt.

7.4 Produktionssequenzen in Aktion

Um eine Vergleichsbasis für die individuellen Bearbeiter zu haben, wurde mithilfe der Forschungsliteratur eine ideale Produktionssequenz für die Herstellung von bifaziellen Geräten erstellt. Diese basiert hauptsächlich auf E. Callahans (2000; 2006; 2016) Arbeit und betrifft vor allem die etwas komplexeren Fischschwanzdolche Typ IV. Die generelle Vorgehensweise ist aber für alle bifaziellen Geräte gleich, typischerweise werden Sicheln etwas weniger komplex hergestellt als Dolche. Unterschiede in der Herstellung betreffen vor allem die letzten Produktionsschritte. So werden die hier betrachteten Typ IC Dolche nach der Flächenbearbeitung überschliffen und mit einer parallelen Druckretusche versehen, ehe die Kanten gerichtet und geschärft werden. Diese Arbeitsschritte fehlen bei Sicheln vollkommen und sind auch nicht bei jedem Dolchtyp zu finden. Nach der Flächenbearbeitung und finalen Formgebung erfolgt dort höchstens eine Schärfung der Kanten in Druckretusche.

7.4.1 Die Ideale Produktionssequenz

Typischerweise wird die Bearbeitung von bifaziellen Geräten in acht Phasen aufgeteilt, wobei mindestens zwei der Phasen nicht an jedem Gerät zum Einsatz kommen. Die erste Phase ist dabei die Beschaffung des nötigen Rohmaterials. Dazu wird in der Regel wenig Gerät benötigt, dafür jedoch Wissen um Rohmaterialquellen, -eigenschaften und -anforderungen für einen erfolgreichen Abschluss der Arbeit. In der zweiten Phase wird das Material meist durch direkten harten Schlag in eine grobe Form gebracht. Wichtig ist hierbei vor allem, die umlaufende Kante zu gestalten, von welcher aus die Bearbeitung der Flächen erfolgen kann. Die Form wird in der dritten Phase weiter ausgearbeitet, ebenso beginnt die Reduzierung der Dicke des Geräts. Während die Arbeit voranschreitet, wachsen die Ansprüche nicht nur an die motorischen Fähigkeiten und Erfahrungen des Bearbeitenden, sondern auch an das konkrete Wissen. Ebenso wird die Bandbreite der benötigten Arbeitsgeräte größer (siehe Tab. 4). In Phase vier wird die Form weiter ausgearbeitet, Ziel ist aber vor allem die Reduzierung der Dicke durch große, lange Abschläge über die Fläche des Arbeitsstücks. Die praktische Erfahrung wird hier erstmals wichtiger, da das Wissen, was zu tun ist, alleine nicht ausreicht, um das Ziel zu erreichen. Unerfahrene Bearbeitende verringern häufig vor allem die Breite des Stücks, wohingegen die Dicke sich kaum verändert. Die fünfte Phase beendet die Formgebung und hat hauptsächlich das Ziel, die letzten Unebenheiten auf den Flächen des Geräts zu entfernen und die Außenkante symmetrisch zuzuarbeiten.

Hier trennt sich die Produktionssequenz der verschiedenen Geräte und Typen. Während die Sicheln und auch die gängigsten Dolchtypen mit diesem Schritt fertiggestellt sind und gegebenenfalls nur noch eine finale Retusche der Kanten benötigen, führt die Arbeit an den komplexeren Typen noch weiter. Die folgenden Phasen sind dabei nicht mehr vorwiegend funktionaler Natur, sondern tragen zur Ästhetik des Werkstücks bei.

In der sechsten Phase findet keine schlagende Bearbeitung des Stücks statt. Die Flächen werden geschliffen, um eine glatte und negativfreie Oberfläche zu erhalten, die für die siebte Phase, die parallele Retusche, nötig ist. Während das Schleifen keine großen Anforderungen an Können oder Wissen des Bearbeitenden stellt, verlangt die parallele Retusche der Flächen einiges an Können und Erfahrung. Der letzte Schritt der Bearbeitung, die Phase acht, ist dann die abschließende Retusche der Kanten, um eventuelle Asymmetrien zu entfernen und scharfe, gerade Kanten zu erhalten.

Mit Fertigstellung des Geräts ist häufig weder die Bearbeitung noch der Lebenszyklus abgeschlossen, der für die vollständige *chaîne opératoire* wichtig wäre. Sowohl die Dolche als auch die Sicheln wurden vermutlich geschäftet und in den meisten Fällen auch genutzt, was dazu geführt hat, dass sie nachgeschärft oder anderen Zwecken zugeführt und umgearbeitet wurden, wenn sie für ihren ursprünglichen Zweck nicht mehr zu verwenden waren. Die *chaîne opératoire* endet erst mit der endgültigen Aufgabe des Objekts. Da hier aber experimentelle Inventare betrachtet werden, ist der finale Bearbeitungsschritt zur Fertigstellung die letzte Phase, die betrachtet werden kann, daher auch die Ansprache und Referenz auf die Produktionssequenz anstelle der *chaîne opératoire*.

7.4.2 Unterschiede in den individuellen Produktionssequenzen

Die detaillierte Beschreibung der Produktionssequenzen und der Vergleich mit den Beobachtungen an den Merkmalsausprägungen der Abschläge dient nicht nur dem Verständnis des Ablaufes und der Unterschiede in den Arbeitsweisen der Bearbeiter. Ein Problem der Merkmalsanalyse an Flint ist, dass der Einsatz unterschiedlicher Techniken trotzdem zu ähnlichen bis gleichen technischen Merkmalen führen kann, was eine korrekte Identifizierung der angewandten Technik erschwert. Umgekehrt ist es aber auch möglich, dass trotz Einsatz derselben Techniken völlig unterschiedliche Merkmale vorhanden sind. Diese Unterschiede lassen sich nur sicher erkennen und verstehen, wenn vorher bekannt ist, mit welchen Materialien und Techniken während der Herstellung gearbeitet wurde. Deswegen wurden die Inventare nicht einfach einzeln aufgenommen und analysiert, sondern auch die Dokumentation der Herstellung mit einbezogen.

In die Analyse fließen die Produktionsabschläge von fünf Sicheln und zwei Typ IC Dolchen von G. Nunn, A. Benke und P. Wiking ein (Tab. 5 und Abb. 5). Die Abläufe der Produktion in Lejre und Moesgaard wurden in Protokollen festgehalten und durch Fotografien unterstützt. Darüber hinaus existieren zwei Videosequenzen von 2007, die Ausschnitte der Arbeit zeigen. Weiter wurde ein Film in die Analyse eingebunden, der G. Nunn bei der Herstellung und Erläuterung der Arbeit an einem Typ IC Dolch zeigt. A. Benke hat an zwei weiteren Workshops in Schleswig teilgenommen, in deren Verlauf er eine Sichel und einen Typ IC Dolch hergestellt hat. Auch diese wurden sowohl in protokollarischer Form als auch fotografisch festgehalten. Ein weiterer Workshop wurde 2022 in Schleswig mit P. Wiking durchgeführt. Ziel der Dokumentation war hier vor allem, seine Arbeitsweise in Aktion betrachten zu können, da bis zu diesem Punkt nur Fotos und Beschreibungen von ihm zur Verfügung standen. Keines der Inventare von 2022 ist in die Analyse mit eingebunden worden.

Keiner der Bearbeiter hatte vor seiner ersten Teilnahme Erfahrungen mit der Herstellung von bifaziellen bronzezeitlichen Sicheln. Alle drei hatten aber einen großen Erfahrungsschatz in der Flintbearbeitung und im Fall von G. Nunn und A. Benke auch in der Herstellung von bifaziellen Geräten, insbesondere Dolchen. P. Wikings Expertise liegt vor allem in der Klingenproduktion und indirekter Technik. Allen Bearbeitern wurde neben einer Beschreibung der *chaîne opératoire* basierend auf archäologischen Beobachtungen auch ein Artefakt zum Vergleich zur Verfügung gestellt. Das Ziel in allen Versuchen war, eine möglichst realistische Replik auf allen Ebenen zu erstellen.

