



# Between Thy and Tübingen

*Late Palaeolithic and Mesolithic hunter-gatherer worlds in transition*

STUDIES IN HONOUR OF **BERIT V. ERIKSEN**

Sascha Krüger & Daniel Groß (eds)



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Published by Sidestone Press, Leiden

[www.sidestone.com](http://www.sidestone.com)

E-mail: [info@sidestone.nl](mailto:info@sidestone.nl)

Phone: (+31)(0)71-7370131

Imprint: Sidestone Press Academics

This book has been peer-reviewed. For more information see [www.sidestone.com](http://www.sidestone.com)

Lay-out & cover design: Sidestone Press

Photograph cover: © Sascha Krüger; photograph and graphic of flint artefacts: Sofiane Bouziane

ISBN 978-94-6427-156-0 (softcover)

ISBN 978-94-6427-157-7 (hardcover)

ISBN 978-94-6427-158-4 (PDF e-book)

DOI: 10.59641/l6o2i3j4k5



Förderverein Archäologie  
Schloss Gottorf e. V.



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# Preface

Those who have had the fortune to work alongside Berit V. Eriksen know her as a meticulous academic, generous mentor, protector of PhD students, and passionate flint nerd. She has the gift of making the past feel vividly alive, as her enthusiasm of exploring the past is contagious – whether it is while guiding students through courses or rummaging flint and artefact collections in the quiet of the lab.

Over the course of four decades – and while growing loads of chili in her garden and indulging in the Scandinavian cliché of liquorice consumption – Berit's work has significantly contributed to investigating key topics of prehistoric archaeology, such as the explicit study of flint artefacts, human adaptation processes, reindeers as key resources, or burial practices.

From her activity as guest lecturer at universities in Aarhus, Bergen, Cambridge, Copenhagen, Ferrara, Jena, Kiel, Southampton, Tomar and Tübingen, to her pioneering work as scientific director of the ZBSA, her scholarship has consistently challenged assumptions (Eriksen 2013: Looking for facts ... Still missing the boats!) and opened new avenues of inquiry.

This volume not only honours Berit's fourteen-year tenure as scientific director of the Centre for Baltic and Scandinavian Archaeology (ZBSA; 2009–2023) in Schleswig, but also addresses themes connected to the research centre's former scientific clusters: People and Artefacts, People and Society, and People and Environment. The contributions in this anthology reflect the breadth of Berit's career, particularly her focus on explaining human behaviour through interactions with different spheres of life, as well as the significant influence she had, and continues to have, on Stone Age research and on the researchers involved in it. This book celebrates Berit's career in professional archaeology with a vibrant collection of studies centred on lithic and Stone Age research.

In 1989, Berit was the first woman to receive a PhD degree in archaeology in Denmark. In order to honour this achievement, the contribution by Sonja Grimm and colleagues celebrates careers of outstanding women in Danish, German and Norwegian archaeology and highlights Berit's central role in a network of female archaeologists.

Studies into the oldest craft in the world – flint knapping – have been one, if not the most important, focus of Berit's work. Just as the flakes on a tool production site, papers and books on raw material as well as lithic inventories lie scattered along her career path. In acknowledgement to this, several contributions present studies of lithic assemblages. Tobias Reuter explores technical practices of the Glacial Interstadial 1, and together with colleagues explores the evolution of Federmesser Gruppen. These two studies represent investigations of the oldest lithic inventories in this volume.

The succeeding Greenland Stadial 1 is mainly associated with the Ahrensburgian technocomplex. In their contribution, Moiken Hinrichs and Katja Winkler report on new excavations from the Ahrensburgian type locality and on future perspectives for the Ahrensburgian Tunnel Valley. Tomas Rimkus elaborates on a lithic assemblage from the contemporary Swiderian technocomplex, whereas Éva David writes about Ahrensburgian Lyngby axes. Florian Gumboldt and colleagues present an update on investigations

from Ahrensburgian find layers from the Blätterhöhle – a site that spans from the Late Palaeolithic to the Neolithic. Of Neolithic age are two sickle blades found in connection to a large wooden structure from the Federsee fen which are described in the contribution by Julia Goldhammer.

However, it is not exclusively the anthropogenically modified dark grey sedimentary cryptocrystalline quartz – or flint – that was studied by Berit. In a paper from 2002 she explored molluscs and other exotic material in Late Glacial and early Post Glacial southern Germany. As a tribute, Felix Riede presents new insights into exotic raw materials, while Hauke Jürgens and colleagues report on one of the most iconic, yet exotic raw materials – Heligoland flint – and how to identify it.

Just like flint, it had always been adaptation processes to changing environments that were most relevant to Berit's research. This is manifested in many publications and projects, like early papers on *Kontinuitet og forandring fra palæolitikum til mesolitikum i Europa* (1988), editing conference proceedings on *Hunters in a changing world* (2004), or leading the CRC1266-project *Pioneers of the North* (2016-2024).

Such a change that demanded a high degree of adaptation is the Pleistocene–Holocene transition, which heavily affected the environmental background for people's lives and their pursued subsistence strategies. In the course of the Preboreal – be it chronozone or biozone – the transition from Palaeolithic to Mesolithic traditions is recorded. Here, Mikkel Sørensen reflects on our definition of the Mesolithic, while Sönke Hartz and colleagues write about a Mesolithic hot spot area in northern Germany. Daniel Groß and colleagues discuss the potential of scattered Mesolithic finds from contract archaeological work in Denmark, and Svea Mahlstedt and colleagues explore how sites in the northwest German Mesolithic gap can be surveyed and discovered in the future.

A single Mesolithic context is the focus of Lars Larsson's paper which reflects on aesthetics of artefacts from Skateholm. A further aspect of Mesolithic societies is considered by Mari Törv in her intellectual exercise on cremation burials.

Flint tools are major aspects of daily life in past societies as well as important for subsistence, for instance, in case of projectiles. In order to reveal new insights into diachronic patterns of subsistence strategies John Meadows and Anders Fischer apply stable isotope research on 40 Late Mesolithic individuals. Whereas Dorothee Drucker presents results from stable isotope research and investigations on the subsistence of two of the main game animals of the Late Glacial – reindeer and horse.

“Absence of evidence is not evidence of absence” - this quote by Carl Sagan appeared at least once in every teaching lesson given by Berit. But what can be done about the absence of evidence? As part of the *TRAPA* applicant group, Berit successfully received funding for a scientific cruise into the North Sea Basin. *Tracing the Late Pleistocene - Early Holocene landscape of Late Palaeolithic reindeer hunters off the coast of Heligoland* was designed to push the limits in archaeological science and likewise to gather evidence from the lost landscapes of Doggerland – an area mostly void of evidence. In keeping with this, Sascha Krüger and Ben Gearey attempt to foster the formation of hypotheses around this drowned world, while the application of newly developed synergies between archaeology and other disciplines is explored in geophysical case studies in Tyrsted by Erica Corradini and colleagues.

This anthology is not only a scholarly tribute, but likewise a portrait of a scientific life lived in the pursuit of understanding humanity's deep past. In dedicating this volume to Prof. Dr. Berit V. Eriksen, we celebrate a career that has deeply enriched our knowledge, but more importantly, we celebrate a mentor, colleague and friend that enriched our lives. May these pages stand as a record of our gratitude, our admiration, and our enduring commitment to continue the work she has advanced. In closing we would like to thank the copious number of peers for their anonymous reviews and suggestions for improving the contributions to this volume, Sidestone Press for their helpful support and timely production of the book, as well as the Förderverein Archäologie Schloss Gottorf, the National Museum of Denmark, and Museum Lolland-

Falster for financial support. Your help and support made this publication possible in the first place and granted the possibility to make it available in Open Access. Last but not least, we thank all contributors for the efforts they put into their papers and for making the tight schedule feasible.

Kongens Lyngby and Nykøbing F. in December 2025.

Sascha Krüger and Daniel Groß



# Sisterhood in archaeology

Berit Valentin Eriksen as mentor

Sonja B. Grimm, Helene Agerskov Rose,  
Katrine Balsgaard Juul, Charlotte Damm  
and Inger Marie Berg-Hansen

## Abstract

This chapter explores the formative role of *sisterhood* – understood as an informal activist network of mutual support, mentorship, and empowerment – in the development of archaeology as an academic discipline, with particular focus on the career of Berit Valentin Eriksen. Building on recent scholarship in gender archaeology and the recovery of women’s contributions to the field, we situate Berit’s professional trajectory within the contrasting academic cultures of Denmark, Germany, and Norway. While structural barriers long restricted women’s access to professorial ranks and formal influence, informal networks of women – sisters in archaeology – have profoundly shaped disciplinary practice through teaching, collaboration, and mentorship. Drawing on research-historical and biographical evidence, we demonstrate how Berit’s career exemplifies the intersection of individual agency and collective female support systems across national contexts. From her early participation in an all-female thesis group in Aarhus, to her leadership roles in German and Nordic research networks, Berit’s academic influence has extended far beyond conventional metrics of rank or citation. Her work illustrates how sisterhood has fostered intellectual resilience, methodological innovation, and a redefinition of what constitutes academic influence. In highlighting Berit’s career as a case study, this article contributes to broader discussions on gender, mentorship, and equity in archaeology, arguing that sisterhood – both historical and contemporary – remains a key driver of disciplinary transformation and inclusivity.

*Keywords: Women in archaeology, sisterhood, Germany, Denmark, Norway*

## Introduction

Gender archaeology has been debated since the 1970s (Claassen 1992; Conkey and Spector 1984; Dommasnes and Montón-Subías 2012; cf. Gero 1983; Gero and Conkey 1991), but recent years have seen a growing focus on the topic (Coltofean-Arizancu *et al.* 2021; Koch and Kirleis 2019; López Varela 2023; Matic *et al.* 2024; Moen and Pedersen 2025; cf. the Paye ta truelle website for franco-phone countries). In addition to gender perspectives in archaeological interpretations, recent research includes a sociological view on the actors of archaeology and, within the last decade, an increasing number of projects have begun digging up women archaeologists in research history who had been ‘forgotten’ or whose impact has not been acknowledged, such as Trowelblazers (United Kingdom), ArqueologAS (Spain), AktArcha (Germany), or kvinARK (Denmark).

On their websites, these projects show that especially women have been a part of the field since the very beginning as a science. This approach helps to change the picture of archaeologists within the archaeological curriculum and additionally in a wider public allowing for interactive effects with more young women picturing themselves in this profession. However, due to academia not allowing women to participate from the beginning, the number of academic teachers in most countries only began increasing much later. Even these women and their achievements have often not been mentioned after their retirement as they have hardly built 'schools of thought', written 'standard' introductions, led excavations at big sites, or were affected by the cumulative effect of recognition still predominantly ignoring women, the so-called Matilda effect (cf. Bösl and Gutschmiedl-Schumann 2024; Díaz-Andreu 2025; Rossiter 1993). Although individual women were present in academia over several decades, they often filled more informal roles of supporting and mentoring companions, sisters if you like. In this contribution, we are focusing on these less formal roles and propose that the 'sisters' have played a formative role in the education and raising of descendant generations of archaeologists. Yet, only when these 'sisters' started building supportive networks for female peers, sisterhoods in archaeology, their number, influence and visibility grew. Sisterhood as a feminist solidarity concept among (groups of) women has regularly been discussed, also critically in view of the intersectional diversity within women movements since the 1970s and 1980s (e.g. Dill 1983; Hooks 1986; Krocak *et al.* 2025; Mitra 2023; Morgan 1970; Rodak 2020). Here we understand sisterhood as an informal activist network that extends beyond individual friendships, and that fosters mutual support, mentorship and empowerment to navigate the predominantly male academic environments. We believe that sisterhood has played an important role in Berit Valentin Eriksen's career and we will demonstrate this by providing a research-historical context of Berit's contribution to archaeology that situates her within the academic environments in which she operated, specifically in Denmark, Germany and Norway.<sup>1</sup>

The academic discipline of archaeology has emerged and developed differently in these countries and the differing academic cultures, particularly in relation to the role of women created by these cultures, have played an important role for Berit's academic career. Before exploring this, we must, however, set the stage, particularly regarding some important differences in the use of academic ranks between countries. In Denmark and Norway, only few scholars were granted the professorial title, although it has become more

frequent in recent years. In Germany, only scholars with a habilitation could until very recently become professors. Since the early 2000s, equivalents such as lead positions of junior research groups or assistant professor programmes may be accepted by university institutions. Yet, in Germany only the professorial rank allows supervising PhD students and forming a new generation of archaeologists, whereas in Denmark and Norway it only requires the supervisor to hold a PhD.

## The academic environment in Denmark

Danish archaeology seen from a female perspective is often described as a field where women entered late and had to try extra hard to be accepted as professionals (Balsgaard Juul 2024, 87; Bender Jørgensen 1998, 214; Sauer 2023). Prehistoric archaeology became an academic field at the University of Copenhagen from 1855 to 1866 and again from 1930 onward, and at the University of Aarhus in 1950 (Klindt-Jensen 1975). When Berit enrolled as a student at Aarhus University in 1978, 21 men and ten women had previously earned their MA degrees in prehistoric archaeology (Bender Jørgensen 1998, 226).

In 1962, Karen Frifelt became the first woman to receive a research fellowship at the department of prehistoric archaeology at Aarhus University, followed by Else Roesdahl in 1970. The research fellowships allowed them to conduct their own research into the Arabian Gulf and Viking Age Scandinavia, respectively. Both held a non-tenured teaching position from 1968/69 and 1970, respectively, whereas all tenured positions belonged to male colleagues (Bender Jørgensen 1998). This began to change in the 1980s when more women, including Berit who finished her master's degree in prehistoric archaeology in 1984, were granted research fellowships, senior research fellowships and non-tenured teaching positions, although all tenured positions still belonged to male colleagues (Bender Jørgensen 1998, 229). In 1989, Berit was the first woman to become a PhD in archaeology from Aarhus University. Else Roesdahl became the first female professor of Medieval archaeology in Denmark in 1996 and Helle Vandkilde the first female professor of prehistoric archaeology in 2004. Both are affiliated to the University of Aarhus (Balsgaard Juul 2025, xxii). In 2023, the University of Copenhagen appointed Eva Andersson Strand as their first female professor of archaeology (Mannering *et al.* 2024). The proportion of women in research today are comparable to the EU mean, but below the mean for tenured staff. The number of female professors (all disciplines and institutions) is increasing, from 16% in 2011 to 24% in 2020 (Uddannelses- og Forskningsstyrelsen 2022).

Berit (Fig. 1) held several non-tenured lecturer positions at Aarhus University during the 1990s and 2000s, where she educated generations of new archaeologists. From 1992–1995 Berit was assistant professor (adjunct)

1 We will – against the usual standard – refer to Berit Valentin Eriksen by her first name, as this is the name we would respectfully refer to her as our 'big sister'.



Figure 1: Berit through her 'ages' - A: At a tour in Norway in September 1979 (photo: Jytte Nielsen); B: in 1984 at a party at Moesgård with Bodil Holm Sørensen (photo: Charlotte Damm); C: in 1998 (photo: Torsten Madsen); D: A happy, flint-collecting Berit at Lejre in 2006 (photo: Ole Malling, Sagnlandet Lejre).

followed by a postdoc at Thisted Museum. From 1997–2002 she functioned as associate professor (lector) at Aarhus University, while conducting her second postdoc in a collaboration with Thisted Museum and Ferskvandsmuseet. From 2002–2004 Berit was academic project manager at Moesgaard Museum and between 2004–2007 she was senior researcher there. She was also an associate professor at Aarhus University from 2007–2008. Berit was an inspiring and supporting but also demanding lecturer and mentor that left an enduring impression on the students, even after she started working in Germany in 2009. Berit continues to be a significant and strong pioneer in early Stone Age archaeology in Denmark and archaeologists at Danish museums and universities continue to benefit from Berit's support and assistance – whether they are launching new research projects, preparing seminars or struggling with strange flint tools at excavations. Berit may have realized the value of informal support for young scholars during her own years as young scholar when she was a key member of an all-female thesis writing group in Aarhus in 1986–1989. Although this sisterhood wrote on completely different topics and periods, they supported each other through reading drafts, helping with writer's blocks and discussing progress.

### **The academic environment in Germany**

Individual women were active in archaeology in the different German and/or German speaking states from the late 18<sup>th</sup> century (Gutsmiedl-Schümann *et al.* 2023; Koch 2023), but it took more than a century for women to even acquire regular access to the academic environment (Bräuning 2009). The general permission for women to enrol into universities and to complete dissertations in the German empire ranged from 1895 in the Grand Duchy of Baden to 1908 in the Kingdom of Prussia (Gutsmiedl-Schümann *et al.* 2023). Previously, women could only ask for individual professors' permission to attend university lectures (Fries and Gutsmiedl-Schümann 2013). Nonetheless, the first woman being awarded a professor title in archaeology was Johanna Mestorf in 1899. Yet, the title was merely honorary and did not include permission to teach and it took until 1909 when she also received an honorary doctorate from the medical faculty of Kiel University (Koch and Mertens 2002). She worked as a custodian at the Museum for patrimonial antiquities at Kiel University (then Prussia). A position she had qualified for by her extensive translations of Scandinavian literature and seminars with Amalie Buchheim, the first woman with a paid position in archaeology as custodian in Schwerin since 1835 (Gutsmiedl-Schümann *et al.* 2023). This connection indicates that already then sisterhood played a relevant role in archaeology as a profession. Between 1906 and 1912 five women graduated with a PhD in classic archaeology from Bonn University with Elvira Fölzer being the first in 1906, followed by Margarete

Bieber in 1907 (Gutsmiedl-Schümann *et al.* 2023). In fact, all women who graduated in archaeology before World War I, had Georg Loeschke at Bonn University as supervisor (Fries and Gutsmiedl-Schümann 2013). Leonard Franz in the Austrian empire (Prague, Bohemian Kingdom, and Innsbruck, county of Tyrol) and Gustav Eichhorn at Jena University probably also encouraged female students (Gutsmiedl-Schümann *et al.* 2023), which demonstrates that women still required strong male supporters to achieve an academic degree.

The Weimar Republic gave women more equal rights in 1919, including the right to qualify for habilitation in 1920 (Bösl and Gutsmiedl-Schümann 2024). Considering the relevance of habilitations in German academia, the previous denial has effectively restricted women from an entire academic career until 1920. Margarete Bieber received the permission to habilitate at the University of Gießen in 1919 (Gutsmiedl-Schümann *et al.* 2023). In 1923, she became the director of the Institute of classical studies, but when she was appointed to a full professor chair in 1932, the political climate in Germany had changed and she was disbanded from the academic service due to her “political unreliability” and Jewish ancestry (Bösl and Gutsmiedl-Schümann 2024). She migrated to London in 1934 and, later, further to New York, where she received an associate professor position (Bonfante 1979).

Several professors had been teaching prehistory since the late 19<sup>th</sup> and early 20<sup>th</sup> century as scholars in other disciplines, such as (but not restricted to) geology, art history, and anthropology (*e.g.* Schäfer 2013; Strobel 2010). As the establishment of prehistory as an academic discipline at German universities closely related to the increasing nationalism, numerous institutes were founded during the 1930s (Gramsch 2007). At least a dozen women graduated with a PhD in prehistory between the late 1920s and the end of World War II from at least seven different universities. The first was Hildegard Knack in 1928 at Jena University, who was a student of the above-mentioned Gustav Eichhorn (Gutsmiedl-Schümann *et al.* 2023). Although ideologically unwanted in the beginning, these women were increasingly needed with men being conscripted to war. After World War II, the number of female PhD graduates in western Germany remained on a similar level as before with still only few male supporters such as Herbert Kühn (then Mainz University). Despite the generally stronger rights for women in eastern Germany, academic careers there appeared reserved for men (Gutsmiedl-Schümann *et al.* 2023; cf. Struwe 1998).

The first habilitations by women in prehistory date to shortly after World War II with three women (Clara Redlich in 1946, Gisela Freund and Elisabeth F. Schmid in 1949) in western Germany and one in eastern Germany (Waltraut Schrickel in 1952; Bräuning 2009). These women were partially ignored for positions shortly after their habilitation

in a period of male restoration, perhaps sparking the strong queen bee syndrome in German prehistory. But they eventually gained professorial positions in the late 1960s to early 1970s. At this time, the first professorial generation of prehistory retired, and new positions were established at several newly founded universities in western Germany. Apparently, this increased availability of positions eventually allowed individual women to be appointed or at least to be promoted to higher ranks. Waltraut Schrickel received an associate professor position in 1967 in Heidelberg and Clara Redlich also became associate professor in 1968 at Free University of Berlin. Palaeolithic archaeologist Gisela Freund was appointed to the chair in Hamburg but decided to become the first female ordinaria in prehistory at Erlangen in 1969. Elisabeth Schmid became the first ordinaria of Switzerland in Basel in 1972. Frauke Stein, who had finished her habilitation in 1969, received an associated professor position in 1973 at the institute in Saarbrücken. In eastern Germany, Edith Hoffmann became ordinaria shortly after her habilitation ('Promotion B') in prehistory at Leipzig University in 1979.