Aus der Dokumentation ließen sich früh Unterschiede auf verschiedenen Ebenen feststellen, die nicht alle tatsächlichen Einfluss auf die Merkmalsbildung an Abschlägen haben, aber zur persönlichen Signatur der Bearbeiter beitragen. So ließ sich für G. Nunn feststellen, dass er der idealen Sequenz am nächsten folgt (Tab. 6 und 7). Er beginnt die Bearbeitung mit direkter harter Technik und wechselt graduell zu weniger schweren Geräten, je weiter die Bearbeitung voranschreitet. Im Gegensatz zur idealen Sequenz setzt er den Kupferdruckstab schon recht früh in der Sequenz ein, während Druckstäbe mit anderen Materialien gar nicht genutzt werden. Die Kante des Arbeitsstücks wird häufig und großflächig präpariert, bevor ein Abschlag erfolgt.

Anders als G. Nunn setzt A. Benke kaum Steine als Schlagmedium ein. Seine Präferenz liegt ganz deutlich auf dem Geweihschlägel, den er zu fast allen Arbeiten nutzt (Tab. 8 und 9). Während G. Nunn und P. Wiking eher dazu tendieren, die Kanten mit dem Stein nachzubearbeiten, nutzt A. Benke auch hierfür den Geweihschlägel. Auch präpariert er häufiger eher kleine Abschnitte der Kante und baut Material ab, solange es möglich ist, ehe eine weitere Präparation vorgenommen wird. Er arbeitet auch eher problem- als zielorientiert, was dazu führen kann, dass Problemzonen zu große Priorität bekommen können und das eigentliche Ziel der Arbeit etwas aus dem Blick gerät. Wie G. Nunn setzt auch A. Benke den Druckstab mit Kupferspitze sehr früh ein. Wenn er sehr sorgfältig und vorsichtig arbeiten möchte, wechselt er zur indirekten Technik und arbeitet dann häufig mit einem kupfernen Punch.

Wie bereits erwähnt, hatte P. Wiking vor den ersten Versuchen in Lejre weniger Erfahrung mit der Herstellung von bifaziellen Geräten als die anderen beiden Bearbeiter. Zwischen 2006 und 2007 war er in den USA, hat unter anderem G. Nunn besucht und an einem seiner Bearbeitungskurse teilgenommen. Somit bietet sich hier die einmalige Möglichkeit, die technische Herangehensweise vor und nach ‚Lerneinheiten' zu vergleichen. Im Gegensatz zu A. Benke und G. Nunn sind P. Wikings Schlagsteine alle recht groß und schwer, ebenso nutzt er lieber schwere Geweihschlägel (Tab. 10 und 11). Leichte Geräte kommen hauptsächlich in den letzten Produktionsschritten zum Einsatz. Für die Verwendung von indirekter Technik finden sich in der Dokumentation der Versuche von 2006 und 2007 wenige Hinweise, 2022 war es aber eine von ihm sehr häufig genutzte Technik. Ebenso wurde für Lejre die Verwendung von Kupferdruckstäben festgehalten, während 2022 gar nicht damit gearbeitet wurde. Es kann sein, dass P. Wiking sich seinerzeit aufgrund der geringeren Erfahrung mit der bifaziellen Methode enger an die ideale Herangehensweise gehalten hat, als es mittlerweile der Fall ist. Im Gegensatz zu den anderen beiden Bearbeitern arbeitet er sehr schnell und nimmt auch eher Fehlschläge in Kauf.

Durch den Vergleich der individuellen Herangehens- und Arbeitsweise der Bearbeiter wurden vier Arten von Unterschieden in der Produktion herausgearbeitet. An erster Stelle stehen Arbeitsschritte, die identisch verlaufen und daher keine Unterschiede in der Technik oder Handhabung während der Arbeitsschritte aufweisen (Abb. 6 und 7). In der technischen Analyse sollten sich die Merkmale daher nicht unterscheiden, unabhängig davon, welcher Bearbeiter den betreffenden Arbeitsschritt ausgeführt hat.

In seltenen Fällen konnten Arbeitsschritte beobachtet werden, in denen eine völlig andere Technik genutzt wird (Abb. 8). Ein Unterschied ist, dass A. Benke häufig eher zum Druckstab greift, um problematische Zonen zu bearbeiten, als P. Wiking und G. Nunn, die eher mit dem Stein weiterarbeiten. Generell nutzt P. Wiking selten die Drucktechnik und arbeitet sehr ungern mit der Kupferspitze.

Auch indirekte Technik wird von allen drei Bearbeitern unterschiedlich und in verschiedenen Kontexten eingesetzt. P. Wiking hat eine Präferenz für indirekte Technik in fast allen Arbeitsschritten, was mit seinem Hintergrund in der Klingenherstellung zusammenhängen könnte. A. Benke nutzt indirekte Technik häufig, wenn er eine höhere Kontrolle über den Hergang erlangen möchte, vor allem während der Ausarbeitung und Korrektur der umlaufenden Kante oder beim Ausbessern von Problemzonen. G. Nunn dagegen verwendet sehr selten indirekte Technik, und wenn, dann hauptsächlich, um problematische Stellen gezielter zu bearbeiten. In dieser Kategorie sollten die technischen Merkmale mehr oder weniger deutlich voneinander zu unterscheiden sein und die Differenzen zwischen den Bearbeitern sichtbar werden.

Die nächste Ebene betrifft Arbeitsschritte, bei denen sich das Material der Arbeitsgeräte unterscheidet, die generelle Technik aber gleich bleibt. Dieser Unterschied ist eher eine Variante der vorherigen Ebene (Abb. 9 und 10). Während die Handhabung gleich bleibt, ändert der Einsatz der unterschiedlichen Materialien auch die zu erwartenden Merkmale. Der größte wahrgenommene Unterschied findet sich hier zwischen A. Benke und den anderen beiden Bearbeitern. Während letztere meist der idealen Sequenz folgen und den direkten Schlag mit Steinen zur Entrindung der Knollen nutzen, greift A. Benke nur in Ausnahmefällen zu einem Schlagstein.

Unterschiedliche Materialien wurden auch bei der indirekten Technik festgestellt. Während G. Nunn und P. Wiking klassisch einen Geweihpunch und einen Holzschlägel verwenden, wechselt A. Benke zwischen Geweih und Kupfer als Punch sowie zwischen Geweih und Holz als Schlägel. Die Unterscheidung zwischen der Wahl einer anderen Technik oder der Wahl eines anderen Materials für die Technik ist nicht immer klar zu treffen und lässt sich schwer allein anhand der Merkmale ausmachen. Zusammensetzungen können hier helfen, die Entscheidungsprozesse zu verstehen und zu erkennen, ob es sich um unterschiedliche Materialien zur Bearbeitung oder tatsächliche Unterschiede in der angewandten Technik handelt.

Die letzte Ebene der Unterschiede wird nur sehr flüchtige Hinweise in den Merkmalen hinterlassen, falls überhaupt. Hierbei ist die Handhabung des Artefakts während der Arbeitsschritte unterschiedlich (Abb. 11). Der markanteste Unterschied wurde hier zwischen P. Wiking und den anderen beiden Bearbeitern beobachtet. Während letztere das Artefakt während der Arbeit fast immer auf einen Teil ihres Körpers aufstützen, um einen ungewollten Bruch des Stücks zu verhindern, hält P. Wiking das Artefakt häufig frei in der Hand. Dieser Unterschied scheint besonders geeignet zu sein, um Lerntraditionen herauszuarbeiten, lässt sich archäologisch aber nur schwer nachvollziehen.

Die signifikanteste Differenz zwischen den Bearbeitern, die sich in der statistischen Analyse der Merkmalsausprägungen finden lassen sollte, ist vor allem der Einsatz der unterschiedlichen Formen des direkten Schlags. Während G. Nunn und P. Wiking im Lauf der Produktion immer wieder zwischen Stein und organischem Schlägel wechseln, nutzt A. Benke fast ausschließlich den Schlägel. In seinen Inventaren sollten die Merkmale für direkten harten Schlag also signifikant geringer vertreten sein als in denen der ersten beiden Bearbeiter. Auch die Hinweise auf den Einsatz von Bearbeitungsgeräten aus Kupfer sollten Unterschiede aufweisen, dieses Mal sollten die Hinweise jedoch in P. Wikings Inventaren weniger häufig auftauchen als in denen der anderen beiden Bearbeiter.

7.4.3 Beobachtete Unterschiede an Abschlagsprodukten

Schon sehr früh während der Aufnahme konnten auf rein subjektiver Basis Unterschiede zwischen den Arbeitsweisen der Bearbeiter erkannt werden, die immerhin so prägnant waren, dass anhand des Inventars klar war, wessen Material gerade aufgenommen wurde. Diese Unterscheidung lässt sich natürlich nicht an einzelnen Abschlägen treffen, sondern basiert auf generellen Beobachtungen vieler Abschläge. Da eine ähnlich eindeutige Aufteilung nach Bearbeitern in archäologischen Kontexten nicht zu erwarten ist, wird die einfache Differenzierung kaum durch die Sichtung des Materials erfolgen können. Dies wäre noch am ehesten möglich, wenn alle Bearbeiter nach derselben strikten Handwerkstradition gearbeitet hätten.

Unterschiede wurden vor allem an den Schlagflächenresten und Abbaukanten wahrgenommen. Die Unterschiede in der Präparation der Schlagflächen scheinen tatsächlich weniger mit den Materialeigenschaften und der eingesetzten Technik zu tun zu haben, sondern vielmehr auf die mentale Planung und Vorgehensweise des Bearbeitenden hinzudeuten. In den häufigsten Fällen sind die Unterschiede so gering, dass sie kaum in der vereinfachten Codierung der statistischen Analyse aufgedeckt werden würden. Ein sehr prägnantes Beispiel sind hierbei die dachförmig präparierten Schlagflächenreste (Abb. 12). In G. Nunns Inventaren sind diese meist durch zwei größere Negative geformt und bilden eine markante Erhebung, die eine exakte Platzierung des Schlags erlaubt. Anders sieht es in A. Benkes Inventaren aus, wo die Dachform häufig eher einen zufälligen Charakter hat und auch die Erhebung wesentlich weniger ausgeprägt ist. P. Wikings dachförmige Schlagflächenreste scheinen im Spektrum zwischen den Extremen von G. Nunn und A. Benke zu liegen. Sie scheinen häufig ebenfalls eher zufällig zu sein und sind nicht so ausgeprägt wie G. Nunns, aber deutlicher als A. Benkes. Im Unterschied zu den beiden anderen wird das Dach auch seltener direkt getroffen, was mit der Handhabung des Artefakts während des Abbaus zusammenhängen könnte. Da P. Wiking das Stück meist locker in der Hand hält, ist mehr Spiel während des Schlags möglich, wodurch auch das Risiko steigt, nicht exakt die Stelle zu treffen, die anvisiert wurde.

Überraschend war die relativ geringe Anzahl von Abschlägen, die Abrasion als Kantenpräparation aufweisen, obwohl alle drei Bearbeiter dabei beobachtet wurden, die Kanten viel und häufig zu abradieren. Aufgrund der wahrgenommenen Unterschiede wurden den Bearbeitern Typen zugewiesen.

G. Nunns Inventare machen einen sehr strukturierten Eindruck. Die Präparation ist darauf angelegt, Risiken während der Bearbeitung gar nicht erst aufkommen zu lassen. Dies wird durch die minutiöse Vorbereitung jedes Abschlags erreicht. A. Benke verfolgt dagegen einen eher intuitiven Weg. Anstelle viel Zeit und Aufwand in die Präparation zu legen, werden häufiger Stellen gesucht, die von sich aus schon die Voraussetzungen für einen erfolgreichen Abbau erfüllen. Auch folgt er weniger den idealen Phasen, sondern arbeitet eher kontinuierlich an mehreren Zielen gleichzeitig. P. Wiking scheint im Ansatz zwischen den beiden zu liegen und einen wesentlich pragmatischeren Weg zu wählen. Auch er nutzt Möglichkeiten, die vorhanden sind, ebnet sich aber auch durch Präparation den Weg, den er verfolgen will. Seine sehr pragmatische Herangehensweise zeigt sich auch in der Herstellung allgemein. Während G. Nunn und A. Benke viel Zeit und Aufwand in die erfolgreiche Fertigstellung des Artefaktes investieren, arbeitet P. Wiking wesentlich schneller und nimmt in Kauf, dass das Stück vor Vollendung brechen könnte. Dies lässt sich zum Teil auch mit der Herkunft der Bearbeiter erklären. P. Wiking stammt selbst aus Skandinavien, wo gutes Rohmaterial in ausreichender Menge zugänglich ist. Dies trifft für A. Benke und G. Nunn nicht zu, die daher vermutlich schon mit einer viel vorsichtigeren Einstellung an die Herstellung herangehen.

Obwohl alle drei sehr ähnliche Artefakte in vergleichbarer Qualität geschaffen haben, ließen sich doch deutliche Unterschiede in ihrer Herangehensweise identifizieren, die sich auch in der technischen Analyse der Merkmale wiederfinden sollten. Die an den Abschlagsprodukten beobachteten Unterschiede wurden in der statistischen Analyse als Leitfaden genutzt.

7.5 Statistische Analyse der Daten

Dieses Kapitel ist vom Einfachen zum Speziellen aufgebaut. Nach einer kurzen Einordnung und Analyse der Inventare folgt ein Teil mit deskriptiver Statistik einzelner technischer Merkmale, bevor kombinierte Merkmale mit multivariaten Verfahren betrachtet werden.

7.5.1 Die Inventare

Für die Analyse wurden acht Inventare von vier Bearbeitern aufgenommen (Tab. 5). Das Inventar von E. Callahan umfasst nur die erste Bearbeitungsphase und diente mehr als Test für das Aufnahmesystem. Es wird nicht im Detail analysiert, dient aber als Quervergleich zu G. Nunns Inventaren. Eine Einteilung nach Produktionsphasen vor der Aufnahme war nur in Ausnahmefällen möglich.

Die Aufnahmestrategie hat sich während der Arbeit aus verschiedenen Gründen verändert, was zu unterschiedlichen Anzahlen an Abschlägen führt, die tatsächlich in die Analyse eingehen (Tab. 13). Für die statistische Analyse wurden nur Abschläge mit proximaler Erhaltung genutzt, da diese die meisten technischen Informationen tragen. Die beiden Dolchinventare, sowie die Sichelinventare von 2007 umfassen alle verfügbaren Abschläge mit proximaler Erhaltung, während in den Sichelinventaren von 2006 gerade in den kleineren Größenklassen nicht die maximal verfügbare Anzahl aufgenommen wurde, denn aus Zeitgründen wurden lediglich signifikante Stichproben genommen.

Auffällig ist die höhere Anzahl an Abschlägen, die in den Dolchinventaren zu finden sind. Dies hängt mit den zusätzlichen Arbeitsschritten zusammen, aber wohl auch mit der sorgfältigeren Arbeitsweise, die weniger risikofreudig ausfällt. Ein weiterer Grund ist vermutlich die Größe der für die Dolche gewählten Knollen, die den Abbau von mehr Material nötig machen (Tab. 14). Ebenso kann die Qualität des Materials Einfluss auf die Abschlagsmenge haben.

7.5.2 Das Rohmaterial

Mit Ausnahme des Dolchinventars von G. Nunn, das aus Edwards-Plateau-Texas-Flint gearbeitet wurde, wurden für alle Versuche Rohmaterialknollen aus dem Kreidebruch in Hillerslev, Dänemark, zur Verfügung gestellt. Flintabbau ist für das Neolithikum an dieser Stelle bekannt. Der genutzte Flint stammt aus dem Maastrichtian und ist von schwarzer bis grauer Farbe. Die Qualität ist oft sehr homogen und damit gut für die bifazielle Bearbeitung geeignet, aber festere, graue Einschlüsse können vorkommen. Für die Versuche in Lejre und Schleswig wurden möglichst gute und große Knollen ausgewählt (Tab. 14).

7.5.3 Rekonstruktion von Produktionsphasen

Um die Aufnahme einfacher zu gestalten, wurden die Abschläge nach Größenklassen angelehnt an V. Arnold (1981b) sortiert oder, falls nicht während der Aufnahme erfolgt, später rechnerisch zugewiesen (Tab. 17). Diese sagen mehr über die Wahrscheinlichkeit aus, mit der ein Abschlag während der

Grabung gefunden wird (und damit auch über die Sorgfalt der Grabung), als dass technische Details in ihnen enthalten sind. Zum Teil wurden die Größenklassen auch gewählt, um potentiell eine schnellere Differenzierung in Produktionsphasen vornehmen zu können. Generell gehören größere Abschläge eher früheren Phasen an als kleinere. Das Dolchinventar von A. Benke wurde als Testinventar für die Korrelation zwischen Abschlagsgröße und Produktionsphase genommen, da dieses nach Phasen getrennt verpackt und aufgenommen wurde. Da A. Benke weniger strukturiert nach Phasen arbeitet als G. Nunn, war nur mit einer bedingten Vergleichbarkeit zu rechnen.