Women's studies and feminist approaches were introduced to German prehistory in the late 1980s and prompted by a symposium on "Feminism and archaeology" at the University of Tübingen in 1991. This meeting led to the founding of FemArc, a network for women working in archaeology that organises meetings and a publication series focused on gender related topics from all fields of archaeology (Dommasnes and Montón-Subías 2012; Mertens and Koch 2005) – so, a formal sisterhood. Also in 1991, Renate Rolle received a chair of prehistory at Hamburg University, making her along with Sabine Rieckhoff (1993, Leipzig) and Sabine Gerloff (1995, Erlangen) an increasingly collaborating generation following on the late 1960s/70s professors (Bräuning 2009; Gutschmiedl-Schumann *et al.* 2023).

In 2006, the number of habilitated women in archaeology ranged around 20% with a slightly increasing tendency and there were already six female professors for prehistory at German universities (Bräuning 2009) as well as some habilitated female lecturers. The numbers of both habilitated women and female professors have further grown in the last decades. In 2024, 29% of all professors (all disciplines and institutions) in Germany were women (Statistisches Bundesamt 2025). The total number of positions has however also increased in the same period with funding from the European Research Council and excellence initiatives of the German government obscuring that the "proverbial glass ceiling was and is still substantial" (Gutschmiedl-Schumann *et al.* 2023, 301).

As a fresh graduate interested in the Palaeolithic, Berit tried to connect with Gisela Freund but this pioneer was no trailblazer for other women in archaeology. Instead Berit decided for Hansjürgen Müller-Beck and the forager

archaeology department at the University of Tübingen where she was introduced to the German academic system when she first visited on a DAAD stipend during her research for the PhD between 1984–89. She arrived at a pivotal moment when women started to build supportive networks or sisterhoods in German archaeology, with Tübingen being a centre of this movement. Barbara Scholkmann was appointed honorary professor in 1988 and received the chair for Medieval archaeology in 1994 at a then merged prehistory department. During Berit's second research stay 1990–92 on an Alexander von Humboldt postdoctoral stipend, the "Feminism and archaeology" symposium was held there and although she was not aware of it at the time, the generally constructive feminist environment in Tübingen of that time also affected her and the group of women around her in Tübingen. Surprisingly, the first woman to habilitate in prehistory at Tübingen University was Linda Owen as late as 2004, followed by Miriam Haidle in 2006, Katerina Harvati in 2008 and Berit herself in 2010. At this time, Berit had been appointed head of research at the German Centre for Baltic and Scandinavian Archaeology (ZBSA) at Schloss Gottorf in Schleswig and now needed the habilitation to supervise PhD students in Germany. She transferred the habilitation to Kiel University only a year later to attract students through her regular courses at Schloss Gottorf. As in Denmark, Berit is known among the students as a knowledgeable and strict, but also fair teacher. With access to Late Palaeolithic and Mesolithic lithic material and funding opportunities from collaborations with other institutions, she built up a corresponding research group. Several researchers who passed through Schleswig during these years consider Berit as their mentor.

### **The academic environment in Norway**

For the better part of the 20<sup>th</sup> century the archaeological community in Norway was small, yet women made an impact at an early stage both at archaeological museums and in education. In 1933, Eva Fett was the first woman to graduate as a Magister in archaeology, after which she worked as a researcher at the Bergen University Museum. In 1946, Charlotte Blindheim was employed as curator at the Historical Museum in Oslo and several women were employed at the university museums from the 1940s onwards, including Elizabeth Skjelsvik, Wencke Slomann, Irmelin Martens and Gerd Stamsø Munch. In 1964, Eldrid Straume was the first woman to become lecturer in archaeology at Oslo University, soon to be followed by Gro Mandt at Bergen University in 1971 (Næss 2007). Numerous other women made a significant impact from the early 1970s, Jenny Rita Næss, Else Johansen Kleppe, Grete Lillehammer, Liv Helga Dommasnes and Anne Stalsberg to mention a few. Already in 1975, 38% of the Norwegian archaeologists were in fact women, and by 1985 the number had increased to 47% (Myrvoll 1985, 52; Næss 1985, 7).



Figure 2: Berit as a proud supervisor with some of her PhD students – A: Together with Katja Winkler shortly after her defence 14<sup>th</sup> June 2018, in the background is Tobias Reuter, another PhD student of Berit (photo: Sonja B. Grimm); B: With Sascha Krüger shortly after his defence 14<sup>th</sup> May 2020 (photo: Selina Schnetger).

While there were many women in Norwegian archaeology from early on, the number in influential positions was initially minimal (Næss 1985; 2007). This combination was perhaps one of the reasons why Norway was one of the first European countries to focus on gender-biased interpretations as well as gender-inequality in the discipline. The first research seminar in 1979 on the topic “Were they all men?” was however met with ridicule and dismissal (Næss 1985). In 1985, Næss, Mandt, Dommasnes, and Kleppe Johansen were instrumental in establishing KAN - Kvinner i Arkeologi i Norge (women in archaeology in Norway). The forum published a journal regularly until 2005 and although the forum’s explicit feminist perspective was certainly not endorsed by all, it helped increase the focus on gender inequality at archaeological workplaces. This background probably made Norwegian archaeologists also a driving force in the establishment of a community on Archaeology and Gender (AGE) within the European Association of Archaeologists in 2008 (Dommasnes and Montón-Subías 2012). The Norwegian policy to increase the number of women in top positions in academia also gradually bore fruit and the late 1980s and early 1990s saw a veritable flood of appointments of female professors in archaeology across universities. In Bergen Randi Håland (1988), Bergljot Solberg (1989), Ingvild Øye (1994), Gro Mandt (1995); in Tromsø Ericka Engelstad (1991); and in Oslo Eldrid Straume (1990), Lotte Hedeager (1996). Some were appointed to formal ‘chairs’, while others received personal promotions. In 2025, 38% of all professors (all disciplines and institutions) in Norway were women (Tønnesen 2025). This means that students in archaeology for more than three decades have had numerous female role models and supervisors, and

that gender equity has been openly discussed, even if not always resolved.

The field in lithic technology was for a long time dominated by men, but women were prominent from early on in Norway (Skar and Coulson 1986; 1987). At the University of Oslo, Sheila Coulson introduced her students to this topic in the period 1985–2018, influencing several generations of students. In the same period, the majority of archaeology students were women, and many were recruited as field staff to a large number of Stone Age excavations, including Coulson’s own investigations. This motivated several of these women to pursue an academic career, which meant that when Berit took up an offered professor II-position in Bergen in 2014–17 she was met by a large group of scholars committed to her favourite research topic. Berit maintains a strong connection to the Norwegian archaeological environments and her edited volume *Flintstudier* (Eriksen 2000), and in particular her own chapters in that book, are still today on the reading list at most Norwegian universities.

### A pioneering academic influencer

Academic influence is traditionally measured in professional rank, number of supervised students and dissertations, number of publications and citations and external funding, whereas academic activities such as reviews or commission work are indistinct values. As demonstrated above, women have historically been structurally hindered in reaching the full professorial rank and, thus, in ‘traditionally’ influencing coming generations of archaeologists. The definition of academic influence is however gradually changing in some systems that now also consider, for instance, the involvement in public outreach

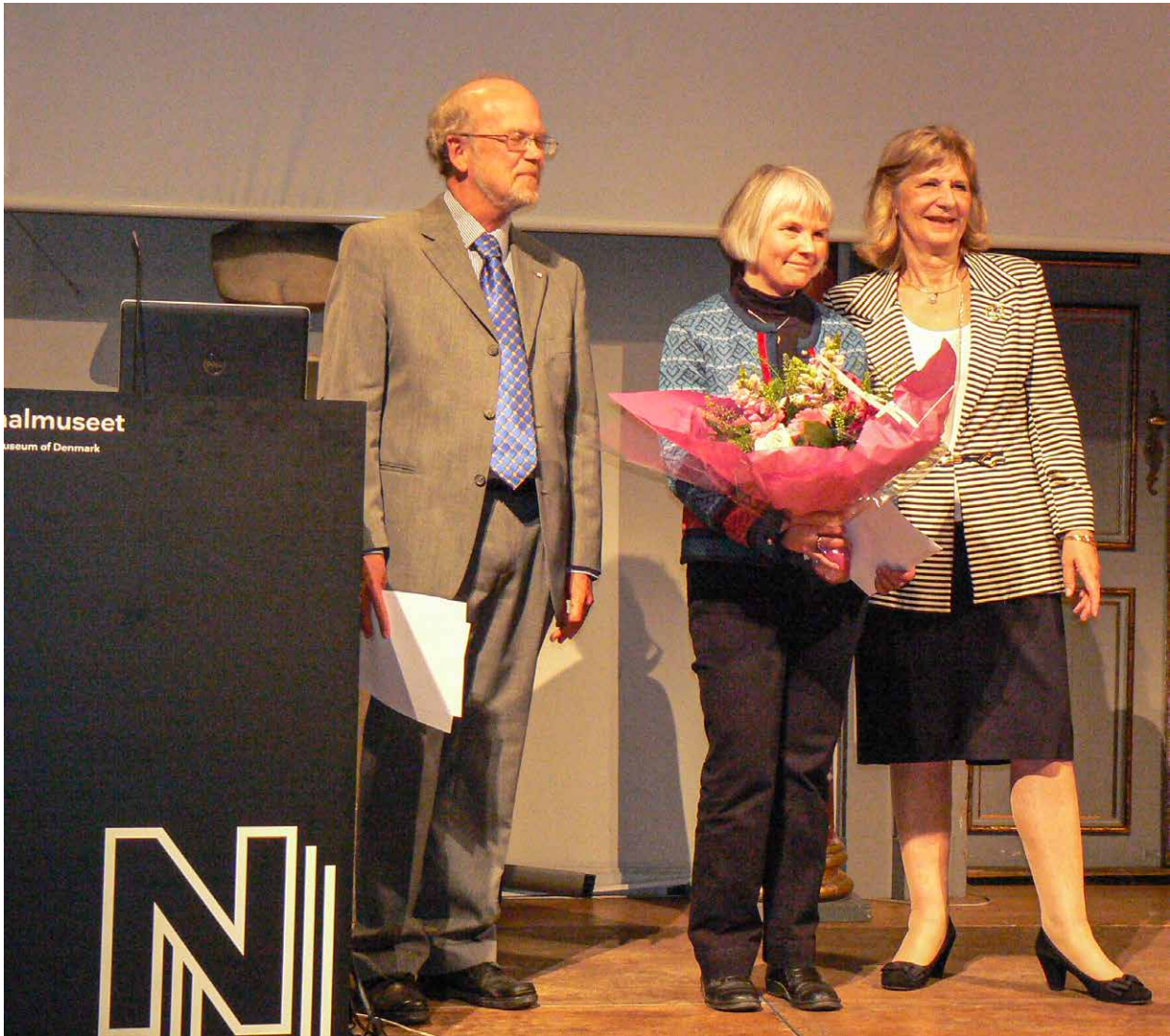


Figure 3: On 9<sup>th</sup> May 2014 Berit received the prestigious Westerby price of the Danish National Museum in Copenhagen presented by Susse Westerby and Kristian Madsen. She has been awarded this prize for her commitment to research about Ice Age people in Denmark and Schleswig-Holstein (photo: Sonja B. Grimm).

as measured in public lectures, public publications or broadcasting. We propose that sisterhood also plays an important role in affecting academic influence today, and probably always has considering how Johanna Mestorf followed seminars with Amalie Buchheim. Here we use Berit as an example to review how sisterhood and other types of influences have left marks on the discipline for those willing to see it.

### **An invisible hand of mentorship**

The probably most influential relationship in academic environments is the connection of mentor to mentee. In the above-mentioned traditional list, this is measured by the number of graduates and PhD students. Berit has been

the chair or member of PhD Committees at the universities of Aarhus, Copenhagen, Göttingen, Kiel, Mainz, Oslo and Stockholm and has been a main supervisor of at least eight master and eleven PhD scholars during her ZBSA time (Fig. 2). Two of her former doctoral students are now employed at Danish museums: Daniel Groß, Research Coordinator at Museum Lolland-Falster, and Sascha Krüger, in pollen analysis and environmental archaeology at the National Museum of Denmark (both editors of this volume). Another two PhD scholars (Moiken Hinrichs and Tobias Reuter) hold positions at the Archaeological State Office Schleswig-Holstein. A substantial part of Berit's mentoring work has, however, been more subtle, starting from her thesis writing sisterhood in Aarhus. In those days supervisor support

was significantly less intensive, already showing Berit, in her early formative years, the significance of (informal) support for young scholars. Something which was likely further settled during her research stays at the University of Tübingen in 1984–89 and again in 1990–92.

Berit has contributed to Stone Age archaeology, particularly lithic technology and its social dimensions for decades and is in particular known for her strong but invisible hand of mentorship, providing discrete support of students and junior researchers. Following through from her early career at Aarhus University to her later career at the ZBSA, Berit has made sure to employ master students and PhD students for all her research projects,<sup>2</sup> and many more have benefited from her strong encouragement to form networks and take on their own research projects to investigate new perspectives on the past. Another demonstration of Berit's invisible hand of mentorship are the numerous scientific advisory boards across northwestern Europe where she influenced the research agenda as well as the researchers. She also had an influence on the lived experience of junior researchers as a serving member of executive boards where she fought for their right to have a voice and actively supported their career prospects.

Berit is a well-known and respected lecturer and researcher, owing to her many years of teaching at universities in Aarhus, Kiel and Bergen and her position as head of research at the ZBSA. This was officially acknowledged by the Danish archaeological community in 2014 when she received the esteemed Westerby award for her research into the Early Stone Age and the people who settled Denmark and Schleswig-Holstein (Fig. 3). Danish archaeology has benefitted greatly from her contributions, particularly through collaborative projects and scholarly research. Notable examples include Helene Agerskov Rose's doctoral project, conducted under the umbrella of "CRC 1266: Scales of Transformation – Human–Environmental Interaction in Prehistoric and Archaic Societies"; ongoing collaborations with Morten Fischer Mortensen from the National Museum of Denmark on, for instance, Palaeolithic reindeer antler tools; and a project investigating kettle holes from the Late Palaeolithic. In this context, former doctoral candidate at the University of Kiel, Erica Corradini, together with Berit, Morten Fischer Mortensen, Martin Krog Nielsen, and others, examined a hunting site dated to the Bromme Culture (c. 11000–10500 BCE), located near a kettle hole at Tyrsted near Horsens (see also Corradini *et al.* this volume).

## Networks & edited volumes

Besides the informal mentoring networks, Berit also worked towards the establishment of more formalised networks

over years at different scales and levels (Fig. 4). For instance, from 2009, Berit has been a central member of the working group for The Nordic Blade Technology Network (NBTN). The network gathered an international group of Stone Age researchers from the Nordic countries, Germany and Russia and organized a series of workshops in 2009, financed by the Nordic Council of Ministers. The topic of the workshops was the Early Holocene pioneer settlements of Scandinavia, and the approach was to conduct joint visits to key sites from this period and together discuss the lithic assemblages and their interpretation (Apel *et al.* 2018; cf. Sørensen *et al.* 2013).

Following a similar approach, this was followed up by a research/doctoral network led by Kjell Knutsson, Uppsala University, and with Berit as one of the teachers/senior researchers in 2012–2014. Financed by STINT (the Swedish Foundation for International Cooperation in Research and Higher Education), the network gathered a group of c. 20 people, including doctoral fellows and central researchers in the field of lithic technology from the Nordic countries, Germany, Poland, Lithuania, Russia and Belarus. The results of the network workshops have had a great influence on the Stone Age research in this region of Europe, still making its mark, especially regarding theoretical and methodological approaches.

Much of this regionally more focused group could rely on Berit's large network formed by her activities in the UISPP (International Union of Prehistoric and Protohistoric Sciences), where she belonged to the founders of a commission on the "Final Palaeolithic of the Great European Plain" that later was re-named into "The Final Palaeolithic of Northern Eurasia" (Fig. 5). She first served as secretary (1998–2009) and then as president (2009–18) of this commission, handing over to an all-female board in 2018. She also served as a national member for Denmark in the UISPP council from 2006–10 and then received a member position in the Executive Board of the UISPP from 2010–18.

Before these large prehistory networks, Berit had already built a considerable network in the Quaternary sciences by participating in commissions and working groups of the INQUA (International Union for Quaternary Research) during the 1990s. This background clearly continues helping her in her interdisciplinary projects, for instance, within the cluster of excellence "ROOTS" and her on-going research in the German North Sea with the geophysical department of Kiel University. The latter arose especially from her project within the collaborative research centre 1266 "Scales of Transformation", where geophysicist Stine Detjens wrote her PhD thesis. In the same project, Berit shared the PI position with Mara-Julia Weber after a first 4-years period and through the 8 years of the project, she engaged Sonja B. Grimm as a postdoc giving the Late Palaeolithic research a strong female impression.

<sup>2</sup> <https://www.sfb1266.uni-kiel.de/en/news/activities#Eriksen>.



Figure 4: In the late 1970s a very young Berit was confronted with a very masculine culture at excavations in Denmark that had an emphasis on being able to move heavy wheelbarrows and relish beer drinking at breaks. Finding her (not) place in this culture, Berit used opportunities to work abroad which helped building her international experience and ramified networks. A: Berit with Siri Myrvoll in 1979 at a Medieval excavation in Skien, Norway (photo: Jytte Nielsen). B: Berit and Bodil Bratlund excavating at the Mesolithic site Duvensee, Germany, in 1984 (photo: unknown; provided by Bodil Holm Sørensen).



Figure 5: Group picture of participants of the annual meeting of the UISPP commission “The Final Palaeolithic of Northern Eurasia” during the excursion to the famous Bromme site on 28<sup>th</sup> June 2024. From left, front row: Mikkel Sørensen, Berit, Sonja B. Grimm, Jessie Van Cauter; second row: Tomas Rimkus, Tor Arne Waraas, Kristina Jennbert, Iwona Sobkowiak-Tabaka, Inger Marie Berg-Hansen, Kristoffer Buck Pedersen (photo: Bart Vanmontfort).

Berit’s strong standing in the research community may also result from the 12 books (and still counting) she has (co-)edited since 1996 together with 14 different co-editors of which some repeatedly worked with her. Many of the books are proceedings of conference sessions and meetings resulting from Berit’s large research network but also further expanding it. Furthermore, from 2010–17 she was part of the editorial board of *Quartär* that published 6 volumes during this time. *Quartär* is the international yearbook for Ice Age and Stone Age research that is funded by the Hugo Obermaier Society that was cofounded by Gisela Freund. A dedicated peer reviewer herself, Berit took mostly care of the book reviews, helping to make otherwise expensive publications available to often young colleagues who in addition could also get their first publication experience. Again, this also reflects Berit’s intention to mentor and support younger scholars into an archaeological career.

### Concluding remarks

Through her impressive career Berit Valentin Eriksen has contributed immensely to Danish, German and Norwegian archaeology. Her academic contributions can be measured through her research work. It is, however, perhaps the more subtle contributions of Berit that we value the most, although these are more difficult to measure. We have all been pushed by Berit in a productive way. We have all been encouraged and granted assistance when needed. Her approach is continuous and unselfish, meaning that she has been supportive beyond the formal mentoring period and that her effort has not necessarily produced a lot of extra references for her. Yet, as the big sister of an

informal sisterhood of archaeology, her impact is perhaps also to some degree informal yet incredibly strong. She has been teaching us all to bring the sisterhood of archaeology forward as a literal give and take. To be kind, demanding, and supportive at the same time. But also, to bring as many women as possible beneath the metaphorical glass ceiling to take it down with joint forces. During her academic lifetime, also through her and the example she set, the previously (and occasionally still) prevailing queen bee syndrome in German female academia is gradually replaced by a cooperative spirit – the sisterhood.

A sisterhood is not exclusive; it supports people independent of their sex/gender as exemplified by Berit. But being aware of the still existing inequality of women in academia and archaeology, in particular, specific support of women over men remains necessary to make a change. Doris Gutmiedl-Schumann and her colleagues recently stated: “Women’s contributions to German archaeology have often remained in the shadows despite the wide variety of tasks women performed and the diverse fields in which they were active” (Gutmiedl-Schumann *et al.* 2023, 283). Probably, we can widen this statement to also encompass Denmark and Norway to some degree, but with different timings of when these contributions were taken from the shadows and into the (spot)light.

It is crucial for young scholars to have strong role models, and it is in particular important for young female scholars to have strong female role models in academia. Seeing how others have succeeded with their career goals is inspiring. Berit is a private person and does not request the spotlight, but she plays an important role in archaeology today as a role

model. She understands that the only constant is change, that constructive feedback is an invitation to improve and, hence, she continues working on herself to become an even better researcher, teacher and mentor. She is our original pioneering academic influencer demonstrating that it is possible to reach further as part of a sisterhood. Without the influential scholarship of Berit, archaeology as a discipline in Denmark, Norway and Germany would lack much of its present intellectual depth, openness, and methodological integrity. We argue that sisterhood – both historical and contemporary –

remains a key driver of disciplinary transformation and inclusivity in archaeology, as exemplified here by Berit's career and her influence as a mentor.

## Acknowledgements

We thank all the supportive colleagues a lot who made photos of Berit available to us of which we could only show a small selection here. Furthermore, we are very grateful to two anonymous reviewers for their valuable suggestions to improve our text.