Die Analyse der aufgenommenen Inventare lieferte folgende Resultate: Die Einteilung der Abschläge in Produktionsphasen auf Grundlage der Maße oder Ausdehnung der Kortexreste erbrachte keine zuverlässigen Ergebnisse (Abb. 15-21). Auch der Versuch, Phasen anhand unterschiedlicher Techniken basierend auf Unterschieden in der Schlagflächenrestdicke zu erkennen, war nicht erfolgreich (Abb. 22-24, Tab. 18). Die Überlappung der Abschlagsgrößen zwischen den Stufen ist zu groß; auch werden die Techniken während der unterschiedlichen Phasen nicht ausschließlich genug verwendet, um die Änderung der Anwendung genau bestimmen zu können. Die Ergebnisse wären vermutlich aussagekräftiger gewesen, wenn die einzelnen Abschläge entweder nach dem genutzten Werkzeug oder nach dem Ziel des Abschlags registriert und dann aufgenommen worden wären. Die letzte Variante wäre die interessantere, da die Unterschiede nicht nur zwischen den Werkzeugen, sondern auch zwischen der Anwendung der Werkzeuge bei unterschiedlichen Arbeitszielen untersucht werden könnten. Allerdings würde das Sammeln von Abschlagsprodukten auf diese Weise zu erheblichen Unterbrechungen im Herstellungsprozess führen. Da das Ziel dieser Studie nicht in erster Linie darin bestand, die Unterschiede in der Anwendung der Werkzeuge zu ermitteln, sondern vielmehr die Unterschiede in der Vorgehensweise der einzelnen Bearbeiter bei der Produktion herauszuarbeiten, wurde versucht, ihren Arbeitsfluss so wenig wie möglich zu stören.

7.5.4 Technische Unterschiede während der Produktion

Die Analyse der Unterschiede in der Präparation während der Produktion war etwas erfolgreicher. Die Vorbereitung der Abbaukante und der Schlagfläche sowie die Form des Schlagflächenrestes sind abhängig von den Bearbeitern, allerdings nur sehr schwach statistisch signifikant (Abb. 25-31).

Im Anschluss an die Auswertung individueller Präparationsmerkmale wurden multivariate Analyseverfahren angewandt. Aufgrund der Art der Daten wurden Korrespondenzanalyse und hierarchische Clusteranalyse genutzt. Die Korrespondenzanalyse ergab, dass die Variation zwischen den Inventaren vor allem im Arbeitsaufwand der Präparation zu finden ist. Die Zuarbeitung der Schlagfläche ist in der ersten Dimension von stark zu weniger stark entlang der Achse von links nach rechts abgestuft (Abb. 32-33). In der zweiten Dimension scheint dagegen der Materialverbrauch die strukturierende Kraft zu sein. Die Verteilung der Inventare in der Grafik entspricht den in der Dokumentation beobachteten Mustern; die Inventare von G. Nunn sind am weitesten links positioniert, was auf einen höheren Aufwand bei der Präparation hinweist. A. Benkes Inventare befinden sich eher im rechten, unteren Teil des Biplots, was auf einen geringeren Beitrag zur Präparation der Kanten und Schlagflächen hinweist. P. Wikings Inventare positionieren sich dazwischen. Positiv überraschend war die sichtbare Annäherung der

Inventare von G. Nunn und P. Wiking aus dem Jahr 2007, was darauf hindeutet, dass ein Wissenstransfer zwischen und wechselnde Arbeitsweisen von Handwerkern erkennbar sind. Aufgrund der begrenzten Anzahl von Inventaren sind die Ergebnisse jedoch mit Vorsicht zu behandeln. Die Veränderung kann auch andere Gründe haben, die nicht unbedingt mit der Weitergabe von Wissen oder Änderungen in der persönlichen Arbeitsweise in Verbindung stehen. Ein Vergleich mit zusätzlichen Inventaren könnte aufzeigen, wie aussagekräftig das hier beobachtete Muster ist. Doch dies hätte leider den zeitlichen Rahmen der Studie gesprengt.

Um festzustellen, wie sich die Inventare zueinander verhalten, wurde eine Clusteranalyse durchgeführt (Abb. 34-37). Das Ergebnis spiegelt nicht die Verteilung im Biplot der Korrespondenzanalyse wider; es wurden nur zwei Cluster festgestellt. Der erste umfasst alle Inventare von G. Nunn und P. Wiking sowie das Dolchinventar von A. Benke, während der zweite die Sichel von A. Benke und E. Callahans Dolchvorarbeit beinhaltet. Das Ergebnis unterstreicht die in der Dokumentation festgestellten Tendenzen. Die Inventare von G. Nunn und P. Wiking aus dem Jahr 2007 sind sich sehr ähnlich, aber haben auch eine Ähnlichkeit zu P. Wikings Inventar von 2006 und A. Benkes Dolchinventar. Dies ist nicht völlig überraschend, da P. Wiking von Anfang an als ‚zwischen' G. Nunn und A. Benke stehend wahrgenommen wurde. Auch hat A. Benke während der Herstellung des Dolches einen sorgfältigeren Weg gewählt und brachte sich darüber hinaus die Herstellung von IC-Typen durch das Video von G. Nunn bei. Der erste Cluster besteht somit aus Inventaren, die einen höheren Arbeitsaufwand und bis zu einem gewissen Grad mehr Sorgfalt bei der Produktion erkennen lassen, als der zweite Cluster. Dies ist ebenfalls nicht überraschend, da die Vorarbeit nur Abbauphasen aufweist, die weniger Vorbereitung benötigen, um erfolgreich zu sein. Weiter verfolgt A. Benke eine intuitivere Strategie und nutzt eher die Chancen, die das Material bietet, als dass er Zeit in eine sorgfältige Vorbereitung investiert. Die Trennung der Gruppen ist nicht überwältigend, aber dennoch relativ deutlich und statistisch zuverlässig.

Der nächste Schritt der Analyse bestand darin, die Muster der technischen Merkmale zwischen den Inventaren herauszuarbeiten. Unterschiede zwischen den Bearbeitern waren durchaus zu erwarten, da die unterschiedliche Anwendung der Werkzeuge schon früh im Erfassungsprozess wahrgenommen wurde.

Der Vergleich des Abbauwinkels ergab recht schwache Ergebnisse. Die Bandbreite der Winkel in A. Benkes Inventar scheint etwas eingeschränkter zu sein als diejenige der beiden anderen Bearbeiter (Abb. 38-41, Tab. 19). Die Analyse nach Größenklassen ergab keinen Unterschied, der auf wechselnde Techniken in frühen oder späten Abbauphasen zurückzuführen wäre. Aber bei A. Benkes Dolchinventar wich die Drucktechnik von den Winkeln der anderen Stufen ab. Eine Varianzanalyse wurde durchgeführt, um zu sehen, ob sich anhand der Winkel mögliche Gruppen unterscheiden lassen. Signifikanz war vorhanden, aber es ließen sich keine klaren Gruppen erkennen. Ein Punkt, der das Bild verschleiern könnte, ist, dass die idealen Winkel für das Abheben von Abschlägen bei den verschiedenen Techniken recht ähnlich sind. Ein weiterer Faktor, der möglicherweise Unterschiede verdeckt, ist der Einfluss anderer, nicht registrierter Variablen. Der Abbauwinkel ist kein Merkmal, das bei der Bearbeitung vollständig kontrolliert werden kann, und die Art und Weise, wie das Gerät auf die Schlagfläche trifft, wird von einer Vielzahl von bewussten und unbewussten Entscheidungen und Bewegungen während des Schlages beeinflusst. Ebenso ist die Ermittlung des Winkels nicht immer einfach, es kann zu Fehlmessungen kommen. Obwohl keine

Aussagen über wechselnde Techniken während der Phasen gemacht werden können, ist es möglich, Unterschiede in der Werkzeuganwendung während des Abbaus festzustellen. Ein eingeschränkter Werkzeugsatz, wie der von A. Benke, deutet sich in einer schmaleren Verteilung der Abbauwinkel an.

Die Dicke der Schlagflächenreste wurde als nächstes auf Unterschiede geprüft (Abb. 42). Theoretisch sollte hierdurch die Anwendung unterschiedlicher Techniken nachweisbar sein. Der Abbau mit einem Stein hinterlässt typischerweise dickere Schlagflächenreste als ein organischer Schlägel, da er weiter hinter der Abbaukante auftrifft. Obwohl keine Unterschiede zwischen den Phasen festgestellt werden konnten, zeigte die Varianzanalyse signifikante Unterschiede, die sich bis zu einem gewissen Grad zu sinnvollen Gruppen zusammenfügen ließen. A. Benkes Inventare bildeten eine Gruppe, ebenso wie das Dolchinventar von G. Nunn. Seine Sichelinventare bilden eine Gruppe mit der Sichel von P. Wiking aus dem Jahr 2007, während dessen Sichel aus dem Jahr 2006 eine letzte Gruppe bildet. Dieses Ergebnis unterstreicht nicht nur die wahrgenommenen Unterschiede zwischen A. Benke und den anderen beiden Bearbeitern, sondern zeigt auch, dass die Arbeit von P. Wiking im Jahr 2007 scheinbar G. Nunns ähnlicher wurde. Dass das Dolchinventar von G. Nunn eine getrennte Gruppe bildet, deutet darauf hin, dass auch das Rohmaterial einen Einfluss auf die Dicke der Schlagflächenreste hat, was nicht unerwartet ist.

Unterschiede in der technischen Anwendung könnten auch durch das Auftreten von Schlagaugen erkennbar sein, die weitaus häufiger mit einer Bearbeitung mit Stein und Kupfer verbunden sind. Die Ergebnisse deuten darauf hin, dass Schlagaugen eher in früheren Phasen der Produktion auftreten und eher mit indirekter Technik verbunden sind (Abb. 43-49, Tab. 20-22). Es scheint, dass im Zusammenhang mit der Herstellung bifazieller Geräte Schlagaugen kein verlässlicher Marker für die Anwendung von Druckstäben mit Kupferspitzen sind. Für die Parallelretusche und die abschließende Druckretusche der Kanten wurden keine Schlagaugen festgestellt. Dies ist höchstwahrscheinlich auf den eher geringen Kraftaufwand zurückzuführen, der für die Ablösung der zugehörigen Abschläge erforderlich ist. Die Varianzanalyse ergab signifikante Unterschiede zwischen den Inventaren und dem Auftreten von Schlagaugen, aber die Gruppen ergeben aus technischer Sicht wenig Sinn. Wahrscheinlich ist die Rohstoffqualität hier der gruppierende Faktor. Ein weiterer Test bestand darin, zu prüfen, ob die Schlagaugendurchmesser in Korrelation zur Entfernung des Aufprallpunktes hinter der Kante etwas über die angewandte Technik aussagen. Größere Schlagaugen scheinen mit dem Abbau mit Stein in Verbindung zu stehen und weiter hinter der Kante zu liegen, während Schlagaugen mit sichtbaren Kupferspuren eher nahe der Kante liegen und kleinere Durchmesser haben. Die meisten Kupferspuren wurden in A. Benkes Dolchinventar beobachtet, was darauf schließen lässt, dass Kupferreste und Schlagaugen wahrscheinlicher sind, wenn Kupfer als Punch bei der indirekten Technik verwendet wird.

Wie schwierig eine Unterscheidung der angewandten Techniken anhand von mehreren Merkmalen sein kann, zeigte der Versuch, die Attributausprägung zur Unterscheidung zwischen organischem, weichem und hartem Schlag zu nutzen (Abb. 50). Das erste Problem war die sehr geringe Menge der in der Analyse verbleibenden Abschläge, wenn diese nach gemeinsamem Auftreten von Merkmalsausprägungen sortiert wurden. Letztendlich wurde der Test nur mit den Merkmalen für Bulben- und Lippenbildung durchgeführt und lieferte unerwartete Ergebnisse. Der Einfluss des organischen Schlages auf die Inventare scheint eher gering zu sein, während der harte Schlag deutlich überwiegt. Ein Problem könnte die Kodierung sein, die sich nicht auf metrische Klassen stützt, um die Ausprägung der Merkmale festzulegen. Ein weiterer verdeckender Faktor ist wahrscheinlich die Nutzung von weichen Steinen, die dem organischen Schlag sehr ähneln kann. Vermutlich sind so einige der Abschläge, die in der Analyse der Technik mit dem weichen Stein zugeordnet wurden, wahrscheinlich eher mit Geweih geschlagen worden. Es wurden keine weiteren Versuche unternommen, auf diese Weise kombinierte Merkmale zu analysieren, stattdessen wurden Korrespondenzanalyse und hierarchisches Clustern auf die technischen Variablen angewandt.

Wie bei den Präparationsvariablen erklären die ersten beiden Dimensionen den größten Anteil der Variation der Daten. Die Daten sind in den Dimensionen gut wiedergegeben, aber etwas geringer als bei der Analyse der Präparation. Anhand des Biplots ließen sich keine Gruppen erkennen (Abb. 51-52). Die erste Dimension scheint die technische Variation zu erklären: Die Merkmale für organische und Schläge mit dem weichen Stein sind in der linken Hälfte zu finden, während Merkmale für den harten Stein auf der rechten Seite angesiedelt sind. Die Aussage der zweiten Dimension ist etwas unklar; die Intensität der Radialstrahlen verläuft von der Unterseite des Diagramms bis leicht oberhalb der Achse der ersten Dimension, während die Bulbusaussplitterungen von leicht unterhalb der Achse der ersten Dimension bis zur Oberseite des Diagramms verteilt sind, jedoch ohne offensichtliche Anordnung. Die Inventare ordnen sich wie erwartet der angewandten Technik entsprechend entlang der ersten Achse an. A. Benkes Inventare sind weiter links positioniert, während die von G. Nunn am weitesten rechts zu finden sind.

Die Clusteranalyse ergab drei Cluster, die ebenfalls den erwarteten Ergebnissen entsprechen (Abb. 53-56). Die Inventare von A. Benke bilden einen Cluster mit der Sichel von P. Wiking aus dem Jahr 2006, während die Inventare von G. Nunn und die Sichel von P. Wiking aus dem Jahr 2007 einen zweiten Cluster bilden. Den dritten Cluster bildet die Dolchvorarbeit von E. Callahan. Auf der Grundlage der angewandten Techniken ergeben die Cluster Sinn, und das Ergebnis unterstreicht erneut die Annäherung der Arbeitsweise von P. Wiking und G. Nunn. Die Cluster könnten auch auf regionale – oder hier eher nationale – Bearbeitungstraditionen hindeuten, die eine europäische und eine amerikanische Art der bifaziellen Reduktion unterscheiden. Um zu sehen, ob dieses Muster zutrifft, müssten weitere Inventare analysiert werden, die auch mehr Bearbeitende von beiden Kontinenten einschließen. Im Gegensatz zur Analyse der Präparationsmerkmale sind die Cluster, die auf den technischen Merkmalen beruhen, eher unscharf voneinander getrennt und müssen mit Vorsicht behandelt werden. Dies zeigt, dass die technische Arbeit und damit die Eigenschaften der Merkmale stärker von weiteren Faktoren beeinflusst werden als von persönlichen Entscheidungen und Vorlieben.

Die Ergebnisse der statistischen Auswertung waren nicht so stark oder signifikant wie erhofft, aber dennoch wahrnehmbar. Der nächste Schritt wäre gewesen, in archäologischen Inventaren nach ähnlichen Mustern zu suchen, ohne zu wissen, wer in die Produktion eingebunden war oder wie viele Bearbeitende vertreten waren. Da dies nicht möglich war, wurde ein alternativer Weg beschritten, um zumindest die Übertragbarkeit auf archäologische Kontexte zu testen. Dazu wurden mehr oder weniger zufällige Stichproben aus der vorhandenen Datenbank gezogen und anonymisiert. Der Stichprobenumfang variiert zwischen den generierten Datensätzen, da die Inventare in ihrer Anzahl der für die Stichprobenziehung verfügbaren Abschläge variieren. Dies ist darauf zurückzuführen, dass die Stichproben auf der Grundlage von Abschlagsgrößenklassen gezogen wurden, um Daten zu generieren, die in archäologischen Kontexten ähnlich anzutreffen sind. Dies bedeutet, dass nur vollständig erhaltene Abschläge in die Stichproben einbezogen wurden, was die Verfügbarkeit von Abschlägen für einige Größenklassen stark einschränkte. Da kein Abschlag zweimal in die Analyse einbezogen werden sollte, schränkte dies die möglichen Kombinationen und Tests weiter ein. Letztendlich wurden vier verschiedene Szenarien mit neun verschiedenen Datensätzen getestet. Da die Korrespondenzanalyse und das hierarchische Clustern die besten Ergebnisse lieferten, wurden nur diese in den Testanalysen verwendet.