## References

- AktArcha: <https://aktarcha.hypotheses.org>
- Apel, J., Glørstad, H., Knutsson, H. and Knutsson, K. 2018. The Early Settlement of Northern Europe: Technology and Communication. In: Knutsson, K., Knutsson, H., Apel, J. and Glørstad, H. (eds.), *Technology of Early Settlement in Northern Europe - Transmission of Knowledge and Culture* (Volume 2). Sheffield, Equinox Publishing, 63–98. <https://api.equinoxpub.com/books/2304>
- ArqueologAs: <https://www.arqueologas.es>
- Balsgaard Juul, K. 2024. Hvor er Arkæologiens Glemte Mødre? *Horsens Historier* 4, 85–95.
- Balsgaard Juul, K. 2025. Helle Vandkilde – A groundbreaking pioneer in Danish archaeology. In: Nørgaard, H. W. and Reiter, S. S. (eds.), *Bronzization. Essays in Bronze Age Archaeology*. Bicester, Archaeopress Publishing, xxii–xxvi.
- Bender Jørgensen, L. 1998. The State of Denmark. Lis Jacobsen and other women in and around archaeology. In: Díaz-Andreu, M. and Stig Sørensen, M. L. (eds.), *Excavating Women. A history of women in European archaeology*. London, Routledge, 214–234.
- Bonfante, L. 1979. Margarete Bieber. *Gnomon* 51(6), 621–624. <http://www.jstor.org/stable/27687337>
- Bösl, E. and Gutmiedl-Schümann, D. 2024. Breaking Ground: Women's roles in German archaeology since the Nineteenth Century. *Bulletin of the History of Archaeology* 34(1), 6. DOI:10.5334/bha-680
- Brauning, A. 2009. Wider das Vergessen. Professorinnen in der Archäologie (Vor- und Frühgeschichte). In: Bagley, J. M., Ettl, C., Neumann, D. and Schefzik, M. (eds.), *Alpen, Kult und Eisenzeit. Festschrift für Aimei Lang zum 65. Geburtstag*. Rahden/Westf., Verlag Marie Leidorf GmbH, 3–24.
- Classen, C. (ed.) 1992. *Exploring gender through archaeology. Selected papers from the 1991 Boone Conference*. Madison, Prehistory Press.
- Coltofean-Arizancu, L., Gaydarska, B. and Matic, U. (eds.) 2021. *Gender stereotypes in archaeology. A short reflection in image and text*. Leiden, SidestonePress. <https://www.sidestone.com/books/gender-stereotypes-in-archaeology>
- Conkey, M. W. and Spector, J. D. 1984. Archaeology and the study of gender. In: Schiffer, M. B. (ed.), *Advances in Archaeological Method and Theory, Volume 7*. San Diego, Academic Press, 1–38. DOI:10.1016/B978-0-12-003107-8.50006-2
- CRC 1266: <https://www.sfb1266.uni-kiel.de/en/news/activities#Eriksen> (CRC 1266 – Scales of Transformation website from December 13, 2021)
- Díaz-Andreu, M. 2025. The Matilda effect in archaeology. Recovering women for the history of the discipline. In: Moen, M. and Pedersen, U. (eds.), *Routledge Handbook of Gender Archaeology*. Milton Park and New York, Routledge, 126–145. DOI:10.4324/9781003257530-12
- Dill, B. T. 1983. Race, class and gender: Prospects for an all-inclusive sisterhood. *Feminist Studies* 9(1), 131–150.
- Dommasnes, L. H. and Montón-Subías, S. 2012. European Gender Archaeologies in Historical Perspective. *European Journal of Archaeology* 15(3), 367391. DOI:10.1179/1461957112Y.0000000016
- Fries, J. E. and Gutmiedl-Schümann, D. 2013. Pionierinnen der Archäologie - warum, woher und wohin. In: Fries, J. E. and Gutmiedl-Schümann, D. (eds.), *Ausgräberinnen, Forscherinnen, Pionierinnen. Ausgewählte Porträts früher Archäologinnen im Kontext ihrer Zeit*. Münster, Waxmann, 15–28.
- Gero, J. M. 1983. Gender bias in archaeology: A cross-cultural perspective. In: Gero, J. M., Lacey, D. M. and Blakey, M. L. (eds.), *The Socio-Politics of Archaeology*. Research Report 23. Amherst, University of Massachusetts, 51–57.
- Gero, J. M. and Conkey, M. W. (eds.) 1991. *Engendering archaeology: Women and prehistory*. Oxford, Blackwell.
- Gramsch, A. 2007. Ein Abriss der Geschichte der Prähistorischen Archäologie in Deutschland: Genese, Entwicklung und Institutionalisierung. *Das Altertum* 52, 275–304.
- Gutmiedl-Schümann, D., Koch, J. K. and Bösl, E. 2023. Women's contributions to archaeology in Germany since the Nineteenth Century. In

- López Varela, S. L. (ed.), *Women in Archaeology: Intersectionalities in Practice Worldwide*. Cham, Springer International Publishing, 283–307. DOI: 10.1007/978-3-031-27650-7\_14
- Hooks, B. 1986. Sisterhood: Political solidarity between women. *Feminist Review* 23, 125–138. DOI: 10.2307/1394725
- Koch, J. K. and Kierleis, W. (eds.) 2019. *Gender transformations in Prehistoric and Archaic societies*. Scales of transformation 6. Leiden, Sidestone Press. DOI: 10.59641/g9023js
- Koch, J. K. and Mertens, E.-M. (eds.) 2002. *Eine Dame zwischen 500 Herren. Johanna Mestorf, Werk und Wirkung*. Internationales Symposium der Christian-Albrechts-Universität Kiel vom 15. bis 17. April 1999 in Bad Bramstedt. Münster, Waxmann.
- Krocak, H., Szczepaniak, C., Cybort-Zioło, N., Makowska, A., Adamska-Kijko, M., Bochno, E. and Czerepaniak-Walczak, M. 2025. Sisterhood in Academia. Understanding and experiencing women's collaboration in the Social Sciences. *Educational Studies Review* 50, 9–25. DOI: 10.12775/PBE.2025.013
- KvinArk: <https://www.katrinebalsgaardjuul.com/kvinark>
- López Varela, S. L. 2023 (ed.). *Women in Archaeology: Intersectionalities in Practice Worldwide*. Cham, Springer International Publishing. <https://link.springer.com/book/10.1007/978-3-031-27650-7>
- Mannering, U., Nosch, M.-L. and Drewsen, A. 2024 (eds.), *The Common Thread. Collected Essays in Honour of Eva Andersson Strand*. Turnhout, Brepols Publishers. <https://www.brepolsonline.net/action/showBook?doi=10.1484%2FM.NAAEB.5.138139>
- Matić, U., Gaydarska, B., Coltofean, L. and Díaz-Guardamino, M. 2024 (eds.), *Gender trouble and current archaeological debates*. Cham, Springer. DOI: 10.1007/978-3-031-68157-8
- Mertens, E.-M. and Koch, J. K. 2005. Jenseits von „weiblichen Kammern und Särgen“. Entwicklung der archäologischen Geschlechterforschung in Deutschland. In: Fries, J. E. and Koch, J. K. (eds.), *Ausgegraben zwischen Materialclustern und Zeitscheiben. Perspektiven zur archäologischen Geschlechterforschung*. Bericht 1. Sitzung AG Geschlechterforschung, Ingolstadt 2003. Münster, Waxmann, 25–54.
- Mitra, D. 2023. Sisterhood Is X: On feminist solidarity then and now. *South Atlantic Quarterly* 122(3), 431–452. DOI: 10.1215/00382876-10643959
- Moen, M. and Pedersen, U. 2025 (eds.), *The Routledge handbook of gender archaeology*. Milton Park and New York, Routledge.
- Morgan, R. (ed.) 1970. *Sisterhood is powerful. An anthology of writings from the women's liberation movement*. Random House, New York.
- Myrvoll, S. 1985. Forskningspolitiske implikasjoner – strategier og handlingsprogram. *KAN Kvinner i arkeologi i Norge*, 1. Universitetet i Bergen, 52–58.
- Næss, J.-R. 1985. Tenkegruppens bakgrunn og perspektiv. *KAN Kvinner i arkeologi i Norge*, 1. Universitetet i Bergen, 6–15.
- Næss, J.-R. 2007. Prolog. Kvinne – arkeolog – kvinnearkeolog gjennom 45 år. Om og til Gro. In: Barndon, R., Innselset, S.M., Kristoffersen, K.K. and Lødøen, T.K. (eds.), *Samfunn, symboler og identitet. Festschrift til Gro Mandt på 70-årsdagen*. UBAS 3. Bergen, University of Bergen, 15–25.
- Paye ta truelle: <https://payetatruelle.wixsite.com>
- Rodak, L. 2020. Sisterhood and the 4th wave of feminism: An analysis of circles of women in Poland. *Oñati Socio-Legal Series* 10(1S), 116–134. DOI: 10.35295/osls.iisl/0000-0000-0000-1163
- Rossiter, M. W. 1993. The Matthew Matilda effect in science. *Social Studies of Science* 23(2), 325–341. DOI: 10.1177/030631293023002004
- Sauer, N. 2023. Kvindefald i den danske arkæologiske forskningsverden. *Arkæologisk Forum* 49, 22–38.
- Schäfer, M. 2013. Geschichte des Instituts für Ur- und Frühgeschichte an der Universität zu Köln 1925-1945. In Kunow, J., Otten, T. and Bemann, J. (eds.), *Archäologie und Bodendenkmalpflege in der Rheinprovinz 1920-1945*. Tagung im Forum Vogelsang, Schleiden, 14.-16. Mai 2012. LVR-Amt für Bodendenkmalpflege im Rheinland (Treis-Karden), 315–330.
- Skar, B. and Coulson, S. D. 1987. The Early Mesolithic Site of Rørmyr II. A reexamination of one of the Høgnipen Sites, SE Norway. *Acta Archaeologica* 56, 167–183.
- Skar, B. and Coulson, S. D. 1986. Evidence of Behaviour from Refitting - A Case Study. *Norwegian Archaeological Review* 9(2), 90–102.
- Sørensen, M., Rankama, T., Kankaanpää, J., Knutsson, K., Knutsson, H., Melvolve, S., Eriksen, B. V. and Glørstad, H. 2013. The first eastern migrations of people and knowledge into Scandinavia: Evidence from studies of Mesolithic technology, 9th-8th Millennium BC. *Norwegian Archaeological Review* 46(1), 19–56. DOI: 10.1080/00293652.2013.770416
- Statistisches Bundesamt 2025. Statistik des Hochschulpersonals. Berichtsjahr 2024. GENESIS-Online. Available at: <https://www-genesis.destatis.de/datenbank/online/statistic/21341/table/21341-0001/search/s/SG9jaHNjaHVscGVyc29uYWw=> (published: 02/10/2025).
- Strobel, M. 2010. Das Urgeschichtliche Institut der Universität Tübingen zwischen 1933 und 1945. In: Wiesing, U., Brintzinger, K.-R., Grün, B., Junginger, H. and Michl, S. (eds.), *Die Universität Tübingen im Nationalsozialismus*. Stuttgart, Franz Steiner Verlag, 321–349.

Struwe, R. 1998. When the wall came down. East German women employed in archaeology before and after 1989. In: Diaz-Andreu, M. and Sørensen, M. L. S. (eds.), *Excavating women. A history of women in European archaeology* London, and New York, Routledge, 146–154.

Tønnesen, E. 2025. Det blir flere kvinnelige professorer, men det går sakte. *Khrono*. Available at: <https://www.khrono.no/det-bli-er-flere-kvinnelige-professorer-men-det-garsakte/949620> (published: 07/03/2025).

Trowelblazers: <https://trowelblazers.com>

Uddannelses- og Forskningsstyrelsen 2022. Mænd og kvinder på de danske universiteter Danmarks talentbarometer 2022. Available at: <https://ufm.dk/publikationer/2023/maend-og-kvinder-pa-de-danske-universiteterdanmarks-talentbarometer-2022>

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# Technical Practices and Social Dynamics

## A Comparative Study of Havelte Group and Federmesser-Gruppen in Late Glacial Northern Europe

Tobias Reuter

### Abstract

This study presents a comparative analysis of the technological traditions and social dynamics of two Late Palaeolithic technocomplexes in northern Europe: the Havelte group (Hamburgian) and the Federmesser-Gruppen (FMG). Examining lithic assemblages from key archaeological sites across northern Germany and Denmark, the analysis investigates technological decision-making processes and identifies patterns of conformity and variation in lithic production. Drawing on Simmel's sociological model of network structure, the analysis challenges traditional environmental determinism by demonstrating how environmental conditions alone do not directly determine technological outcomes, revealing that fundamentally different technological responses during the Late Glacial (c. 12500–10800 cal BCE) emerge through varying network configurations. The findings suggest that higher levels of group conformity in lithic production – as seen in the Havelte group – are linked to networks with limited interconnectedness, supporting group cohesion in challenging conditions. Conversely, greater network connectivity fosters individual autonomy and technological flexibility, as demonstrated by the FMG's more adaptive approach. Both strategies were culturally significant in their respective social contexts, demonstrating that technological development does not necessarily progress along a single path towards greater efficiency.

*Keywords: Late Palaeolithic, lithic technology, Hamburgian (Havelte group), Federmesser-Gruppen (FMG), social networks*

### Introduction

Technological traditions among hunter-gatherer societies emerge through shared practices – such as hunting, gathering, and crafting – in which social relations are continually formed and maintained through social interaction. As such, technical practices are fundamentally social phenomena, embedded within the daily interactions and organizational structures of hunter-gatherer communities. Understanding how these traditions vary across time and space therefore offers insights into social settings and group dynamics of past populations.

In the study of Late Palaeolithic hunter-gatherers, adopting this perspective broadens the interpretive framework for understanding variability in lithic technologies. Traditional

approaches often emphasize environmental adaptation – the idea that technological differences reflect responses to specific ecological challenges or resource availability (e.g. Binford 1980; Nelson 1991; Shott 1996). While environmental factors undoubtedly influence technological choices, ethnographic evidence demonstrates that hunter-gatherer societies operating in similar environments can develop markedly different technological traditions (cf. Jordan and Shennan 2009; Mathew and Perreault 2015). This diversity of responses suggests that social factors may play a more important role in shaping technological variation than suggested by traditional approaches. The present study therefore explores how social agency contributes to technological decision-making. Rather than environmental conditions directly determining technological outcomes, this study proposes that network structural characteristics shape how groups engage with their environment through technical practices.

One useful way to analyse the relationship between network structure and technological variability draws on Simmel's sociological model from 1908, centering on network structural diversity. According to this model, individuals in networks with high boundary permeability and extensive interconnectedness gain greater autonomy, which promotes flexibility within groups. Conversely, individuals in networks with limited interconnectedness and low boundary permeability remain dependent on single groups, fostering conformity to specific group norms and resistance to variation. These contrasting network configurations – boundary-induced conformity and open network-driven flexibility – provide a useful analytical framework for interpreting technological diversity in the archaeological record.

This study investigates the relationship between technological traditions and their associated network structures by examining two diverging lithic technologies within this sociological framework. Specifically, it analyses lithic assemblages from key archaeological sites attributed to the later phase of the Hamburgian – the Havelte group – and the Federmesser-Gruppen (FMG) of the North European Late Palaeolithic. The Hamburgian (c. 12700–11800 cal BCE) and the FMG (c. 12200–10800 cal BCE) partly overlap in time and space (see Grimm and Weber 2008; Riede and Edinborough 2012 and discussions therein), but are technologically distinct, providing an excellent opportunity to explore how technological responses emerge from the interplay of multiple factors, including network configurations and environmental conditions.

Using a *chaîne opératoire* approach, this research reconstructs technological decision-making processes and identifies shared or divergent patterns in lithic production. The results are discussed in relation to previous lithic studies and broader aspects of hunter-gatherer life, including subsistence, settlement, mobility, and environmental

conditions. Finally, within the sociological framework, the study offers a tentative interpretation of the complex relationship between technology and network organization revealed by these investigations.

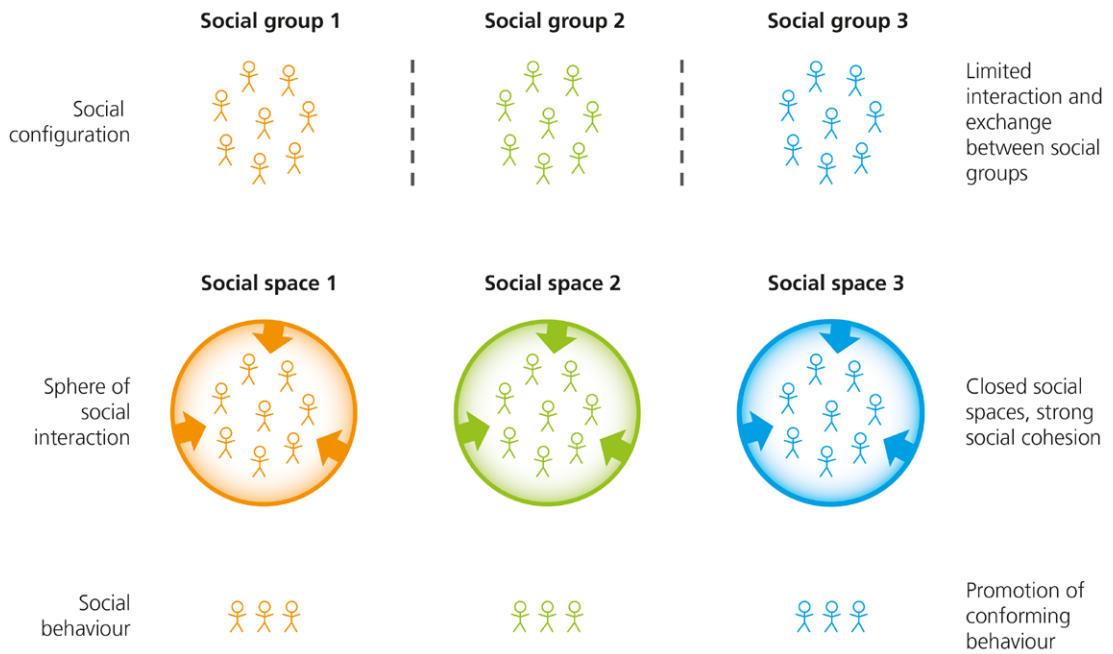
## Analytical framework and methods

Georg Simmel developed a sociological model focusing on sedentary societies, which also provides a valuable perspective on understanding the relationship of social settings and technology of mobile hunter-gatherer communities (Simmel 1992, 547–563). In this model, the principal mechanism governing the balance between behavioural conformity and variation is network structural diversity. He states that higher levels of group conformity arise when network structural characteristics promote isolation and bounded interactions. In small-scale communities with limited boundary permeability, reduced interconnectedness with external social networks restricts exposure to alternative cultural practices. Consequently, community members reinforce traditional, group-specific practices (Fig. 1). This process gives rise to behavioural conformism, leading to fairly steady and consistent behavioural patterns that may be identifiable in material culture (e.g. Berg-Hansen 2018; Furholt 2018).

By contrast, social networks characterized by extensive interconnectedness appear to support individual autonomy more, allowing for greater variation in individuals' preferences and ways of life (Simmel 1992, 547–563). In this way, variability arises from socially mobile actors who participate in diverse practices across different group constellations within highly permeable network boundaries. This sociocultural dynamic fosters multiple group affiliations and promotes frequent information exchange through dense interconnections. Consequently, high levels of network connectivity are established, leading to the emergence of diverse intra-group habits and practices. Despite this local diversity, consistency can be maintained on a broader, supra-regional scale through ongoing interconnectedness and shared knowledge networks with high boundary permeability.

The adaptation of this simple sociological framework involves several explanatory clarifications. First, the relationship between network structural characteristics and technological behaviour operates as a tendency rather than a deterministic rule (cf. Simmel 1992, 552). Secondly, although the model was initially designed for sedentary societies, it has been adapted here for prehistoric hunter-gatherer contexts. Nevertheless, recent ethnographic and cross-cultural studies among hunter-gatherers corroborate these principles, highlighting how network flexibility and multilevel sociality – defined by fluid social structures, high between-camp mobility and multilocality – facilitate significant behavioural variation and flexibility through enhanced

**a) Boundary-induced conformity**



**b) Open network-driven flexibility**

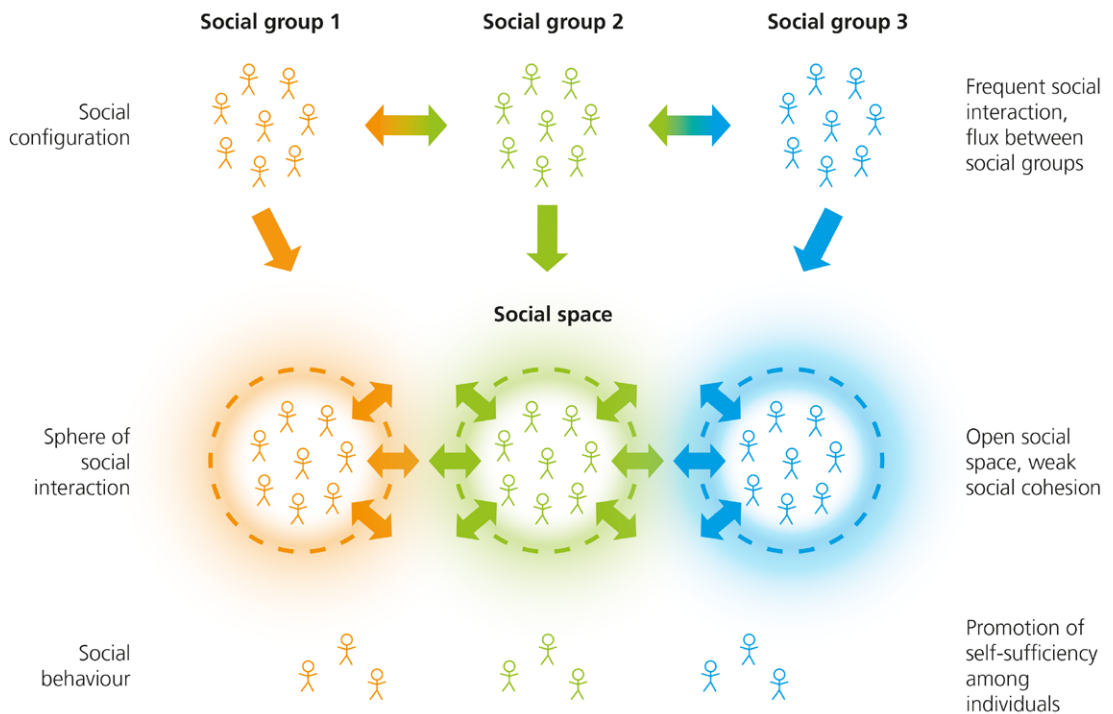


Figure 1: Schematic representation of Simmel's theory of how specific social configurations relate to a) boundary-induced conformity and b) open network-driven flexibility (after Reuter in press, Figs. 88, 89).

interconnectedness and boundary permeability (Hewlett *et al.* 2024; Migliano *et al.* 2020). Conversely, cultural transmission research emphasizes group effects on individual learning, particularly through conformist bias – the tendency for individuals to disproportionately adopt behaviours that are common within their reference group (Boyd and Richerson 1985; Henrich and Boyd 1998; Muthukrishna *et al.* 2016). This implies that when interconnections between groups are sparse and boundary permeability is low, intensified within-group interaction reinforces adherence to established cultural norms and limits behavioural diversity. Together, these findings substantiate the argument that network structural characteristics modulate the balance between conformity and flexibility in hunter-gatherer societies.

As the principal mechanism governing the balance between conformity and variation is network structural diversity, it is essential to define and qualify factors that identify this parameter. In sedentary societies – prior to digital communication – this diversity is often inferred from spatial mobility, which tends to reflect the extent of network interconnectedness and reach. However, in hunter-gatherer populations, where high mobility is common, spatial mobility alone is an unreliable proxy for network density or interconnectedness intensity. Therefore, to accurately capture network structural characteristics among hunter-gatherer groups, one must incorporate additional, context-specific indicators. In Late Glacial contexts, researchers currently employ multiple complementary approaches to reconstruct demography and social networks, including site density analyses, radiocarbon summed probability distributions (SPD) and raw material circulation patterns as proxies for mobility and interconnectedness (*e.g.* Pettitt *et al.* 2012; Schmidt *et al.* 2025; Shennan and Edinborough 2007). However, some of these methods are not applicable in all regions: in the moraine landscapes of northern Germany and Denmark, for instance, the scarcity of radiocarbon dates limits the utility of SPD approaches, while raw material provenance studies are hampered by the widespread glacial transport of flint from multiple source areas all over the area.

The analytical framework requires the identification of contextual factors, as well as patterns of conformity and variation within archaeological lithic assemblages. Technical choices and practices can be detected at every stage of the production sequence (*chaîne opératoire*), from initial raw material acquisition through final artifact discard (Audouze 1999; Leroi-Gourhan 1964; Lemonnier 1992). This comprehensive examination of manufacturing stages reveals the overall operational scheme (*schéma opératoire*) by evaluating decisions and strategies employed throughout the entire production process. The primary aim involves distinguishing

between normative aspects of lithic manufacturing – those occurring regularly and considered characteristic of specific network-transmitted norms – and variable elements subject to individual choices within particular network configurations. This differentiation addresses fundamental questions regarding raw material exploitation patterns, preparation methods, progression of blade production and production stages, knapping technique, production objectives and technological characteristics of tools and points.

## Archaeological record

The study is based on six lithic assemblages from northern Germany, comprising four FMG sites and two Havelte group sites (Fig. 2; Tab. 1). The FMG site selection strategy prioritized obtaining a comprehensive representation of lithic technological practices across the study area, incorporating spatial diversity while focusing on well-preserved, undisturbed archaeological contexts recovered through systematic excavation when available. Access restrictions during the COVID-19 pandemic and publication rights limitations prevented full inclusion of Danish materials, though these assemblages received cursory technological examination (Tab. 1). The exclusion of significant Danish sites, particularly the substantial Slotseng FMG inventory with its rich tool and projectile assemblage (Holm 1991; 1996), represents a notable limitation that may have influenced the assessment of FMG technological variability in the region.

The Hamburgian technocomplex is conventionally divided into two phases: the Classic Hamburgian, characterized by shouldered points, and the Havelte group, distinguished by tanged points. Given the closer chronological proximity of the Havelte group to the FMG (Grimm and Weber 2008; Riede and Edinborough 2012), the present study places its primary focus on this later phase, while occasional reference to the Classic Hamburgian is nevertheless included where relevant.

The selection of sites of the Havelte group selection followed a different approach, aiming to supplement existing comprehensive technological studies of Hamburgian traditions in the research area (Hartz 1990; Madsen 1992; 1996; Pedersen *et al.* 2022; Weber 2012) rather than seeking regional representativeness. Consequently, two Havelte group sites from Ahrenshöft underwent detailed technological analysis to complement the established research foundation.

## The technocomplexes in the context of their environmental conditions

According to lithostratigraphical, palynological and radiocarbon evidence, the Havelte group occupied the region during the second part of the Meiendorf/Bølling interstadial and the Older Dryas period (Fig. 3; Grimm

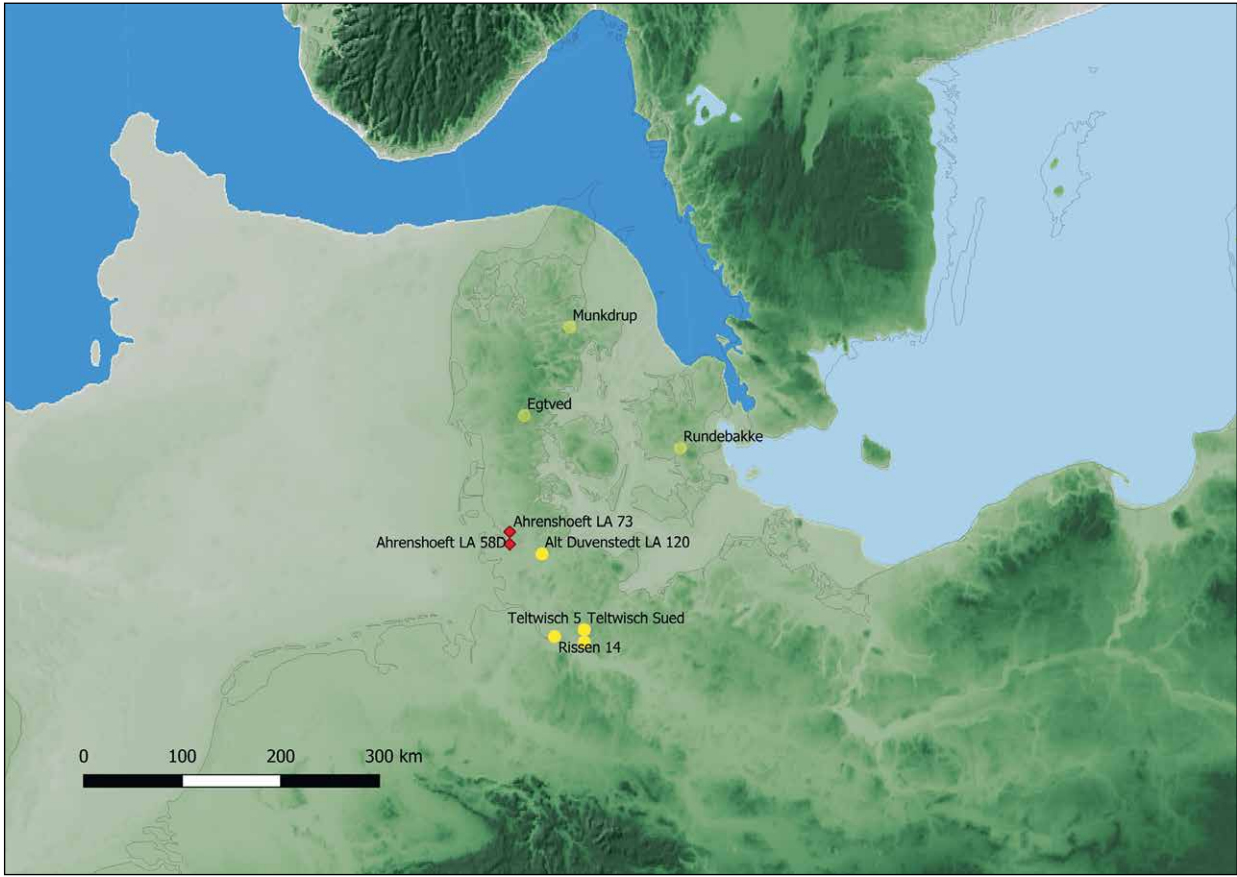


Figure 2: Site distribution of the archaeological record used in this study. Red diamonds: Havelte group sites; yellow circles: FMG sites; light yellow circles: FMG sites with cursory technological investigations (after Reuter in press, Fig. 16).

and Weber 2008; Reuter in press, 51–60). Palaeoecological investigations indicate that during this time, an open tundra ecosystem with steppe-like and arctic elements predominated in the research area (Krüger *et al.* 2020; Merkt and Müller 1999; Mortensen 2007). Regional variations in vegetation were minimal, though north-south gradients and edaphic factors contributed to some differentiation.

The FMG technocomplex, reliably dated from the Older Dryas to approximately mid-Allerød in Northern Germany, experienced pronounced environmental alterations (Fig. 3). The period was characterized by an initial dry grass-dominated steppe during the Older Dryas (with more pronounced landscape opening in the north), a gradual transformation to open woodland during the early Allerød punctuated by episodes of vegetation decline, and finally denser yet patchy woodland with habitat diversification from mid-Allerød onwards (Krüger *et al.* 2020; Merkt and Müller 1999; Mortensen 2007). Importantly, the FMG tradition cannot be associated with a single distinct environmental condition but rather encompasses diverse and varying climatic conditions and environments.

## Results of the technological investigation

This section presents the technological investigations of the Havelte group and the FMG, outlining the main characteristics of their lithic production. To achieve this, data from single artefact analysis and from refitting assemblages (when available) were considered and compared to existing technological investigations (Reuter in press, 89–164).

### Havelte group

The technological study of the lithic assemblages from the Havelte group at Ahrenshoift LA 58D and LA 73 reveals a deliberate and methodical strategy in lithic production. The principal technique employed appears to have been a systematic bidirectional reduction process. This method relied on the careful selection of generally flawless, medium-sized lithic raw materials – a necessity due to the limited presence of larger nodules in the old moraine landscape surrounding these sites. Initial preparation of the nodules involved shaping acute angles between the reduction surface and two opposing platforms. Blade removal typically began at the core's front and progressed towards the sides. Blades

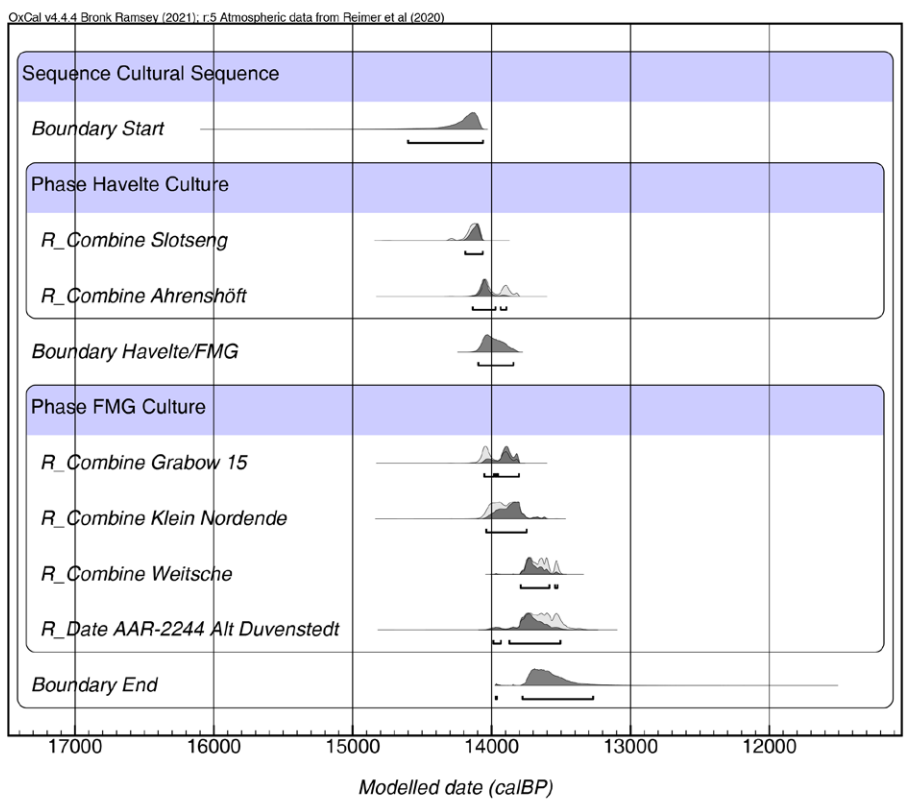


Figure 3: Sequential Bayesian chronological model using Boundaries to estimate cultural transitions. Radiocarbon dates from the same sites combined using R\_Combine function. Phase durations calculated with Span function. All dates calibrated using IntCal20 (graphics T. Reuter, compiled with Oxcal v.4.4.4; Bronk Ramsey 2021).

originating from the core's front displayed straight platform remnants, while those from the flanks bore oblique remnants due to the sloping angles involved (see also Hartz 1987). The bidirectional blade production method involved alternating the direction of strikes – sometimes after a single blow, a few blades, or an entire sequence – likely to maximize the yield of regular, slender, and straight blades. Utilizing opposed platforms not only allows for corrections to the convexity of the core's volume as needed but also provides the means to maintain suitable convexities throughout the knapping sequence, thereby preventing reduction problems before they occur (cf. Weber 2012, 121-122). A portion of these standardized blades was then fashioned into projectile points and various tools.

There is clear evidence that blanks of specific sizes were chosen for certain modified implements, with the thinnest and narrowest pieces being selected for transformation into Havelte points. Overall, tool modification followed a consistent pattern, with particular focus on the production of Zinken, burins, endscrapers, and Havelte points. However, some differences are apparent between the two sites. At Ahrenshöft LA 58D, endscrapers frequently show additional retouching along both lateral edges, whereas at Ahrenshöft LA 73, such retouching is either absent or limited to one lateral edge. No such variation is observed among the other tool types. The production of Havelte points was notably standardized, involving alternating

retouching of the tang and the lateral edges of the tip. While a few examples deviate from this pattern, these exceptions can generally be attributed to the unique characteristics of individual blanks, aimed at achieving optimal symmetry between the tang and the tip of the point.

Comparative analysis reveals that Classic Hamburgian and Havelte group inventories shared very similar blade production processes and blank selection for tool manufacture. Weber's (2012) comprehensive analysis of Ahrensburg Tunnel Valley inventories documented well-defined, standardized Hamburgian lithic technology for regular, slender blade production. Danish Havelte group sites Jels 1 and 2 showed no significant differences in lithic production between northern Germany and Denmark (Madsen 1992; 1996), involving meticulous planning with finely faceted platforms (Madsen 1996, 63). Refitting from Havelte group site Sølbjerg 3 confirmed operational schemes consistent with general Hamburgian characteristics, including thorough preparation and bidirectional reduction for slim, regular blades (Johansen 2000, 199-200; Weber 2012, 163). Moreover, due to the abundance and diversity of tool types (Hartz 1990; Holm and Rieck 1992, 82-83; Weber 2012, 88-89), the presence of the whole *chaîne opératoire* in lithic production across these sites (Bureau 2019; Madsen 1996; Weber 2012), and comparable processing of hunted game (where preserved), these factors testify to a wide and

Site / Stage	Choice of Raw Material	Preparation Methods	Progression of Blade Production & Stages	Knapping Technique	Production Objectives & Blank Selection	Technological Characteristics of Tools
Ahrenshöft LA 73	Flat and bulky nodules of high quality	Installation of opposing platforms with acute angles	Hierarchical sequences, bidirectional and systematic reduction	Soft hammer	Slender and regular blades	Standardized tools, highly standardized lithic points
Ahrenshöft LA 58D	Flat and bulky nodules of high quality	Installation of opposing platforms with acute angles	Hierarchical sequences, bidirectional and systematic reduction	Soft hammer	Slender and regular blades	Standardized tools, highly standardized lithic points
Alt Duvenstedt LA 120	Deliberate selection of bulky, high-quality nodules	Intensive, but simple core preparation	Simple, regular sequences, systematic reduction	Soft and hard hammer percussion	Long blades for points and tools	Standardized tools and points, systematic retouch
Teltwisch Süd	Mostly irregular pieces, a few cylindrical	Minimal core preparation and natural surfaces	Short, irregular series, <i>ad hoc</i> reduction	Hard hammer percussion	Irregular blades and flakes, robust blanks for tools	Few modified pieces, varied retouch
Teltwisch 5	Mostly irregular pieces of irregular dimensions, a few cylindrical	Minimal core preparation and natural surfaces	Short, irregular sequences, <i>ad hoc</i> reduction	Hard hammer percussion	Irregular blades and flakes, robust blanks for tools	Simple and variable retouch, mostly burins and scrapers
Rissen 14	Irregular and small nodules, often containing internal cracks and inclusions	Minimal core preparation and natural surfaces	Short blade sequences, irregular reduction, <i>ad hoc</i> decisions	Soft hammer percussion?	No clear selection for regular blades; tools made on irregular flakes and blades	Simple, expedient retouch; dominance of scrapers, burins
Munkdrup	Irregular and regular nodules often with internal cracks and inclusions	Minimal core preparation and natural surfaces	Short, irregular series, <i>ad hoc</i> reduction	Hard hammer percussion	Irregular and regular blades and flakes, robust blanks for tools	Simple, expedient retouch

Table 1: Schematic representation of the results of the lithic technological analysis.

similar range of domestic activities as well as nearby hunting carried out across the Hamburgian sites (see also Reuter in press, 72). However, more detailed functional analyses are necessary to verify this assumption and to better understand intra-site activity patterning.

The analysis of lithic technology conducted in this research reveals that there are no notable distinctions when compared to the Havelte group in Denmark or the Classic Hamburgian sites of Schleswig-Holstein. As a result, both the technological assessment presented here, and the findings of other researchers suggest that flint knappers associated with Hamburgian sites in northern Germany and Denmark adhered to remarkably consistent methods in their lithic production techniques.

### Federmesser-Gruppen

An analysis of the FMG inventories from Teltwisch 5, Teltwisch Süd, Rissen 14, Munkdrup, and Alt Duvenstedt LA 120 reveals a generally consistent *chaîne opératoire*. This approach involved utilizing a broad spectrum of raw materials, including those of lesser quality. Alt Duvenstedt LA 120 stands out as an exception, showing a preference for selecting and working with large, bulky, and flawless raw materials. Further insights from other sites of Schleswig-Holstein confirm the finding that there is considerable variability in the raw materials used (Bokelmann 1978; Bokelmann *et al.* 1983; Clausen and Hartz 1988; Hartz 2012;

Kotthaus 2013; Lempcke 1996; 2000; Trölsch 1976), indicating an absence of strict selection criteria.

The reduction process was characterized by relatively straightforward sequences, with little clear differentiation between distinct stages, unlike the more sequential processes observed with the Hamburgian assemblages. Typically, the steps involved initial decortication (when performed at all), the establishment of a primary platform either through the removal of large flakes or by taking advantage of existing convexities, occasional preparation of reduction surfaces via cresting, and the subsequent production of blades and blade-like pieces. Rather than following a rigid sequence of defined phases, the process was marked by fluid transitions and decisions made on an *ad hoc* basis. Within this framework, various reduction strategies were identified, including the exploitation of either the narrow or broad end of the nodule, frequent changes in orientation, and production runs yielding differing quantities of artefacts. Consequently, the resulting blanks exhibit a wide range of sizes, and a generally rougher finish compared to those produced by the Hamburgian. At Alt Duvenstedt LA 120, there is evidence of greater precision in preparing platforms, with more thorough shaping prior to blade production and a more pronounced separation between the different stages of manufacture. Contrasting with the Havelte group opposed platform reduction, unipolar reduction often involves the opportunistic use of

the core's natural form. This feature is commonly observed in FMG assemblages from northern Germany, as reflected in other inventories. While most researchers have noted that blade and blade-like flake production at FMG sites typically results in irregular forms (Clausen and Hartz, 1988; Lempcke 1996; 2000; Trölsch 1976), instances of more standardized blade production have also been documented (Bokelmann 1978; Kotthaus 2013). At the Munkdrup site, the predominant strategy is a straightforward, opportunistic reduction focused on exploiting a single platform, particularly evident in concentrations A-600 and A-601. In contrast, concentrations A-602 and A-603 display evidence of more regular blade production, as indicated by cores with systematically placed negatives and sequences of blade removals, typically using raw materials that lack surface cracks.