Grundlage für die konstruierten Befunde in Test A bildeten die verschiedenen Bearbeiter. Aus den vorhandenen Inventaren wurden hierfür Stichproben nach Bearbeiter, aber nicht nach Artefakten getrennt, gezogen. Die Analyse der technischen Attribute führte zu ähnlichen Ergebnissen wie die offene Analyse (Abb. 57-60). Die erste Dimension zeigt auch hier wieder die Unterscheidung zwischen harten und weichen Techniken, wobei sich keine Gruppen zu bilden scheinen. Die Clusteranalyse ergab zwei Gruppen: Befund A allein und die Befunde B und C zusammen. Die Trennung der Cluster ist allerdings sehr vage. Auch die Analyse der Präparationsmerkmale war der offenen Analyse recht ähnlich, ohne allerdings eine klare Gruppierung aufzuweisen (Abb. 61-64). Auch hier wurden Befund A allein sowie die Befunde B und C gemeinsam als Cluster identifiziert und wiesen eine etwas bessere Trennung als die Ergebnisse der technischen Variablen auf. Löst man die Anonymisierung auf, stimmen die Ergebnisse mit der offenen Analyse überein. Befund A war eine Stichprobe der Arbeit von A. Benke, Befund B von G. Nunn und Befund C umfasste die Inventare von P. Wiking. In ungemischten Kontexten sollte es demnach möglich sein, Ähnlichkeiten und Unterschiede zwischen den Bearbeitenden zu erkennen. Aufgrund der schwachen Ergebnisse scheint es jedoch eher unwahrscheinlich, tatsächlich individuelle Bearbeitende erkennen zu können. Wahrscheinlicher ist, dass Unterscheidungen zwischen Kontexten mit kontrastierenden generellen Herangehensweisen herausgearbeitet werden können.

Test B ist so konstruiert, dass ein Befund mit nur einem Bearbeiter gegen zwei gemischte Befunde getestet wird, die nicht den Bearbeiter des ersten Befundes einschließen. Das Ergebnis der technischen Attribute war etwas anders als bei den vorangegangenen Analysen (Abb. 65-68). Die Abstufung zwischen den Techniken war immer noch wahrnehmbar, aber nicht mehr so deutlich wie zuvor. Befund D schien einen größeren Abstand zu den beiden anderen Befunden zu haben. Die Clusteranalyse unterstrich diesen Unterschied und identifizierte D als getrennten, eigenen Cluster und G und J als zweiten Cluster. Die Trennung der Cluster voneinander war wieder eher gering. Die Analyse der Präparationsmerkmale verlief ähnlich wie die offene Analyse, es wurden die gleichen Cluster wie bei den technischen Variablen erlangt, sogar mit einer etwas besseren Trennung der Cluster (Abb. 69-72). Befund D ist eine Stichprobe des Dolchinventars von G. Nunn, Befund G enthält Abschläge der Sichel von P. Wiking aus dem Jahr 2006 und A. Benkes Sichel, während Befund J P. Wikings Sichel von 2007 und A. Benkes Dolchinventar umfasst. Das Ergebnis war in dieser Form nicht erwartet worden. Für die Präparationsmerkmale wäre auch eine Gruppierung von D und J möglich gewesen und damit eine Nähe zwischen den Inventaren, die den größeren Aufwand in die Präparation investieren. Die persönliche Note ist immer noch vorhanden, es ist aber auch erkennbar, dass das Rohmaterial einen gewissen Einfluss auf die Ergebnisse hat.

Dies wird in Test C noch deutlicher. Auch hier wird ein Befund nur eines Bearbeiters gegen zwei gemischte Befunde getestet, doch dieses Mal ist der Einzelbefund-Bearbeiter auch an den anderen Befunden beteiligt. Bei den technischen Merkmalen passt die Korrespondenzanalyse nicht mehr zu den bisherigen Analysen (Abb. 73-76). Diesmal scheint der Faktor der Variation der Kraftaufwand während des Abbaus zu sein. Befund D unterscheidet sich erkennbar von den Befunden E und H, was auch durch die Clusteranalyse erkannt wird. Die Trennung ist unerwartet gut. Dieses Bild wiederholt sich jedoch nicht in der Analyse der Präparationsmerkmale, auch die Cluster werden hier anders gebildet als bei der technischen Analyse, wobei E als einzelner Cluster belassen und D und H zusammen gruppiert werden (Abb. 77-80). Aus der Interpretation der Variablenverteilung des Biplots scheint es, dass im Befund E weniger Arbeit in die Präparation investiert wird als in D und H. Der Abstand zwischen den Clustern ist wiederum erwartungsgemäß eher gering. Befund D ist der gleiche wie in Test B, Befund E enthält G. Nunns Sichel aus 2006 und A. Benkes Sichel, und Befund H G. Nunns und P. Wikings Sicheln aus 2007. Da alle Proben die Arbeit von G. Nunn enthalten, wurde kein klarer Unterschied in den Ergebnissen erwartet. Die technische Analyse macht Sinn, wenn das Rohmaterial betrachtet wird, das sich bei G. Nunns Dolch deutlich unterscheidet. Damit erklärt sich auch der Unterschied im Kraftaufwand während des Abbaus, da Texas Flint härter als skandinavischer Flint und somit mehr Kraft erforderlich ist, um ähnliche Abschläge zu entfernen. Dies hat bis zu einem gewissen Grad auch Einfluss auf die technischen Entscheidungen. Es scheint aber, dass die Einschränkungen durch das Rohmaterial hier einen größeren Einfluss auf die Ergebnisse haben als die technischen Entscheidungen. Der Einfluss auf die Präparation ist deutlich geringer, was zu den erwarteten Ergebnissen führt. G. Nunn investiert mehr Zeit und Arbeit, was sich etwas ausgleicht, wenn die beiden anderen Bearbeiter mit einbezogen werden.

Beim letzten Test, D, waren alle Befunde gemischt, aber nicht jeder Bearbeiter war in jedem Befund vertreten. Die Analyse der technischen Variablen unterschied sich wiederum von der offenen Analyse und entspricht eher den Ergebnissen von Test C (Abb. 81-84). Die treibende Kraft der Variation in der ersten Dimension scheint der Kraftaufwand während des Schlages zu sein. Die Befunde G und I bilden eine Gruppe und scheinen mit mehr Kraftaufwand bearbeitet worden zu sein als Befund H, aber der Abstand der Cluster ist wieder eher gering. Die Analyse der Präparationsmerkmale unterscheidet sich nicht von den früheren Analysen (Abb. 85-88). Befund G scheint allgemein mehr Arbeitsaufwand für die Präparation zu enthalten, während Befund I mehr Arbeit für die Präparation der Kante zeigt. Die Clusteranalyse trennt Befund G von den Befunden I und H. Die Veränderung in den Clustern zwischen den Variablen unterscheidet sich wiederum von der offenen Analyse, ähnelt aber den Ergebnissen in Test C. Die Trennung der Cluster ist besser als bei den technischen Variablen, aber dennoch nicht sehr deutlich. Befund G umfasst Abschläge von P. Wikings Sichel 2006 und A. Benkes Sichel, Befund I von G. Nunns und A. Benkes Dolchinventar, Befund H setzt sich aus P. Wikings und G. Nunns Sicheln aus dem Jahr 2007 zusammen. Die Aussage der Verteilung der Merkmale entlang der Achsen der technischen Variablen ist nicht sofort erkennbar. Weder der Kraftaufwand noch die Materialeigenschaften scheinen die leitenden Faktoren zu sein. Wahrscheinlich ist die Wahl der Technik die zugrundeliegende Variation, da die Merkmale einschließlich der Befunde von A. Benke eher auf der Seite mit den Variablen für den weichen Schlag liegen als die anderen Befunde. Bei den Präparationsvariablen stehen die

Ergebnisse im Einklang mit den bisherigen Analysen. Auch in gemischten Inventaren heben sich G. Nunns und P. Wikings Aufwand für die Präparation von den Inventaren von A. Benke ab, aber auch sein sorgfältigeres Vorgehen beim Dolch ist zu erkennen.

Die statistische Analyse war nicht ganz so hilfreich wie erhofft, lieferte aber dennoch vielversprechende Ergebnisse. Es konnten Tendenzen von Unterschieden zwischen den Bearbeitern festgestellt werden, die die während der Aufnahme schon wahrgenommenen Unterschiede unterstrichen. In einigen Fällen konnten überraschende Muster erkannt werden, aber die Signifikanz der Ergebnisse war durchweg gering. Die einzige Ausnahme ist die Analyse der technischen Variablen im gemischten Test C, die offenbar mehr über die Rohstoffqualität auszusagen scheinen als über die angewandten Techniken selbst. Im Allgemeinen scheinen die Präparationsmerkmale aussagekräftigere und zuverlässigere Ergebnisse hinsichtlich persönlicher Vorlieben und Unterschiede in der Produktion zu liefern als die technischen Variablen. Letztere scheinen von einer großen Anzahl anderer und komplexerer Prozesse beeinflusst zu werden.

Die bisherigen Ergebnisse haben auch gezeigt, dass viele der erfassten Merkmale nicht sehr aussagekräftig sind und demnach hätten ausgeschlossen werden können. Ebenso hätten einige Merkmale bessere Ergebnisse erbringen können, wenn sie auf andere Weise aufgenommen oder Bearbeiter mit ausgeprägteren Unterschieden im Können einbezogen worden wären. Würde die Aufnahme mit den gleichen Zielen fortgesetzt werden, sollte der Fokus auf die Präparation und die technischen Merkmale gelegt werden, während die anderen Merkmale zugunsten einer zeitsparenden Aufnahme ausgeschlossen werden könnten. Da die Größenklassen ebenfalls nicht wirklich bei der Interpretation helfen, wäre es nicht notwendig, sie weiterhin einzubeziehen. Sie erleichterten jedoch die Erfassung und Auswertung der Inventare, doch vier bis fünf Klassen hätten zu diesem Zweck ausgereicht. Ein weiterer wichtiger Aspekt ist die Struktur der Experimente. Das Sammeln der Abschläge nach Arbeitsziel und verwendetem Werkzeug könnte die Identifizierung der in der Studie bisher beobachteten Tendenzen verbessern. Die Unterbrechung im Produktionsprozess hätte allerdings einen großen Einfluss auf die Vorgehensweise des Bearbeitenden, wie zum Beispiel die unbewusste Entscheidung, so lange wie möglich mit demselben Werkzeug an demselben Ziel zu arbeiten, um Unterbrechungen des Arbeitsflusses zu vermeiden. Andererseits bedeuten Unterbrechungen auch Leerlauf – und somit Zeit, die von den Bearbeitenden zum Nachdenken über das weitere Vorgehen genutzt werden und Einfluss auf deren Entscheidungen haben könnte. Doch Abschläge, die auf diese Weise gesammelt werden, könnten genutzt werden, um Unterschiede zwischen den Abschlagstypen zu bestimmen, was wiederum dazu beitragen könnte, die einzelnen Produktionsphasen in Inventaren deutlicher voneinander zu unterscheiden.

Eine weitere Möglichkeit wäre die Verwendung von umfangreichen Zusammensetzungen. Diese würden die nachträgliche Einteilung der Abschläge erlauben, ohne die Produktion zu stören und wäre im Falle archäologischer Inventare die einzige Möglichkeit, den Zweck eines Abschlags zu bestimmen. Zusammensetzungen sind sehr zeitaufwendig, bieten dafür aber viele detaillierte Informationen. Die Entscheidung, sich auf Zusammensetzungen zu stützen, müsste für jedes Projekt einzeln getroffen werden. Aber eine stärkere Einbeziehung dieser Praxis und die anschließende Verfügbarkeit der Daten würden mehr als nur einem Forschungsprojekt zugutekommen.

Die Anwendbarkeit der Studie auf archäologische Inventare ist nicht vollständig geklärt. Aber die gemischten Tests deuten darauf hin, dass Unterschiede nachweisbar sein sollten, wenn auch nicht auf persönlicher Ebene, so doch zumindest auf der Ebene einer technologischen Tradition. Dies erfolgt unter der Annahme, dass Menschen, die voneinander lernen, ähnlicher arbeiten als andere Personen. Die Antwort auf die Ausgangsfrage für dieses Projekt ist damit: ja, es ist möglich, individuelle Präferenzen der Flintbearbeitung in Abschlagsinventaren zu erkennen, was zumindest dazu beitragen kann, Lerntraditionen in archäologischen Kontexten zu identifizieren. Diese Studie bietet eine Möglichkeit zur Interpretation von Mustern, die in archäologischen Kontexten nachweisbar sein können, und stützt sich dabei auf mehr als persönliche, technologische Kenntnisse des Bearbeitenden. Sie hilft somit, Unterschiede zu erklären, die zur Identifizierung verschiedener Handwerkender oder wechselnder technologischer Traditionen führen können, ohne dass die Forschenden unbedingt praktische Kenntnisse des Handwerks erwerben müssen.

7.6 Zusammenfassung und Ausblick

Ziel dieser Studie war es, eine belastbarere Basis für die Identifizierung einzelner Bearbeitender in Flintabschlagsinventaren zu finden. Dafür wurden Bearbeiter mit unterschiedlichen (Lern-)Hintergründen ausgewählt und deren Arbeitsweisen analysiert. Da die bifazielle Methode und die Herstellung von Flintdolchen von modernen Bearbeitenden erst hatte wiederentdeckt und neu erlernt werden müssen, besteht trotz allem eine gewisse Beziehung zwischen allen Bearbeitern dieser Studie.

Obwohl alle drei die gleichen Objekte hergestellt haben und sich dabei derselben Methode bedienten, ließen sich doch auf technischer Ebene unterscheidende Merkmale herausarbeiten. Neben diesen ließen sich auch Unterschiede in der Herangehensweise beobachten, die nicht direkt auf angewandte Techniken zurückzuführen sind. So wiesen Art und Umfang der Präparation sowie der Erhalt der Arbeitskante Unterschiede auf, die die Bearbeiter voneinander unterscheidbar machten.

Eine Befürchtung während der Aufnahme der Inventare war, dass die Simplifizierung der Merkmale für die statistische Analyse einen Teil der Unterschiede überdecken würde, was sich vermutlich auch tatsächlich in der generell geringen Signifikanz der Resultate niederschlägt. Es ließen sich trotzdem aussagekräftige Resultate generieren. Die besten Ergebnisse lieferten die multivariaten Methoden, vor allem anhand von Merkmalen für die Präparation. Der unterscheidende Faktor der Inventare schien hier der aufgewandte Einsatz an Zeit und Intensität der Präparation zu sein. Die Analysen erbrachten auch dann stabile Resultate, wenn die untersuchten Stichproben nicht mehr nach Bearbeitern getrennt waren. Auch ließ sich hierbei eher eine Annäherung der Arbeitsweisen der Bearbeiter beobachten.

Dagegen waren die Ergebnisse der Untersuchung der technischen Merkmale variabler und schwerer zu interpretieren. Generell scheint die Korrespondenzanalyse die technische Tendenz der Inventare zu erklären, aber in den gemischten Analysen traten auch die Rohmaterialqualität und damit die eingesetzte Kraft während der Bearbeitung als Faktoren der Variation hervor. Gänzlich überraschend war das Resultat nicht, da die Wahl der Technik für den Abbau von den Eigenschaften des Rohmaterials beeinflusst wird.

Eine Zuweisung der Abschläge zu Produktionsphasen war anhand von Merkmalen und Maßen nicht möglich, da die Überlappungsbereiche zu groß waren. Mehrheitlich sind die Unterschiede in der technischen Vorgehensweise ohnehin auf einige wenige Arbeitsschritte beschränkt, was eine Identifizierung in der Menge der Abschläge gleicher Bearbeitung schwierig macht. Die Möglichkeiten wären hier vermutlich größer gewesen, wenn die Abschläge nach angewandter Technik und Arbeitsziel aufgenommen worden wären. Für weitere Analysen sollte das Aufnahmesystem entsprechend angepasst werden, um zielgerichteter nach technischen Unterschieden suchen zu können.