The subsequent modification of some artefacts does not indicate a strong preference for blanks of specific dimensions, resulting in a considerable variety of blank sizes being selected for tools such as burins and scrapers. Additionally, these implements were altered to differing extents, though the majority of modifications were relatively minor. As a result, the inherent properties of the blanks played a significant role in shaping the morphological features of FMG-associated tools (cf. Bokelmann 1978; Bokelmann *et al.* 1983; Bureau 2019; Clausen and Hartz 1988; Kotthaus 2013; Lempcke 1996; Petersen 1992; Rust 1958; Schwabedissen 1954; Trölsch 1976). In contrast, blanks selected for the production of backed points were predominantly slim and regular in form. These projectile points required particular attributes, including minimal thickness (3–5 mm), narrow widths, and high length-to-width ratios. The presence of larger backed points at Alt Duvenstedt LA 120, which differ in size from the finer examples, suggests they may have served as knives rather than as projectiles (*couteaux á dos*, see Coudret and Fagnart 1997).

The placement of retouch on backed points displays considerable variation both within and across different assemblages. Typically, one lateral edge is continuously retouched, either straight or curved, with the extent of backing varying; however, in some cases, both lateral edges are modified, as seen in complete examples from Teltwisch 5 and Borneck-Ost (Rust 1958; Kotthaus 2013). Additionally, both the form and retouching of the base on backed points suggest the presence of (potentially regional) distinctions. FMG inventories from the Ahrensburg Tunnel Valley – such as Teltwisch 5, Teltwisch Süd, Borneck-Ost, Borneck-West, and Borneck-Mitte – frequently include backed points with either a straight truncation or a straight natural edge at the base (Reuter *in press*, Figs. 19, 29; Rust 1958, Pls. 13.14, 14.14, 25.3, 26.4–5, 26.7–8). In contrast, the fine backed points from Alt Duvenstedt LA 85 and 120 are characterized by pointed bases (Clausen and Hartz 1988, Figs. 8.5–7). Similar pointed bases on FMG-

associated backed points have also been found at Klein Nordende A (Bokelmann *et al.* 1983, Pl. 8.3–5). Moreover, curve-backed points featuring oblique basal retouch or oblique truncation are more commonly found in Denmark, as demonstrated by specimens from Slotseng, Rundebakke, and Stoksbjerg Vest (Holm and Rieck 1992, Figs. 5, 52.1, 52.3–5; Johansson 2003, Fig. 43; Petersen 1992, Fig. 7.1; Pedersen 2009, Fig. 7), as well as by two examples from concentration A-602 at Munkdrup (Madsen 2018). Despite these tendencies, there remains a notable diversity in basal forms within individual assemblages, indicating that there was no strict standardization in the production of specific base types at each settlement. In fact, all mentioned variants can be found within single inventories, such as at the FMG site Schalkholz II (Schleswig-Holstein), where backed points with a variety of bases are represented (Bokelmann 1978, Pl. 7.3, 7.7–9, 7.11).

## Application of analytical framework and discussion

The lithic assemblages associated with the Havelte group demonstrate an exceptional level of standardisation in technological practices, particularly in the manufacture of projectile points. This pattern of normative practices is also observed in other aspects of the Hamburgian technocomplex. Analyses of reindeer osseous remains highlight systematic resource use, with evidence for the extensive exploitation of whole animals and their body parts for consumption (Grønnow 1987, 155–156). Notably, even in contexts of massive hunting success, as seen in the Ahrensburg Tunnel Valley, carcasses were fully exploited (Bratlund 1994, 76). Rather than taking a fully rationalized approach, these communities exploit resources in a more rigid manner and rely more heavily on persistent traditions (see also Weber 2013, 85). The systematic and standardized approach is also evident in the manufacturing of osseous material (Wild 2020, 208; Wild *et al.* 2020). Eventually, the linear arrangement of Hamburgian sites and find spots may reflect the main expansion routes of hunter-gatherers into the north (Petersen and Johansen 1991, 34). When considered alongside archaeological evidence of settlement patterns, a linear mobility pattern involving the repeated use and extension of established routes is suggested (Fig. 4; cf. Bokelmann 1979; Bratlund 1994, 89–90, Fig. 8b; Eriksen 1999, Fig. 5; Petersen and Johansen 1991; 1994, Fig. 17; Tromnau 1975, 14).

An examination of the archaeological record shows that the Havelte group displays an exceptional degree of standardisation in lithic technology, systematic patterns of resource exploitation, and a persistent adherence to established routes across both temporal and spatial dimensions. According to Simmel's model, such behavioural conformism and reduced variability are characteristic of social contexts defined by small network size, low

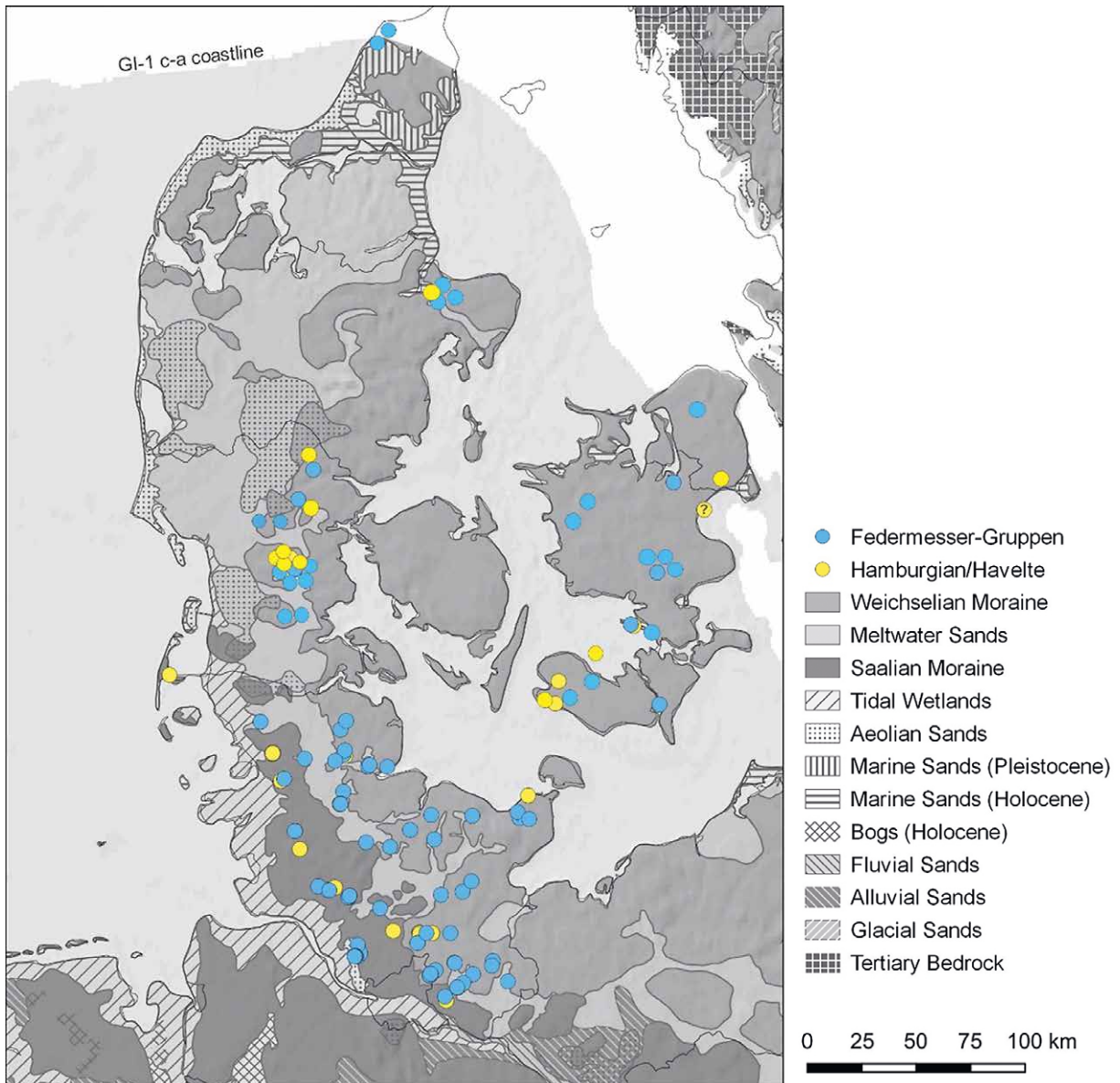


Figure 4: Distribution of finds associated with the FMG (blue) and the Hamburgian (yellow), including single finds and surface collections as well as settlement sites (after Reuter, in press, Fig. 15).

population density, limited interconnectedness, and low boundary permeability. These findings therefore suggest that the Havelte group most likely represents a small social unit characterized by minimal network diversity.

This assumption must be understood within the broader demographic context. Population estimates indicate that density in this region and period was very low (Kretschmer 2015; Lundström *et al.* 2021; Schmidt *et al.* 2021). Despite spanning about five centuries, Hamburgian settlements in northern Germany and Denmark appear to represent transient, intermittent occupations rather than permanent habitation (Reuter

in press, 73–76). This settlement pattern is consistent with pioneer societies colonizing new territories and navigating largely unexplored landscapes (cf. Rockman 2003). The limited human presence, combined with the fact that these groups were exploring marginal territories at the fringes of human habitation, suggests that social interactions between different groups or traditions were also limited.

This pattern demonstrates that technological standardisation in the Havelte group was shaped less by environmental adaptation than by the specific network configuration arising from pioneering conditions. The

social environment – defined by low population density, geographic isolation, and the structural constraints of early settlement – encouraged the maintenance of established practices and conformity to tradition. The persistence of these standardized traditions within both the classic Hamburgian and the Havelte group thus corroborates the model's prediction that structurally constrained networks reinforce existing norms and limit behavioural variation.

These behaviours should not be understood merely as outcomes of the specific social configuration but as vital components for coping with the particular circumstances of the setting. The Havelte group's marginal position at the periphery of human settlement likely fostered conditions in which traditional practices served multiple roles: maintaining group cohesion in harsh environments and preserving cultural identity during territorial expansion. Rather than representing a straightforward environmental adaptation, the standardized technological repertoire of the Hamburgian thus reflects the social dynamics of small-scale, structurally constrained networks, in which conformity to established norms provided both practical and social advantages.

The technological analysis of FMG lithic assemblages presented in this study suggests diverse rather than systematic patterns of action. These patterns are also evident in settlement sizes, tool quantities (Reuter in press, Tab. 6), hunting game, and possibly also hunting techniques (Reuter in press, 67–79). Variability manifests on two distinct levels: as inter-site variability, meaning differences observable between sites, and as intra-site variability, expressed in the flexibility within individual sites. This intra-site flexibility derives from the fact that reduction methods were not rigidly predetermined, thereby permitting individual decision-making and the execution of *ad hoc* reduction strategies. This finding is consistent with evidence from other FMG sites across Europe, as demonstrated by technological analyses of FMG lithic inventories in regions such as the central Rhineland (Mevel and Grimm 2019), western Poland (Pyżewicz *et al.* 2020), the Paris Basin (Jacquier *et al.* 2021), the Somme Valley (Coudret and Fagnart 1997), west-central Germany (Heidenreich 2008; Holzkämper *et al.* 2013), eastern Germany (Winkler 2010), northern Belgium (De Bie and Caspar 2000), and the Rhine-Main area (Löv 2006). Together, these findings highlight that, while individuals and groups associated with the FMG may exhibit less strict adherence to specific overarching norms at the local level, they generally share a common tradition operating at a broader regional scale.

According to Eriksen (2000) the technological and typological differences between lithic inventories associated with Late Glacial hunter-gatherers may be related to cultural, chronological, functional, seasonal, or even accidental factors. Functional interpretations emphasized

the availability of local raw materials as a key factor shaping the flexible reduction schemes of FMG knappers (*e.g.* De Bie and Vermeersch 1998; Kegler 2007; Löv 2006). However, detailed analyses of Late Palaeolithic settlement sites in northern Germany and Denmark indicate that the diverse range of lithic raw materials used by FMG groups cannot be fully explained by raw material availability alone (Reuter in press, 170–172). Instead, this variety reflects deliberate cultural preferences in raw material selection. For example, despite the ready availability of high-quality flint in regions such as the Ahrensburg Tunnel Valley, Randers, and Lieth Bog (Bokelmann *et al.* 1983, 206; Madsen 1983, 1996; Weber 2012, 99–104), FMG flintknappers often predominantly processed raw materials considered 'inferior' or of variable shapes, in contrast to other Late Glacial technocomplexes such as the Hamburgian, Bromme, and Ahrensburgian. Conversely, at specific FMG sites such as Alt Duvenstedt (Clausen and Hartz 1988) and Rundebakke (Petersen 1992), larger and more suitable raw materials were selected and processed, demonstrating the capability to utilize high-quality materials. This pattern cannot be solely attributed to opportunistic exploitation, as good quality raw materials were available at all mentioned settlement sites, yet the choice of materials varies. This suggests that raw material selection among FMG groups was a deliberate process, likely influenced more by site function and cultural factors than by mere availability (see below).

The transition from Magdalenian to FMG has been interpreted as involving the collapse of pan-European Late Magdalenian networks due to environmental changes during GI-1d, resulting in weakened social networks and the emergence of more autonomous regional units (Grimm 2020; Mevel and Grimm 2019). In this context, it is proposed that more regionally self-sufficient groups developed, characterized by frequent migration and brief settlements due to dependency on unpredictable resources (Hamer *et al.* 2019; Street *et al.* 2006). The small size of occupied territories and the frequent movement this entailed demanded a more flexible and adaptive technological system.

In contrast to these hypotheses and models, this study proposes that FMG flexibility resulted from higher social connectivity rather than weakened social networks. Building on a sociological model by Simmel (1992), the analysis suggests that variability between sites reflects individuals engaging in various practices within different group configurations. This gives individuals greater self-sufficiency, reflected by intra-site flexibility.

Evidence from northern Germany and Denmark points to distinct techno-economic functions among FMG sites. Alt Duvenstedt LA 120 and LA 89 are dominated by evidence of early-stage reduction sequences and domestic activities, whereas sites like Teltwisch 5, Teltwisch Süd, and

Rissen 14 BE show complete operational chains with diverse lithic production goals, including a range of projectile points such as fine-backed and large-tanged types, suggesting varied hunting weapons and strategies. Contrastingly, at Klein Nordende CR and A, the exploitation of mainly flat nodules via hard hammer percussion focused on rapid unipolar blade production to produce narrow blades for slender projectile points, despite the availability of larger nodules. Morphological analysis of backed points reveals localized variation: straight bases predominate in the Ahrensburg Tunnel Valley, pointed bases characterize Alt Duvenstedt and Klein Nordende, and oblique bases appear in some Danish sites. This pattern indicates functional or social distinctions across settlements, but the coexistence of multiple backed point types at sites like Schalkholz II highlights a shared technological tradition with regional dominance of certain types. The FMG sites at Slotseng b and e exhibit an unusually high concentration of backed points and Wehlen scrapers, possibly reflecting aggregation camps. This variability likely reflects different site functions: domestic base camps, hunting preparation or specialized lithic production camps, smaller task-specific sites, and aggregation sites, illustrating a complex and flexible techno-economic landscape within the FMG tradition.

FMG socio-economic systems likely consisted of adaptive group structures organized around seasonal task specialization. This hypothesis finds support in ethnographic analogies documented in works by Turnbull (1968), Mauss and Beuchat (1979), and further elaborated by Ingold (1999) and Wengrow and Graeber (2015). Such fluid group formations plausibly corresponded with parallel shifts in social organization, indicating high network structural diversity within FMG networks. Simmel's model predicts that such network characteristics promote behavioural flexibility and variation while maintaining broader coherence through extensive social connections. Testing this prediction against the FMG archaeological record reveals strong correspondence. The material culture exhibits diverse selection of raw materials and flexibility in lithic reduction strategies, characterized by *ad hoc* planning, indicating greater self-sufficiency in technological decision-making.

Within this socially flexible framework, FMG groups engaged dynamically with their environments, responding effectively to varying ecological and resource conditions.

This responsiveness is reflected in adaptive lithic reduction strategies that demonstrate versatility beyond opportunistic exploitation, highlighting complex, context-sensitive engagements with their surroundings.

## Conclusions

This comparative analysis reveals two fundamentally different approaches to technological organization and broader aspects of life among Late Glacial hunter-gatherer communities in northern Europe. By applying an analytical framework that incorporates the social dimension of technology, the study highlights how contrasting patterns in the Havelte group and the FMG may reflect underlying social norms and values.

For the Havelte group, an emphasis on conformity and standardization appears to have supported group cohesion, especially in challenging and unfamiliar environments. By contrast, the FMG adopted a more flexible approach, enabling open and reactive responses to diverse environmental conditions. Both strategies proved effective within their respective social, economic, and environmental settings, suggesting that technological development does not follow a single, linear path.

Overall, this case study underscores the complex relationship between environmental factors and cultural choices within hunter-gatherer societies. It demonstrates that technology should not be viewed solely through the lens of efficiency or practicality; social elements also play a significant role in shaping technological development – and vice versa. In this way, technology is deeply intertwined with social practices and cultural perceptions of the environment, reflecting both the needs and the values of the communities that created and used it.

## Acknowledgements

This paper summarizes my dissertation, which I completed at the Centre for Baltic and Scandinavian Archaeology (ZBSA) in Schleswig, under the supervision of Berit V. Eriksen. I would like to thank Berit for her constant support and guidance throughout my research. She was always willing to listen and help whenever I needed it, and I am deeply grateful for her mentorship. I would also like to thank William Mills for his careful proofreading and the valuable insights he provided, which helped refine the argument and improve the clarity of this paper.

## References

- Audouze, F. 1999. New advances in French prehistory. *Antiquity* 73, 167–175.
- Berg-Hansen, I. 2018. Continuity and change in Late Glacial and Postglacial social networks: knowledge transmission and blade production methods in Ahrensburgian and Early Mesolithic North West Europe. In: Knutsson, K., Knutsson, H., Apel, J. and Glørstad, H. (eds.), *The Early Settlement of Northern Europe: The Technology of Early Settlement in Northern Europe*. Sheffield, Equinox Publishing, 63–98.
- Binford, L. R. 1980. Willow Smoke and Dogs' Tails: Hunter-Gatherer Settlement Systems and Archaeological Site Formation. *American Antiquity* 45(1), 4–20.
- Bokelmann, K. 1978. Ein Federmesserfundplatz bei Schalkholz, Kreis Dithmarschen. *Offa - Berichte und Mitteilungen zur Urgeschichte, Frühgeschichte und Mittelalterarchäologie* 35, 36–54.
- Bokelmann, K. 1979. Rentierjäger am Gletscherrand in Norddeutschland? *Offa* 36, 12–22.
- Bokelmann, K., Heinrich, D. and Menke, B. 1983. Fundplätze des Spätglazials am Hainholz-Esinger Moor, Kreis Pinneberg. *Offa - Berichte und Mitteilungen zur Urgeschichte, Frühgeschichte und Mittelalterarchäologie* 40, 199–240.
- Boyd, R. and Richerson, P. J. 1985. Culture and the evolutionary process. Chicago, University of Chicago Press.
- Bratlund, B. 1994. A survey of the subsistence and settlement pattern of the Hamburgian culture in Schleswig-Holstein. *Jahrbuch des Römisch-Germanischen Zentralmuseums Mainz* 41, 59–93.
- Bronk Ramsey, C. 2021. OxCal Program, Version 4.4.
- Bureau, T. 2019. Technologische Transformationen am Ende der letzten Eiszeit – Frühe Federmesser-Gruppen in Norddeutschland. Unpublished Master's thesis. Kiel, Christian-Albrechts-Universität zu Kiel.
- Clausen, I. and Hartz, S. 1988. Fundplätze des Spätglazials am Sorgetal bei Alt Duvenstedt, Kreis Rendsburg-Eckernförde. *Offa* 45, 17–42.
- Coudret, P. and Fagnart, J.-P. 1997. Les industries à Federmesser dans le bassin de la Somme: chronologie et identité des groupes culturels. *Bulletin de la Société préhistorique française* 94, 349–360.
- De Bie, M. and Caspar, J. P. 2000. Rekem. A Federmesser Camp on the Meuse River Bank. *Acta Archaeologica Lovaniensia Monographiae* 10. Leuven, Leuven University Press.
- De Bie, M. and Vermeersch, P. M. 1998. Pleistocene–Holocene transition in Benelux. *Quaternary International* 49–50, 29–43.
- Eriksen, B. V. 1999. Late Palaeolithic Settlement in Denmark - How do we read the record? *Folia Quaternaria* 70, 157–173.
- Eriksen, B. V. 2000. Patterns of ethnographic variability in Late Pleistocene Northwestern Europe. In: Peterkin, G.L. and Price, H.A. (eds.), *Regional Approaches to Adaptation in Late Pleistocene Western Europe*. Oxford, Oxbow, 147–168.
- Furholt, M. 2018. Translocal Communities – Exploring Mobility and Migration in Sedentary Societies of the European Neolithic and Early Bronze Age. *Prähistorische Zeitschrift* 92, 304–321.
- Grimm, S. B. 2020. *Resilience and Reorganisation of Social Systems during the Weichselian Lateglacial in North-West Europe: An Evaluation of the Archaeological, Climatic, and Environmental Record*. Monographien des Römisch-Germanischen Zentralmuseums 128. Mainz, Verlag des Römisch-Germanischen Zentralmuseums.
- Grimm, S. B. and Weber, M.-J. 2008. The chronological framework of the Hamburgian in the light of old and new 14C dates. *Quartär* 55, 17–55.
- Grønnow, B. 1987. Meiendorf and Stellmoor Revisited. An Analysis of Late Palaeolithic Reindeer Exploitation. *Acta Archaeologica* 56, 131–166.
- Hamer, W. B., Knitter, D., Grimm, S. B., Serbe, B., Eriksen, B. V., Nakoinz, O. and Duttman, R. (2019). Location Modeling of Final Palaeolithic Sites in Northern Germany. *Geosciences* 9–10, 430.
- Hartz, S. 1987. Neue spätpaläolithische Fundplätze bei Ahrenshöft, Kreis Nordfriesland. *Offa* 44, 5–52.
- Hartz, S. 1990. Artefaktverteilungen und ausgewählte Zusammensetzungen auf dem spätglazialen Fundplatz Hasewisch, Kr. Stormarn. In: Cieszla, E., Eickhoff, S., Arts, N. and Winter, D. (eds.), *The big puzzle*. Bonn, Holos, 403–429.
- Hartz, S. 2012. Grundformenerzeugung im Nordischen Endpaläolithikum. In: Floss, H. (ed.), *Steinartefakte*. Tübingen, Kerns, 389–398.
- Heidenreich, S. M. 2008. Late Glacial Hunter-Gatherers in Westphalia - The Final Paleolithic Site of Salzkotten-Thüle (District of Paderborn, North Rhine-Westphalia, Germany). *Archäologische Informationen* 31(1–2), 155–163.
- Henrich, J. and Boyd, R. 1998. The evolution of conformist transmission and the emergence of between-group differences. *Evolution and Human Behavior* 19(4), 215–241.
- Hewlett, B. S., Boyette, A. H., Lew-Levy, S., Gallois, S. and Dira, S. J. 2024. Cultural transmission among hunter-gatherers. *Proceedings of the National Academy of Sciences* 121(48), e2322883121. DOI:10.1073/pnas.2322883121
- Holm, J. 1991. Settlements of the Hamburgian and Federmesser Cultures at Slotseng, South Jutland. *Journal of Danish Archaeology* 10(1), 7–19.

- Holm, J. 1996. The earliest settlement of Denmark. *Acta archaeologica Lundensia* 8(24), 43–59.
- Holm, J. and Rieck, F. 1992. Istidsjægere ved Jelsøerne. *Skrifter fra Museumsrådet for Sønderjyllands Amt* 5. Haderslev, Haderslev Museum.
- Holzkämper, J., Maier, A. and Richter, J. 2013. “Dark Ages” illuminated – Rietberg and related assemblages possibly reducing the hiatus between the Upper and Late Palaeolithic in Westphalia. *Quartär* 60, 115–136.
- Ingold, T. 1999. On the Social Relations of the Hunter-Gatherer Band. In: Lee, R. B. and Daly, R. H. (eds.), *The Cambridge Encyclopedia of Hunters and Gatherers*. Cambridge, Cambridge University Press, 399–410.
- Jacquier, J., Mevel, L. and Bodu, P. 2021. Less simple than expected. New technological and functional insights on the Late Azilian site of Le Closeau (France). *Quartär* 68, 181–214.
- Johansen, L. 2000. The Late Palaeolithic in Denmark. In: Valentin, B., Bodu, P. and Christensen, M. (eds.), *L'Europe centrale et septentrionale au Tardiglaciaire. Confrontation des modèles régionaux de peuplement*. Nemours, APRAIF, 197–215.
- Johansson, A. D. 2003. Stoksbjerg Vest, et senpalæolitisk fundkompleks ved Porsmose, Sydsjælland Fra Bromme- til Ahrensburgkultur i Norden. *Nordiske Fortidsminder, Serie C* 3. København, Kongelige Nordiske Oldskriftselskab.
- Jordan, P. and Shennan, S. 2009. Diversity in hunter-gatherer technological traditions: Mapping trajectories of cultural ‘descent with modification’ in northeast California. *Journal of Anthropological Archaeology* 28/3, 342–365.
- Kegler, J. 2007. Das Azilien von Mas d’Azil. Der chronologische und kulturelle Kontext der Rückenspitzengruppen in Südwesteuropa. Dissertation. Köln, University of Cologne.
- Kotthaus, J. K. 2013. The late glacial Federmesser site of Borneck-Ost, Germany. Master’s thesis. Oslo, Oslo University.
- Kretschmer, I. 2015. *Demographische Untersuchungen zu Bevölkerungsdichten, Mobilität und Landnutzungsmustern im späten Jungpaläolithikum*. Kölner Studien zur Prähistorischen Archäologie 6. Rahden/Westf., Marie Leidorf.
- Krüger, S., Mortensen, M. F. and Dörfler, W. 2020. Sequence completed – palynological investigations on Lateglacial/Early Holocene environmental changes recorded in sequentially laminated lacustrine sediments of the Nahe palaeolake in Schleswig-Holstein, Germany. *Review of Palaeobotany and Palynology* 280, 104271.
- Leroi-Gourhan, A. 1964. *Le Geste et la Parole*, Vol. 1: Technique et langage. Paris, Albin Michel.
- Lemonnier, P. 1992. *Elements for an Anthropology of Technology*. Anthropological Papers 88. Ann Arbor, University of Michigan Museum of Anthropology.
- Lempcke, K.-H. 1996. Agethorst LA 9, Kreis Steinburg. Ein Federmesser-Fundplatz des Spätglazials. *Offa* 53, 7–26.
- Lempcke, K.-H. 2000. Ein mehrperiodischer steinzeitlicher Siedlungsplatz in Drage, Kreis Steinburg. *Archäologische Nachrichten aus Schleswig-Holstein* 11, 7–23.
- Löw, S. 2006. *Rüsselsheim 122 und die Federmessergruppen am Unteren Main*. Dissertation. Köln, Universität zu Köln.
- Lundström, V., Peters, R. and Riede, F. 2021. Demographic estimates from the Palaeolithic-Mesolithic boundary in Scandinavia: comparative benchmarks and novel insights. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences* 376, 20200037.
- Madsen, B. 1983. New Evidence of Late Paleolithic Settlement and East Jutland. *Journal of Danish Archaeology* 2, 12–31.
- Madsen, B. 1992. Hamburgkulturens flintteknologi i Jels (The Hamburgian Flint Technology at Jels). In: Holm, J. and Rieck, F. (eds.), *Istidsjægere ved Jelsøerne*. Haderslev, Haderslev Museum, 93–132.
- Madsen, B. 1996. Late Palaeolithic cultures of south Scandinavia: tools, traditions and technology. *Acta archaeologica Lundensia* 8(24), 61–72.
- Madsen, B. 2018. Fra rensdyrets og kæmpehjortens tidsalder – en gruppe bopladser fra istiden ved Randers. *Museum Østjylland Årbog* 2018, 60–73.
- Mathew, S. and Perreault, C. 2015. Behavioural variation in 172 small-scale societies indicates that social learning is the main mode of human adaptation. *Proceedings of the Royal Society B* 282, 20150061.
- Mauss, M. and Beuchat, H. 1979. *Seasonal variations of the Eskimo: a study in social morphology*. London, Routledge & Kegan Paul Books.
- Merkt, J. and Müller, H. 1999. Varve chronology and palynology of the Lateglacial in Northwest Germany from lacustrine sediments of Hämelsee in Lower Saxony. *Quaternary International* 61, 41–59.
- Mevel, L. and Grimm, S. B. 2019. From one camp to another. First results of a comparative techno-economic analysis of the Federmesser-Gruppen lithic industries from the Central Rhineland. In: Eriksen, B. V., Rensink, E., Harris, S. (eds.), *The Final Palaeolithic of Northern Eurasia. Proceedings of the Amersfoort, Schleswig and Burgos UISPP Commission Meetings, 13*. Kiel, Ludwig, 243–273.
- Migliano, A. B., Battiston, F., Viguier, S., Page, A. E., Dyble, M., Schlaepfer, R., Smith, D., Astete, L., Ngales, M., Gomez-Gardenes, J., Latora, V. and Vinicius, L. 2020. Hunter-gatherer multilevel sociality accelerates cumulative cultural evolution. *Science Advances* 6(9), eaax5913.

- Mortensen, M. F. 2007. *Biostratigraphy and chronology of the terrestrial late Weichselian in Denmark - New investigations of the vegetation development based on pollen and plant macrofossils in the Slotseng basin*. Dissertation. Aarhus, Universitet Aarhus.
- Muthukrishna, M., Morgan, T. J. and Henrich, J. 2016. The when and who of social learning and conformist transmission. *Evolution and Human Behavior* 37(1), 10–20.
- Nelson, M. C. 1991. The study of technological organization. *Archaeological Method and Theory* 3, 1991, 57–100.
- Pedersen, J. B., Poulsen, M. E. and Riede, F. 2022. Jels 3, a New Late Palaeolithic Open-Air Site in Denmark, Sheds Light on the Pioneer Colonization of Northern Europe. *Journal of Field Archaeology* 47, 360–378.
- Pedersen, K. B. 2009. *Stederne og menneskene: istidsjægere omkring Knudshoved Odde*. Vordingborg, Museerne.
- Petersen, B. F. 1992. Rundebakke. En senpalæolitiske boplad på Knudshoved Odde, Sydsjælland. *Aarbøger for nordisk Oldkyndighed og Historie* 1992, 7–40.
- Petersen, P. V. and Johansen, L. 1991. Sølbjerg I—An Ahrensburgian Site on a Reindeer Migration Route through Eastern Denmark. *Journal of Danish Archaeology* 10, 20–37.
- Petersen, P. V. and Johansen, L. 1994. Rensdyrjægere ved Sølbjerg på Lolland. *Nationalmuseets Arbejdsmark* 1994, 80–97.
- Pettitt, P., Rockman, M., and Chenery, S. 2012. The British Final Magdalenian: Society, settlement and raw material movements revealed through LA-ICP-MS trace element analysis of diagnostic artefacts. *Quaternary International* 272, 275–287.
- Pyżewicz, K., Gruzdź, W., Rozbiegalski, P. and Rakoca, A. 2020. Two methods of blade production among arch-backed point groups - a case study from the western polish lowland. In: Grimm, S., Mevel, L., Sobowiak-Tabaka, I. and Weber, M.-J. (eds.), *From the Atlantic to beyond the bug-finding and defining the federmessergruppen/azilian on the north European plain and adjacent areas*. Neumünster, Wachholtz, 91–104.
- Reuter, T. in press. The Social Significance of Technology in Hunter-Gatherer Communities - An Exploration of Lithic Manufacturing during the Lateglacial in Northern Europe. *Untersuchungen und Materialien zur Steinzeit in Schleswig-Holstein und im Ostseeraum*. Baden-Baden, Nomos
- Riede, F. and Edinborough, K. 2012. Bayesian radiocarbon models for the cultural transition during the Allerød in southern Scandinavia. *Journal of Archaeological Science* 39, 2012, 744–756.
- Rockman, M. 2003. Knowledge and learning in the archaeology of colonization. In: Rockman, M. and Steele, J. (eds.), *Colonization of unfamiliar landscapes. The archaeology of adaptation*. London, Routledge, 3–24.
- Rust, A. 1958. *Die jungpaläolithischen Zeltanlagen von Ahrensburg*. Offa-Bücher 15. Neumünster, Wachholtz.
- Schmidt, I., Gehlen, B. and Zimmermann, A. 2021. Population estimates for the Final Palaeolithic (14,000 to 11,600 years cal. BP) of Europe – challenging evidence and methodological limitations. In: Mevel, L., Weber, M.-J. and Maier, A. (eds.), *En mouvement - on the move - in Bewegung. Mobilités des hommes, des objets et des idées pendant le Paléolithique supérieur européen : mobility of people, objects and ideas during the European upper palaeolithic : Mobilität von Menschen, Objekten und Ideen im europäischen Jungpaläolithikum*. Paris, CNRS Éditions, 221–238.
- Schmidt, I., Gehlen, B., Winkler, K., Arrizabalaga, A., Arts, N., Bicho, N., Crombé, P., Eriksen, B. V., Grimm, S. B., Kapustka, K., Langlais, M., Mevel, L., Naudinot, N., Nerudová, Z., Niekus, M., Peresani, M., Riede, F., Sauer, F., Schön, W. and Maier, A. 2025. Large scale and regional demographic responses to climatic changes in Europe during the Final Palaeolithic. *PLoS ONE* 20(4), e0310942.
- Schwabedissen, H. 1954. *Die Federmesser-Gruppen des nordwesteuropäischen Flachlandes: Zur Ausbreitung des Spät-Magdalenien*. Offa-Bücher 9. Neumünster, Wachholtz.
- Shennan, S., Edinborough, K. 2007. Prehistoric population history: from the Late Glacial to the Late Neolithic in Central and Northern Europe. *Journal of Archaeological Science* 34(8), 1339–1345.
- Shott, M. J. 1996. An Exegesis of the Curation Concept. *Journal of Anthropological Research* 52, 259–280.
- Simmel, G. 1992. *Soziologie. Untersuchungen über die Formen der Vergesellschaftung*. Georg Simmel-Gesamtausgabe 11. Frankfurt a. M., Suhrkamp.
- Street, M., Gelhausen, F., Grimm, S.B., Moseler, F., Niven, L., Sensburg, M., Turner, E., Wenzel, S. and Jöris, O. 2006. Inoccupation du bassin de Neuwied (Rhénanie centrale, Allemagne) par les Magdaléniens et les groupes à Federmesser (aziliens). *Bulletin de la Société préhistorique française* 103(4), 753–780.
- Trölsch, O. 1976. Altsteinzeitliche Siedlungsplätze in der Umgebung von Mölln, Herzogtum Lauenburg. *Offa* 33, 5–42.
- Tromnau, G. 1975. *Neue Ausgrabungen im Ahrensburger Tunneltal. Ein Beitrag zur Erforschung des Jungpaläolithikums im nordwesteuropäischen Flachland*. Offa-Bücher 33. Neumünster, Wachholtz.
- Turnbull, C. M. 1968. The importance of flux in two hunting societies. In: Lee, R.B. and DeVore, I. (eds.), *Man the Hunter*. New York, de Gruyter, 132–137.
- Weber, M.-J. 2012. *From technology to tradition: Re-evaluating the Hamburgian-Magdalenian relationship*. *Untersuchungen und Materialien zur Steinzeit in Schleswig-Holstein und im Ostseeraum* 5. Neumünster, Wachholtz.

- Weber, M.-J. 2013. Late Upper and Late Palaeolithic reindeer hunting in the Ahrensburg tunnel valley – Differences between Hamburgian and Ahrensburgian hunting tactics. In: Grimm, O. and Schmölcke, U. (eds.), *Hunting in northern Europe until 1500 AD. Old traditions and regional developments, continental sources and continental influences*. Neumünster, Wachholtz, 75–90.
- Wengrow, D. and Graeber, D. 2015. Farewell to the ‘childhood of man’: ritual, seasonality, and the origins of inequality. *Journal of the Royal Anthropological Institute* 21, 597–619.
- Wild, M. 2020. *Coping with Risk Through Seasonal Behavioural Strategies. Technological Analysis of Selected Late Upper Palaeolithic Antler Assemblages from Northern Germany, Southern Scandinavia and the Paris Basin*. Untersuchungen und Materialien zur Steinzeit in Schleswig-Holstein und im Ostseeraum 12. Neumünster, Wachholtz.
- Wild, M., Mortensen, M. F., Andreasen, N. H., Borup, P., Casati, C., Eriksen, B., Frost, L., Gregersen, K. M., Henriksen, M. B., Kanstrup, M., Olsen, J., Pedersen, K. B., Petersen, P. V., Ramskov, C., Sørensen, L., Sørensen, M. and Wåhlin, S. 2020. Palaeolithic bone and antler artefacts from Lateglacial and Early Holocene Denmark: technology and dating. *Quartär* 67, 105–181.
- Winkler, K. 2010. Der spätpaläolithische Fundplatz Golßen, Lkr. Dahme-Spreewald. Analyse der Steinartefakte und Befunde der Grabung 1968. *Veröffentlichungen zur brandenburgischen Landesarchäologie* 41–42, 7–93.

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# Questioning the linear evolution of the Federmesser-Gruppen/ Late Azilian lithic assemblages

Insights from Northern Germany  
and the Paris Basin

Tobias Reuter, Sofiane Bouziane,  
Mara-Julia Weber and Ludovic Mevel

## **Abstract**

Issues related to the evolution of Late Glacial societies have been a shared focus of research across Europe for several decades. The widespread use of technological approaches to Late Glacial lithic industries has led to the assumption of relative homogeneity in technical traditions across Europe. The archaeological contexts of northern France and the Paris Basin, due to the extensive nature of the excavations carried out and the good preservation of the occupations, have led to the evolutionary model of these regions being generalized to other contexts. However, this rather convenient adoption of the rhythm of change proposed in the Paris Basin suffers from several difficulties. In this paper, we wish to re-examine the proposed evolution in the Paris Basin by revisiting the Closeau and Saleux assemblages, which have undergone a major revision, and comparing these results with those recently obtained in northern Germany. We will see that the situation is much more complex than initially envisaged and that a gradual and linear evolution of the lithic industries for these periods is now far from being the most parsimonious hypothesis.

*Keywords: Late Glacial, lithic industry, lithic technology*

## **From Paris to Schleswig: the evolution of the Azilian and Federmesser-Gruppen**

The question of the evolution of technological systems during the Late Palaeolithic is a fruitful area of research that has been the subject of numerous debates among researchers working on these periods at the European scale. This has resulted in numerous international conferences and round tables organized in the 1990s and 2000s (Cupillard and Richard 2000; Fagnart and Thévenin 1997; Olive and Valentin 2006;

Otte 1988; Pion 2000; Valentin *et al.* 2000). Taking advantage of the discovery of new sites, particularly open-air ones, and the rise of technological approaches to lithic assemblages, these meetings made it possible to redefine the evolutionary trajectories of societies during these periods in considerable detail. However, our knowledge still has considerable room for improvement for several reasons. The first, already highlighted by several colleagues, concerns the apparent homogeneity or homogenization of the technical traditions that succeeded those of the late Magdalenian (Upper/late Magdalenian, Hamburgian, Creswellian) due to the systematization of technological approaches on a European scale (Naudinot *et al.* 2019). Indeed, these shared analytical criteria have had the effect of smoothing our perception of the technical phenomena of these periods by postulating, on a European scale, a gradual simplification of flint knapping methods from GI-1e to GI-1a (see Holzkämper *et al.* 2013; Naudinot *et al.* 2019).

A second sticking point relates to the inaccuracy of radiometric calibrations and the scarcity of stratified open-air settlements. Regarding direct dating, the problems are linked as much to the level of precision of the measurements taken as to their rarity, due to a lack of datable material. This is why it is almost impossible – given the data currently available – to propose a reliable periodization of changes within lithic technical systems, regardless of the geographical scale considered (micro- or macro-regional). The scarcity of stratified occupations makes it impossible to overcome this chronological imprecision and propose a seriation of techno-economic changes, particularly during the GI-1c-b for lithic traditions attributed to the late Azilian or Federmesser-Gruppen (FMG).<sup>1</sup>

While in certain regions, particularly in the Paris Basin, the situation is relatively clear over the long term, especially with regard to the various breaks that we are able to identify between the end of the Magdalenian and the beginning of the Mesolithic, the situation is much less clear with regard to the late Azilian (Bodu 2000; Bodu *et al.* 2011; Jacquier *et al.* 2021; Mevel and Bodu 2018; Valentin 1995). Following the discovery and initial analyses carried out on Le Closeau (Rueil-Malmaison), a proposal for the seriation of the Late Azilian was put forward (Bodu and Valentin 1997). This was based on a possible dichotomy in the lithic industries of the late Azilian phase, with assemblages showing a still pronounced laminar tendency

on the one hand and productions considered to be more simplified on the other. Due to a lack of radiometric or stratigraphic arguments, it was only cautiously proposed that the Azilian underwent a gradual transformation: an early phase still showing some affinities with the Magdalenian; an intermediate phase that would coincide with a significant shift in technical behaviour, with less laminar and more simplified productions; and a final phase that would coincide with the most simplified productions (Bodu and Valentin 1997).

In contrast to the Paris Basin, the classification of FMG in northern Germany reveals a markedly different trajectory of research history. The foundational work of Schwabedissen (1954) established the first systematic classification of FMG assemblages in the North European Plain, proposing a tripartite division into Wehlen, Tjonger, and Rissen groups based on typological criteria of tools and projectile points. This classification system was the first attempt to organise the growing number of surface collections of FMG material on the North European Plain at that time.