Obwohl nicht alle gesetzten Ziele erreicht werden konnten, lieferte die Analyse positive Resultate. Es ist möglich, unterschiedliche Bearbeiter oder zumindest Bearbeitungstraditionen voneinander zu unterscheiden. Darüber hinaus ließ sich auch die Weitergabe und Vermittlung von Wissen fassen. Die Vermittlungssituation kann hier entweder als horizontal oder als schräg definiert werden. Die Weitergabe fand eher als Unterricht statt, wobei verbale Kommunikation nicht immer oder nicht immer vollständig stattfand. Auch individuelles Lernen war in allen Fällen Teil der Vermittlung. Verzerrungen konnten vor allem dadurch entstehen, dass alle Beteiligten schon erfahrene Handwerker waren und ihre eigene persönliche Arbeitsweise entwickelt hatten. Ebenso kann die Sprachbarriere Einfluss auf das Vermitteln und Verstehen gehabt haben. Die Änderungen ließen sich vor allem in den Präparationsmerkmalen finden, die generell besser geeignet scheinen, um individuelle Arbeitsweisen zu identifizieren. In der Dokumentation ließen sich keine Veränderungen in der Arbeitsweise finden, die auf einen Wechsel in der Bearbeitung aufgrund von Wissenstransfer hindeuten. Um tatsächlich verlässliche Aussagen treffen zu können, in wie weit Lernen für die Veränderungen in den Daten verantwortlich ist, müssten allerdings noch mehr Inventare aufgenommen und verglichen werden. Interessant wäre in dieser Hinsicht auch, spätere Inventare derselben Bearbeiter aufzunehmen, um zu sehen, ob die Annäherung bestehen bleibt oder sich die individuellen Herangehensweisen wieder stärker durchsetzen. Ebenso wäre es interessant, weitere Bearbeitende in die Analyse einfließen zu lassen, um zu sehen, ob sich ‚Abstammungslinien' nachvollziehen lassen.

Die Resultate der Studie machen es möglich, Fragen nach technischen und Herstellungstraditionen in archäologischen Inventaren zu verfolgen. Dadurch kann ein besseres Verständnis der technologischen Entwicklung erreicht werden, zudem können Änderungen und Innovationen im Produktionsprozess, aber auch der Verlust von Wissen und technischen Fertigkeiten, nachverfolgt werden. Ebenso können Fragen nach der Organisation der Herstellung zielgerichteter verfolgt und damit ein tieferer Einblick in die Sozialstruktur von Gesellschaften gewonnen werden. Der nächste Schritt dafür wäre eine Anpassung des Aufnahmesystems und die Analyse archäologischer Inventare.

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Appendix

Glossary

Term	Definition
Chaîne opératoire	System of operations during production or more general an action. Connects techniques, knowledge and know-how to a successful outcome. Also: recipe of action, behavioural chain, operational or reduction sequence.
Cortex	Natural surface of a nodule. Mostly outer chalk layer, but no distinction is drawn here between original and 'neocortex' (Inizan 1999, p. 91), which describes the surface of a nodule after alteration of the original cortex by natural processes. Surface unmodified by knapping operations.
Drift	Random changes in transmission which are not triggered directly by: transmission, mutation or selection.
Emulation	Copying of an outcome but not the replication of the process.
Flaking	Action of fracturing raw material with the intention of producing blanks for further use.
Imitation	Replication of process as shown.
Knapping	Action with the intention of fracturing raw material. General term, when not clear what has been done. If known: flaking, shaping, retouching.
Know-how	Subconscious memories. Not transmittable; they have to be acquired through practice. Also: savoir-faire.

Term	Definition
Knowledge	Consciously known facts. Transmittable between individuals. Also: connaissance.
Method	Planned sequence of interrelated actions which leads to the production of predetermined products.
Mutation	Changes to information, for example, due to copying errors.
Recipe of action	Social rules structuring a process.
Retouching	Modification of a blank, to make, finish or sharpen a tool through percussion or pressure.
Schéma opératoire	Mental concept of the individual behind the production. Based on experience.
Selection	An individual's choice which elements from the existing pool of cultural variants to proceed with.
Shaping	Sequence of knapping actions to manufacture a single object by carving raw material to the desired form.
Skill	Ability to perform an action sucessfully. Not present in the same degree in everyone, partly an inherent unalterably trait.
Stimulus enhancement	Exposure to behaviour leads to an adoption of certain behaviours instead of others.
Teaching	Active involvement of both teacher and learner in transmission process. Not necessarily verbal.
Teaching framework	System/structure in which knowledge is transfered and practiced.
Technique	How an action is performed. This is comprised of choice, mode of application and position of tools as well as gestures of the body.
Technology	Structured systems guiding actions. Encompassing artefacts, behaviours and knowledge passed down through generations by teaching and learning.
Techno-science	Scientific principles, e.g. fracture mechanics.
Transmission	Passing on information between individuals through various means.

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The book series 'ROOTS Studies' presents scientific research that proceeds from the implementation of individual and cross-disciplinary projects within the Cluster of Excellence 'ROOTS – Social, Environmental and Cultural Connectivity in Past Societies' at Kiel University. The series addresses social, environmental, and cultural phenomena as well as processes of past human development in light of the key concept of 'connectivity'. The results of specific research topics and themes across various formats, including monographs, edited volumes, proceedings of conferences and workshops as well as data collections, are the backbone of this book series.

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Craftful Minds

Tracing Technical Individuality in Production Processes

The aim of the thesis was to provide a framework for the identification and analysis of individual craftspeople in bifacial flint production. Flint production flakes from replications of South Scandinavian Late Neolithic daggers and Early Bronze Age sickles were the focus of the study, in contrast to research so far, mostly relying on finished and often exceptional pieces.

To identify technical traditions within technological systems and/or personal approaches to production, it is necessary to analyse the complete production process. Studies concerned with the process have mostly relied on typical and easy to identify production flakes. This facilitates the identification of tool manufacture and prevents mixing with other production processes, but it also prevents the actual identification of individual approaches to bifacial flint production. Typical flint flakes are typical because physical laws restrict the mode of possible removal. They are, by definition, strategic moments in the production process, which cannot be changed without altering the outcome, so everyone has to work the flint in more or less the same way. Personal or traditional approaches will not be found there, but in the small, flexible steps in between. This is what the volume presents.

By detailed analysis of the working procedures of modern knappers, combined with statistical analysis of technical attributes on the production flakes, the possibilities for identification of differing approaches are explored. The analysis shows that the differences on personal or traditional levels are not to be found in the process of removal, but are more clearly distinguished in the preparation for removal. Likewise, the preferences for certain working techniques can be reconstructed and used to distinguish between knappers' approaches. The results and the approach of the thesis can help us gain a clearer picture of local technical traditions of flint production. They also provide opportunities to identify and analyse processes of knowledge transmission and by this to reconstruct possible paths of learning, contacts between groups and the development and change of technological systems.

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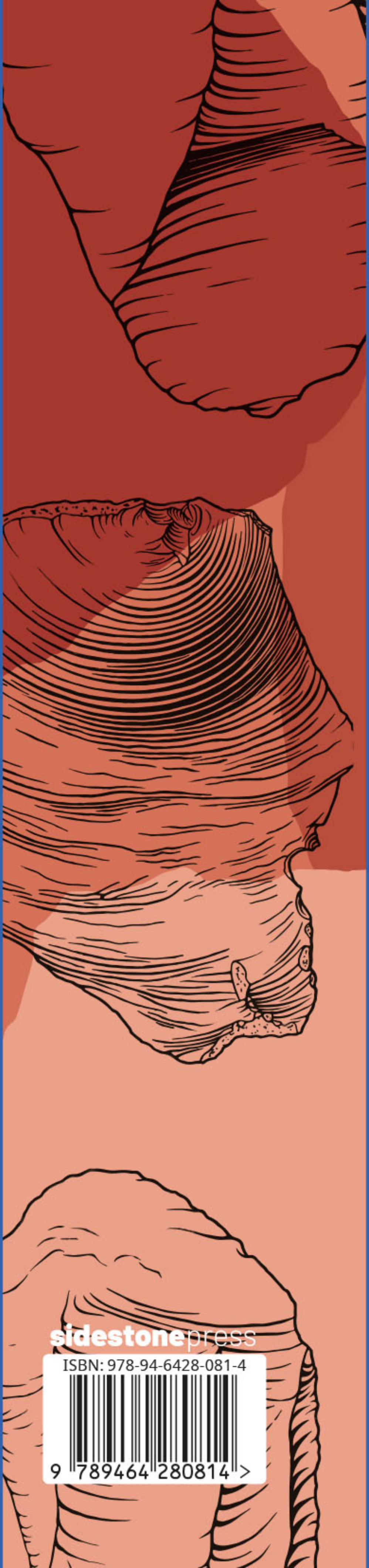

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