However, subsequent research has demonstrated the inadequacy of Schwabedissen's original framework. The differentiation of backed points and tools according to his system has proven inconsistent, with chronological and spatial distinctions failing to correspond to the archaeological record (Ikinger 1998, 281–284; Paddayya 1971, 260–270). Despite these recognized shortcomings, Schwabedissen's classification continued to influence subsequent research for several decades, being employed by numerous archaeologists in their analyses of FMG assemblages in northern Germany (*e.g.* Bokelmann 1978; Bokelmann *et al.* 1983; Breest 1999; Clausen 1998; Günther 1973; Lempcke 1996).

The subsequent classification effort by Ikinger (1998) attempted to address these deficiencies by revising the typological approach to backed points. However, this classification system has a fundamental weakness: it lacks a precise chronological framework. Without a more precise temporal framework, Ikinger's classification offers little insight into changes over time or the development and dispersal of specific point types (Street *et al.* 2001, 380). This severely constrains its utility for investigating cultural development and technological change across FMG assemblages.

More recently, researchers have frequently adopted the assumed chronological distinctions developed for the Paris Basin and applied them to geographically distant assemblages *e.g.* in southern and central Germany and southern Britain. This practice reflects both the appeal of the evolutionary model and the absence of regionally specific alternatives. For instance, the identification of bipoints in inventories from Hengistbury-type sites has been interpreted as evidence for the presence of *Azilien*

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1 In the framework of this paper, we will not discuss the taxonomy used for the lithic traditions. From northern Germany to the Somme valley the GI-1c-b industries are generally attributed to the so-called Federmesser-Gruppen (FMG). In southern areas, including the centre of the Paris Basin, the lithic industries are designated as (Early or Late) Azilian.

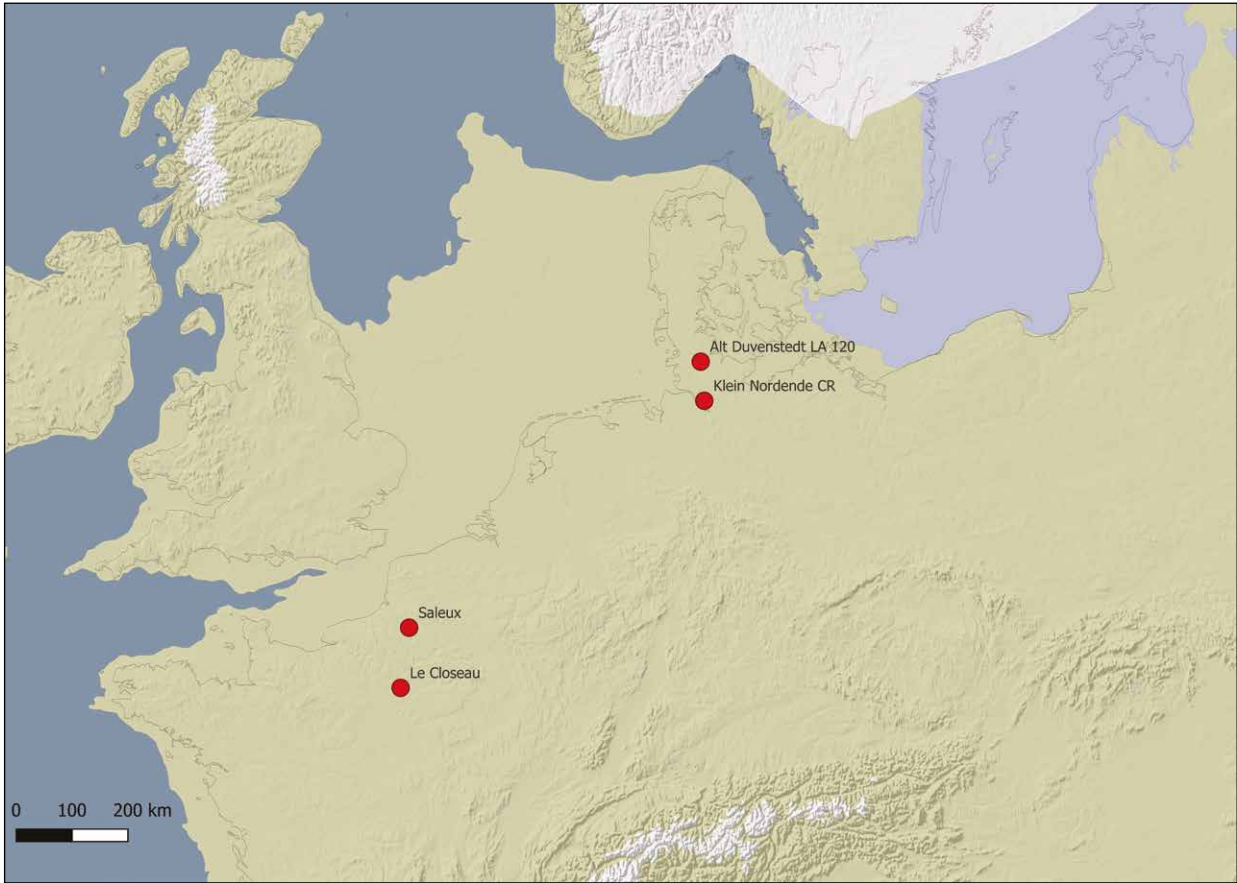


Figure 1: Archaeological sites of the FMG and late Azilian discussed in this paper in the context of the presumed landscape of northwestern Europe during the Allerød (background map: [www.ephz.zbsa.eu](http://www.ephz.zbsa.eu); graphic: Reuter).

*ancien* in northwestern distribution areas (Barton 2015, 37; 2024; Mills 2022). Similarly, assemblages containing backed points exhibiting opportunistic reduction methods have been assigned to later chronological phases than those displaying more elaborate reduction strategies and vice versa (Heidenreich 2008; Holzkämper *et al.* 2013).

However, this rather convenient adoption of the rhythm of change proposed in the Paris Basin suffers from several difficulties. In this paper, we wish to re-examine the proposed evolution in the Paris Basin by revisiting the Closeau and Saleux assemblages, which have undergone a major revision, and comparing these results with those recently obtained in northern Germany (Burau 2019; Reuter *in press*) (Fig. 1). We begin by establishing a chronological framework for both regions, before presenting detailed technological comparisons that reveal significant variability within contemporaneous assemblages. We will see that the situation is much more complex than initially envisaged and that a gradual and linear evolution of the lithic industries for these periods is now far from being the most parsimonious hypothesis.

### A Chronological Perspective on Lithic Assemblages from Northern Germany and the Paris Basin

Both northern Germany and the Paris Basin share the general chronological and evolutionary framework of North-West Europe with the Azilian or the FMG following the Magdalenian and its lowland variant, the Hamburgian. This change also represents the transition from the Upper to the Late Palaeolithic. The timing of this major shift seems to be situated after the Early Azilian in the Paris Basin and the younger Havelte phase of the Hamburgian in the lowlands (Grimm 2019). Interestingly, radiocarbon dates and stratigraphic information in both regions show a chronological continuity or even overlap of the Magdalenian and Hamburgian on the one hand and the Early Azilian and FMG on the other hand from GI-1e via GI-1d to GI-1c2. However, these direct dating methods show a fairly clear diachrony between the two regions – with fairly limited overlap – for cultural groups that could have been considered contemporary. Of course, the dating remains limited, and it would be necessary to supplement these data with new measurements (Fig. 2).

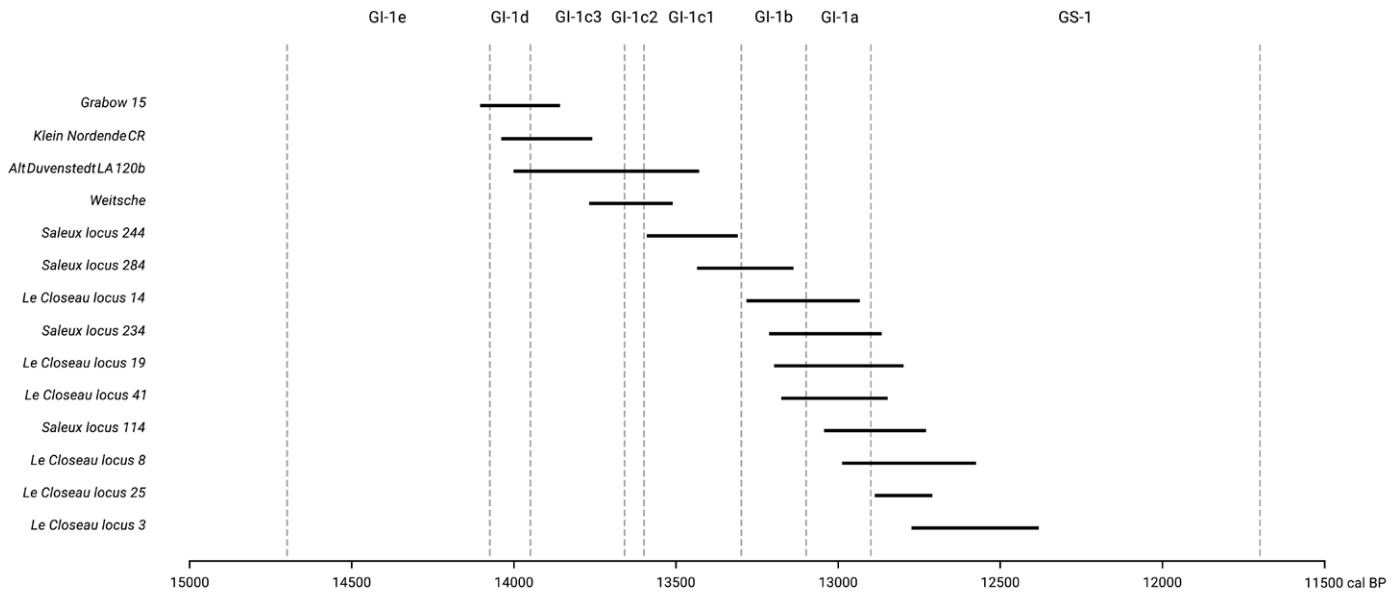


Figure 2: Probability distributions of calibrated radiocarbon dates from FMG and late Azilian sites in Northern Germany and Northwest France (Tab. 1) plotted on the INTIMATE proposed event stratigraphy (Björck *et al.* 1998). Black bars show 2-sigma probability ranges. Multiple dates from individual sites (Grabow 15, Klein Nordende CR, Weitsche, Le Closeau locus 41 and Le Closeau locus 25) were statistically combined using OxCal's R\_Combine function.

In northern Germany, the radiocarbon date for the Havelte site Ahrenshöft LA 58D matches exactly that of the FMG occupation at Klein Nordende CR (Clausen 1998) and, after calibration, shows the same range as the FMG sites Grabow 15, Weitsche, Klein Nordende CR and Alt Duvenstedt LA 120 (Reuter in press). Additionally, Klein Nordende CR is stratigraphically associated with the *Hippophaë* maximum of the Meindorf interstadial (Bokelmann *et al.* 1983). In the southern part of the Paris Basin, the Magdalenian sequences at Pincevent and Étioilles yielded radiocarbon dates which cover not only GI-1e and GI-1d but reach into GI-1c3 after calibration (Bodu *et al.* 2006; Roblin-Jouve *et al.* 2016). Hence, they are contemporaneous and, for some of them, younger than the  $^{14}\text{C}$  results obtained for the Early Azilian at Le Closeau (Bodu *et al.* 2006). Moreover, the Early Azilian occupations appear in the lower geological level at Le Closeau, which comprises a soil formation attributed to the Bølling (Chaussé 2005). This attribution corresponds to that of the lower soil formation at Étioilles, underlying the uppermost Magdalenian level in the locus 2 (Roblin-Jouve *et al.* 2016). The palaeosol of Belloy-sur-Somme, attributed to the Allerød, represents an important stratigraphic marker in the Somme Basin (Fagnart 1997). At Hangest-sur-Somme III-1, it overlies an Early Azilian occupation indicating again the origin of this tradition pre-dating GI-1c3.

The two regions addressed here equally share the difficulty of creating an internal chronology of the Azilian and the FMG apart from their early phases. In the southern Paris Basin, Le Closeau represents a key-site at

which the Azilian assemblages of the upper stratigraphic level have been subdivided in three phases according to technological observations and a supposed evolution of the technical behaviour: an intermediate phase, a late phase and an undetermined phase (Bodu and Valentin 1997). The chronological value of the technological differences could not be demonstrated by radiocarbon dates, which are not all securely correlated with the archaeological material and which overlap between the phases. Also, several measurements highlight probable pollution of the dated samples. It is particularly true for the  $^{14}\text{C}$  dates for locus 3 and 8 whose stratigraphic position and nature of the assemblages are incompatible with dating during the Younger Dryas (Tab. 1, Fig. 2). Recently, re-analyses of different lithic inventories, moreover, showed comparable behaviour beyond the phases whereas contemporaneous  $^{14}\text{C}$  dating ranges of locus 14 of Le Closeau and 234 of Saleux (Tab. 1) are associated with clear differences in the lithic assemblages. In the Somme Basin, Late Glacial sediments are rather well preserved and make it possible to suggest a chronological subdivision of the Late Azilian. Hence, the site of Conty can be dated by stratigraphy and radiocarbon measurements to an early phase of the Allerød (Antoine *et al.* 2012), whereas the upper level of Hangest-sur-Somme III-1 and the site of Saleux are attributed by the same methods to the late Allerød (Coudret and Fagnart 2021; Fagnart 1997). For the FMG in northern Germany, a relative chronological indicator is the position of lithic assemblages within palaeosols attributed generally to the Allerød at Klein Nordende and in the Ahrensburg Tunnel Valley

Site	Region	Lab. code	<sup>14</sup> C BP ±	cal BP (95.4% confidence interval)	Dated material	Method	Reference
Grabow 15	N Germany	KIA-41862	12125 ± 50	14112–13780	charcoal ( <i>Betula</i> sp.)	AMS	Tolksdorf <i>et al.</i> 2013
Grabow 15	N Germany	KIA-41861	12070 ± 100	14217–13613	bone fragments (calcined and unburnt)	AMS	Tolksdorf <i>et al.</i> 2013
Klein Nordende CR	N Germany	KIA-2124	12035 ± 110	14165–13606	plant macrofossil ( <i>Populus</i> sp.)	conv.	Bokelmann <i>et al.</i> 1983
Klein Nordende CR	N Germany	KIA-2152	11990 ± 100	14074–13606	plant macrofossil ( <i>Populus</i> sp.)	conv.	Bokelmann <i>et al.</i> 1983
Weitsche	N Germany	KIA-26439	11980 ± 120	14107–13522	bone fragment (calcined)	AMS	Veil <i>et al.</i> 2012
Alt Duvenstedt LA 120b	N Germany	AAR-2244	11780 ± 110	14002–13429	charcoal	AMS	Kaiser and Clausen 2005
Weitsche	N Germany	KIA-35664	11755 ± 50	13755–13500	bone fragment (calcined)	AMS	Veil <i>et al.</i> 2012
Saleux locus 244	NW France	GrA-18832 (Lyon-1566)	11640 ± 70	13587–13307	metapodial ( <i>Bos primigenius</i> )	AMS	Coudret and Fagnart 2021
Saleux locus 284	NW France	Lyon-4303 (GrA)	11440 ± 70	13431–13134	diaphysis (non determined)	AMS	Coudret and Fagnart 2021
Le Closeau locus 14	NW France	AA 21677 (Lyon 358)	11240 ± 80	13282–12932	charcoal	AMS	Bodu 1998
Saleux locus 234	NW France	GrA-15945 (Lyon-1141)	11200 ± 70	13213–12866	Femur ( <i>Bos primigenius</i> )	AMS	Coudret and Fagnart 2021
Le Closeau locus 41	NW France	Ly-567	11170 ± 105	13236–12785	charcoal	AMS	Bodu 1998
Le Closeau locus 19	NW France	Ly-561	11165 ± 90	13198–12798	charcoal	AMS	Bodu 1998
Le Closeau locus 41	NW France	Ly-568	11120 ± 100	13141–12746	charcoal	AMS	Bodu 1998
Saleux locus 114	NW France	OxA-4932 (Lyon 81)	11010 ± 80	13044–12729	bone ( <i>Bos primigenius</i> )	AMS	Coudret and Fagnart 2021
Le Closeau locus 25	NW France	Ly-564	10885 ± 85	12983–12679	charcoal	AMS	Bodu 1998
Le Closeau locus 8	NW France	OxA 6337 (Lyon 312)	10840 ± 110	12988–12575	bone	AMS	Bodu 1998
Le Closeau locus 25	NW France	Ly-563	10755 ± 90	12808–12540	charcoal	AMS	Bodu 1998
Le Closeau locus 3	NW France	Lyon 7189	10670 ± 110	12773–12381	charcoal	AMS	Bodu 1998

Table 1: Radiocarbon dates and associated information from FMG/late Azilian sites of Northern Germany and the Paris Basin.

(Bokelmann *et al.* 1983; Tromnau 1975). Finally, directly dated single finds of osseous material show a different rhythm of change between osseous and lithic technology (Clausen 2004; Wild and Weber 2017) but cannot contribute either to a chronological subdivision of the FMG.

### The Paris Basin: clear technical variability

The study of lithic industries from the sites of Le Closeau (Bodu 1998; Jacquier *et al.* 2021; Mevel and Bodu 2018) and Saleux (Coudret and Fagnart 2004; 2015; 2021) highlights strong contrasts, revealing the technological variability of

lithic industries dated to the Allerød period. In this study, particular attention has been given to locus 234 at Saleux and to loci 1/11, 14, 19, 26, and 36 at Le Closeau.

At both Saleux and Le Closeau, the raw material used is essentially local (Coniacian flint at Saleux, Campanian flint at Le Closeau) and of good knapping quality. However, differences emerge in the selection of volumes. At Saleux, the exploited nodules reveal a stricter and more homogeneous selection, with elongated, oblong forms of regular shape, most often measuring less than 20 cm. At Le Closeau, a greater variability can be observed within the chosen

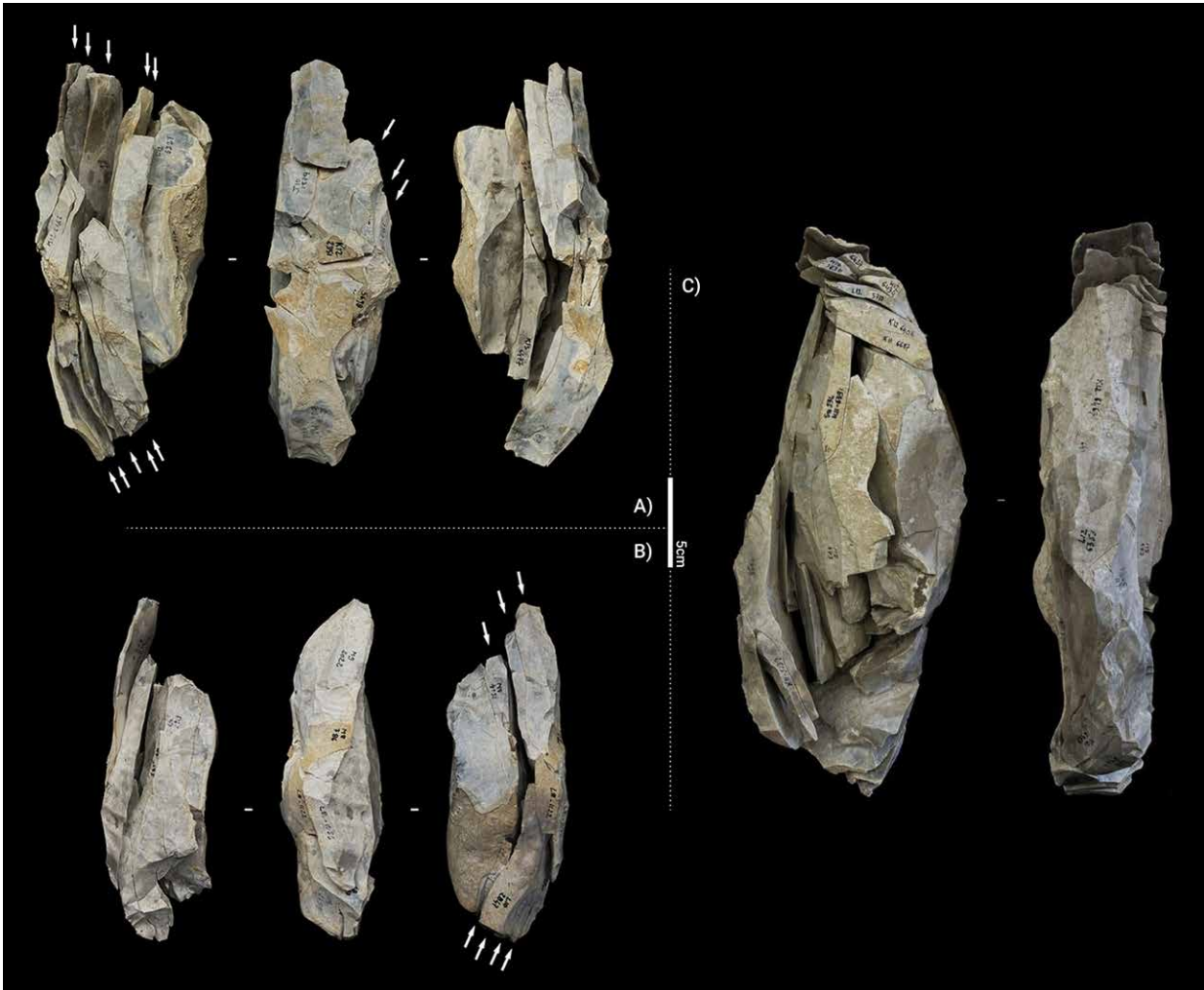


Figure 3: Examples of refit complexes from Le Closeau. A) Unipolar blade debitage with unprepared butts (Le Closeau locus 26). B) Unipolar debitage of elongated, blade-like blanks without striking platform preparation (Le Closeau locus 14). C) Debitage of fairly thick blades from two opposed striking platforms (Le Closeau locus 19) (photos and graphic: Bouziane).

blocks: the cores, often only lightly exploited, indicate a preference for elongated, ovoid, or even spherical volumes, generally ranging between 20 and 25 cm in length. Despite these morphological differences, the overall length of the blocks remains broadly comparable between the two sites.

The technological analyses carried out on both sites, based on the examination of numerous refittings, have clarified the production objectives. The refitting sequences suggest that the core reduction was primarily oriented toward the production of elongated blanks with variable degrees of regularity (Bouziane 2021; 2022; Coudret and Fagnart 2004; 2015; 2021; Jacquier *et al.* 2021; Mevel and Bodu 2018).

The comparison reveals notable differences in the regularity and the degree of standardization of the products obtained. At Saleux, the main objective was the production of blades with a straight profile, approximately 8–10 cm

long (Fig. 3). These productions are fairly regular, carefully executed, and well-calibrated. The pronounced laminar character of the Saleux assemblage represents a major contrast with Le Closeau, where the resulting products are far less regular and correspond more to ‘laminar-like’ flakes than to true blades. Thus, while the productions already differ in their degree of regularity, the lithic assemblages from these two sites also reveal different strategies in the organization of debitage (Fig. 4).

At Saleux, blade production was generally carried out from two opposed striking platforms. Blades were alternately produced from each platform, with the changes serving simultaneously to maintain the convexities of the core (Fig. 3). The shaping and preparation stages, though relatively simple, reflect a diversity of technical choices, including the use of natural convexities or the creation of crests to initiate laminar production. Backs could also occasionally be modified



in various ways, with negatives of transverse removals suggesting the installation of posterior crests. Knapping was performed with a soft stone hammer, generally set back from the platform edge. The butts, fairly thick, were frequently prepared by abrasion, sometimes very pronounced, or by faceting. Striking platforms were regularly maintained by the removal of rejuvenation flakes or tablets.

At Le Closeau, by contrast, refits reveal simplified and less constrained chaînes opératoires, resulting in irregular and poorly standardized productions. Core preparation is minimal or even absent, and maintenance stages are very limited, sometimes even non-existent (Fig. 4). Knapping was carried out with a hard stone hammer, without butt preparation: striking platforms are generally plain, overhangs are only rarely abraded, and the butts are often thick (Fig. 4). Compared to Saleux, the reduction sequences at Le Closeau are far less standardized and regular, with one or two striking platforms established depending on the morphology of the blocks or flakes exploited.

In both cases, production was clearly oriented towards the acquisition of elongated blanks intended for the manufacture of backed pieces, particularly points, which hold a central place within both assemblages. Beyond this shared objective, however, the toolkits of the two sites show significant differences.

Le Closeau is characterized by a very small number of retouched tools. Aside from backed points, which dominate across all studied loci, retouched tools are relatively scarce and not very diverse. As a result, the toolkit is largely composed of unmodified blanks/unretouched tools. These do not correspond to any specific type of blank but instead appear to have been selected according to certain particular attributes (sharp edges, cutting angles, delineation). Moreover, recent use-wear studies (Jacquier *et al.* 2021) have revealed a rather unexpected activity for a Late Palaeolithic site: the importance of plant processing. This activity accounts for the largest share of documented use zones: from the nine loci at Le Closeau that have been studied (loci 1, 11, 26, 14, 16, 20, 34, 36, and 41), 80 out of 247 use zones (33%) show use-wear traces attributable to plant processing (Jacquier unpublished).

The situation at Saleux is markedly different: the number and diversity of retouched tools has no comparison with what has been documented at Le Closeau. While backed points remain predominant, the lithic assemblages of Saleux yielded numerous backed knives, scrapers, burins, and other retouched tools (Coudret and Fagnart 2004; 2015; 2021), suggesting more intensive and varied activities, which also point to the high functional potential of the series.

In sum, although both sites share a common emphasis on the production of backed points, the richer and more diversified toolkit of Saleux stands in sharp contrast to

the scarcity observed at Le Closeau – an opposition that may reflect differences in occupational dynamics and site functions.

### Northern Germany: a similar situation

The examination of Late Glacial lithic assemblages of Klein Nordende CR and Alt Duvenstedt LA 120 provides crucial insights into technological variability during the early FMG in northern Germany. The data from Alt Duvenstedt LA 120 derive from Reuter (in press), while the assemblage from Klein Nordende CR is based on an unpublished analysis by Bureau (2019).

The two sites demonstrate markedly different approaches to the selection of raw materials, reflecting distinct technological organisations. At Klein Nordende CR, knapping was carried out using small, flat nodules with a visible wind polish. Despite the availability of larger, more bulky flint nodules in the region, this selection strategy appears to have been consistently applied. The preference for flatter raw materials suggests a technological approach specifically adapted to the morphological characteristics of these nodules. In contrast, Alt Duvenstedt LA 120 demonstrates a deliberate selection of bulky, high-quality nodules. This choice emphasizes raw material quality and volume.

The degree of core preparation represents one of the most significant technological differences between the two assemblages. Klein Nordende CR exhibits minimal to absent core preparation (Fig. 5). Striking platform preparation involved multiple flakes but generally excluded cortex removal, which was unnecessary given the cores' naturally flat morphology. Initial blade removals typically occurred from a single platform without extensive cortex removal, followed by core rotation and further flaking from other platforms.

Alt Duvenstedt LA 120 displays intensive but simple core preparation methods. The operational sequence included thorough decortication and careful preparation of single platforms through both large and fine flaking. Platform preparation involved massive flake removals that created suitable striking surfaces for subsequent blade production. Decortication took place through the detachment of very sizeable blades and blade-like flakes, generating plain and even surfaces with pronounced convexities at the edges (Fig. 6).

The progression of blade production reveals fundamental differences in technological organization between the sites. Klein Nordende CR demonstrates short, irregular sequences with *ad hoc* reduction strategies that were largely dependent on raw material characteristics. Blade series rarely exceeded five consecutive removals, and reduction patterns lacked systematic organization. Cores exhibit few negatives or irregular flake removals, with morphologies ranging from cylindrical to flatter forms. Reduction was

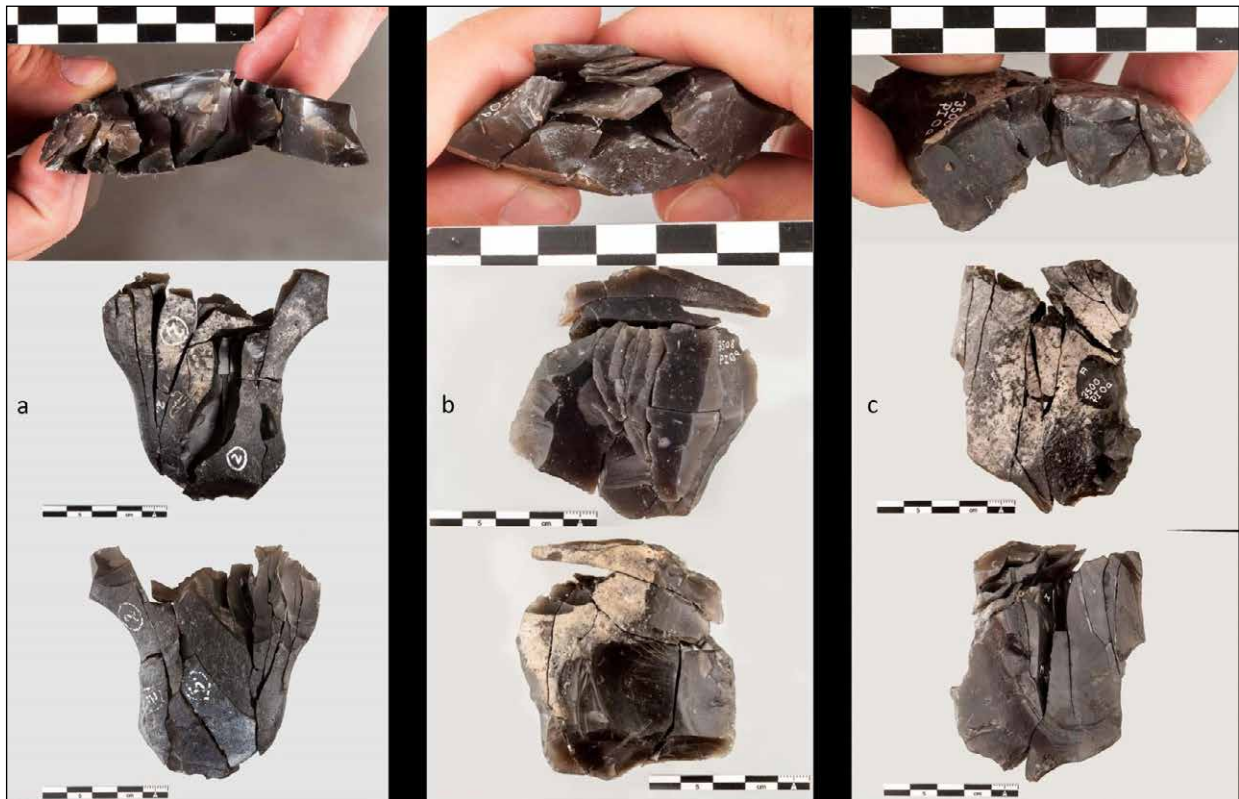


Figure 5: Refit complexes of the lithic assemblage from Klein Nordende CR. Note that at least two blades are missing in the reduction sequence in the middle of each refitting complex (photos: Janke, Stiftung Schleswig-Holsteinische Landesmuseen, Schloss Gottorf).

generally asymmetrical and primarily dictated by the natural shape of the raw nodules. All refitted complexes display a unidirectional blade removal strategy. Alt Duvenstedt LA 120 exhibits simple but regular sequences with systematic reduction approaches. The operational scheme demonstrates clear hierarchical organization with distinct production stages: (1) initial preparation, (2) thorough preparation, (3) blade sequences, and (4) tool and backed point production. Multiple blade sequences were detached from each core, though refits of more advanced reduction stages and cores in general are missing (only two and rather irregular cores), indicating the removal of cores at more advanced reduction stages.

Technological analysis reveals distinct percussion strategies between the assemblages. The knappers at Klein Nordende CR employed hard hammer direct percussion techniques, as evidenced by numerous cones of force, moderate bulbs, relatively few lips, and moderate presence of bulbar scars. At Alt Duvenstedt LA 120, both hard and soft hammer direct percussion techniques were utilized. Considering the striking properties of the artefacts of the refit complexes, it is evident that artefacts of the preparation phase in particular indicate the application of the hard striking with large bulbs and large and thick platform remnants, while during the manufacture of

blades the utilization of a soft hammer is apparent, based on proximal blade attributes of pronounced lip formation and careful preparation of platform edges.

The sites show different priorities when it comes to producing and selecting blanks. The knappers at Klein Nordende CR focused primarily on producing blades for projectile points. The absence of edge-parallel, thin, cortex-free blades within refits is interpreted as intentional removal for the purpose of transforming them into projectile points. In contrast, Alt Duvenstedt LA 120 demonstrates broader production objectives, targeting long blades for both points and tools. However, the rather large backed points with proximal blade sections remaining have been interpreted as functioning as knives. Thus, blade and flake production was mainly aimed at producing domestic tools. Refit analysis reveals that blades from individual sequences were systematically transformed into distinct tool types.

The secondary modification of blanks reveals significant differences in tool and point production strategies. The modified pieces produced at Klein Nordende CR exhibit simple and variable retouching and consist mostly of burins and presumably projectile points that have been removed from the site. These tools exhibit limited standardisation. In contrast, Alt Duvenstedt LA 120 produced standardised tools and points with systematic retouching. The assemblage



Figure 6: Refit complexes of the lithic assemblage from Alt Duvenstedt LA 120, a) depicting intense core preparation, b) serial production of blades, c) careful platform edge preparation and d) serial production of tools. After Reuter in press, figs. 50.53–55 (photos: Janke, Stiftung Schleswig-Holsteinische Landesmuseen, Schloss Gottorf).

Region	Site	Choice of Raw Material	Preparation Methods	Progression of Blade Production & Stages	Knapping Technique	Production Objectives & Blank Selection	Technological Characteristics of Tools
NW France	Saleux	Local raw material, fairly regular oblong volumes	Simplified core preparation (crest or preliminary flaking)	Exploitation from two opposed striking platforms, polarity changes to maintain convexities	Soft stone hammer, abraded butts	Blades and laminar products for backed points and retouched backed knives	Predominance of backed points, greater tool diversity (retouched knives, projectile points, endscrapers, burins)
NW France	Le Closeau	Local raw material, variability in selected volumes, different sizes and shapes (elongated, ovoid, spherical)	Low to absent	Irregular and poorly standardized, mainly 'laminar-like' products and flakes	Mostly hard stone without striking platform preparation, few blades sometimes display abraded butts	'Laminar-like' products for backed points	Predominance of backed points, very low tool diversity, significant part of unretouched tools
N Germany	Alt Duvenstedt LA 120	Deliberate selection of bulky, high-quality nodules	Intensive, but simple core preparation	Simple, regular sequences, systematic reduction	Hard and soft hammer percussion	Long blades for points and tools	Standardized tools and points, systematic retouch
N Germany	Klein Nordende CR	Deliberate selection of flat and small pebbles	Minor to absent	Short, irregular sequences, ad hoc reduction, raw material dependent	Hard hammer percussion	Mainly blades for projectile points	Simple and variable retouch, mostly burins and presumably projectile points

Table 2: Schematic representation of technological aspects of the assemblages from NW France (Le Closeau, Saleux) and Northern Germany (Alt Duvenstedt LA 120, Klein Nordende CR).

includes a diverse range of tool types, such as 13 backed points, 44 end scrapers, 34 burins, and 11 truncations. A total of 124 modified pieces are found against 900 lithic artefacts (excluding splinters), demonstrating a high modification rate produced through systematic blank selection. This pattern is particularly noteworthy given the relatively small surface of the settlement, suggesting intensive tool production activity within a spatially restricted area. Refit complex analysis shows that consecutive blanks from individual reduction sequences were transformed into functionally related tool sets. For instance, one refit complex comprises five burins and one scraper, the blanks of which were all detached consecutively.

Based on these observations, the two sites exhibit contrasting lithic reduction strategies: Klein Nordende CR focused on opportunistic production from small, flat nodules with minimal core preparation to yield blanks primarily for projectile points, whereas Alt Duvenstedt LA 120 employed a systematic, intensive strategy using bulky, high-quality nodules to produce standardized tools and points after extensive core preparation.

### **Linear evolution? A model that remains difficult to argue in the light of archaeological data**

The chronological model positing a progressive shift from real blade production to blade like flake production faces significant challenges when confronted with absolute dating evidence and detailed technological analysis. The situation in northern Germany provides a particularly striking counterexample: Klein Nordende CR, with its simplified production sequences, minimal core preparation, and irregular blade production, would be expected to represent a late phase under the linear evolution model. Yet Alt Duvenstedt LA 120, displaying intensive core preparation, systematic reduction approaches, and carefully organized production stages, does not necessarily predate it in any straightforward chronological sequence. In the Paris Basin and northern France, the chronological argument encounters similar difficulties. A compelling example concerns locus 14 at Le Closeau and locus 234 at Saleux, which yielded statistically indistinguishable radiocarbon ages: locus 14 dated to  $11240 \pm 80$  BP (12932–13282 cal BP), while locus 234 produced dates of  $11200 \pm 70$  BP (12866–13213 cal BP) and  $11160 \pm 70$  BP (12821–13142 cal BP). Despite this chronological contemporaneity, the lithic industries from these contexts exhibit fundamentally different technological characteristics. Le Closeau locus 14 displays the expedient production typical of the site – irregular sequences, minimal preparation, hard hammer percussion, and laminar-like flakes rather than true blades. In stark contrast, Saleux locus 234 demonstrates the carefully organized, standardized blade production characteristic of

that site, with soft hammer percussion, systematic platform preparation, and regular blade morphologies. If temporal differences were the main factor underlying technological variation, these contemporaneous assemblages should exhibit broadly similar characteristics – yet they do not.

Furthermore, the issue arises regarding how the Le Closeau material has been divided into several horizons based on perceived technological variations. Upon revision, these variations appear less pronounced than initially suggested. The laminar character of some productions at Le Closeau requires significant nuancing; in reality, only a limited number of blades are present at the site. Despite this, the supposed laminar nature of certain assemblages was originally used to justify dividing the site into different chronological units and to position some occupations earlier in the sequence. This circular reasoning – using assumed technological evolution to establish chronology, then using that chronology to explain technological change – undermines the explanatory power of the linear model. In fact, these productions could also be contemporary. Le Closeau locus 36, which has been the subject of a study that can be described as exhaustive (Jacquier *et al.* 2021), has shown that several flint blocks were used to produce regular blades, all of which were exported outside the unit (Jacquier *et al.* 2021, Fig. 6). Conversely, Le Closeau locus 14 – also studied exhaustively – shows the presence of a few regular blades that in no way correspond to the supports produced on site (considering the regularity of the supports and the percussion technique – see Bouziane 2022). Therefore, the coexistence of chaîne opératoire with different purposes and highly variable degrees of regularity is a lead that should not be overlooked.

Given the limitations of the chronological hypothesis, several alternative or complementary explanatory frameworks have been proposed, including raw material availability, environmental adaptation, and regionalization processes resulting from weakening supra-regional social networks (cf. Reuter, this volume). However, none of these hypotheses provides a fully satisfactory explanation for the observed technological variability within the FMG.

Perhaps the most promising explanatory framework concerns functional differentiation related to distinct socio-economic configurations and site functions. Significant differences exist between the toolkits and the activities/materials worked at different sites. Northern assemblages, for instance, typically contain abundant burins – often associated with animal processing – while at Le Closeau burins are scarce and plant processing predominates, as demonstrated by use-wear analyses. Is this specificity related to environmental factors, cultural diversity, or the functional orientation of the sites? The characteristics of Le Closeau and Saleux suggest fundamentally different occupation types. Le Closeau comprises 53 loci attributed to the late Azilian, corresponding to poorly structured

concentrations of finds without evidence for constructed hearths. Recent use-wear studies have demonstrated that lithic production objectives remain comparable across loci, with very similar functional profiles. Combined with the absence of refits between certain concentrations, this pattern suggests that the site formed through the accretion of short, successive occupations over time – potentially representing repeatedly visited locations for specific, short-term activities. The predominance of plant processing (accounting for 33% of use-wear traces across nine studied loci), the scarcity of retouched tools beyond backed points, and the importance of unretouched tools all support an interpretation of specialized, task-specific occupations.

In contrast, Saleux comprises ten loci presenting markedly different characteristics: dense, circular concentrations extending over 40–60 m<sup>2</sup>, with domestic space organized around flat hearths associated with large numbers of retouched tools (approximately 150–250 per locus). Each locus is interpreted as a residential occupation, probably lasting an entire season, with diversified activities including both domestic tasks (scrapers, burins, retouched backed knives) and hunting-related activities (backed points). The rich and varied toolkit, the careful organization of domestic space, and the evidence for diverse processing activities all suggest more sustained, multifunctional occupations (Coudret and Fagnart 2021).

The situation in northern Germany presents a parallel pattern (Tab. 2). Klein Nordende CR exhibits characteristics consistent with a specialized location focused on projectile point production. The minimal core preparation, short and irregular reduction sequences, and the apparent removal of suitable blade blanks for transformation into points all support this interpretation. The limited tool diversity and the absence of evidence for diverse processing activities suggest task-specific occupations. Alt Duvenstedt LA 120, conversely, demonstrates a markedly different functional profile. The quantity and diversity of tools (13 backed points, 44 end-scrapers, 34 burins, 11 truncations – 124 modified pieces against 900 lithic artefacts), combined with the presence of burnt animal remains, suggests intensive domestic activities conducted on-site. The

systematic transformation of consecutive blade sequences into functionally related tool sets indicates structured, goal-oriented production supporting diverse processing tasks. The site appears to have functioned as a processing location following successful hunting activities, representing more sustained occupation with diverse activity ranges. Taken together, these regional case studies suggest that the degree of technical investment in the *chaîne opératoire* was closely linked to site function and the duration of occupation.

The comparable patterns observed between NW France and Northern Germany in the technological organization and toolkit diversity of the FMG/Azilian suggest a highly flexible and dynamical approach by these Late Glacial human groups. Rather than following a simple, unidirectional evolutionary trajectory, our data support a view in which technological variability reflect diverse socio-economic configurations (cf. Reuter in press). However, their broader evaluation remains constrained by the limited availability of functional data. The absence of detailed activity-based evidence at many sites prevents direct comparison of activities and makes it difficult to test the functional differentiation model systematically. Nevertheless, the available evidence strongly suggests that the technological variability observed within the FMG/Azilian cannot be adequately explained by a single, linear evolutionary trajectory. This line of evidence indicates that future research would benefit from a stronger emphasis on functional and contextual data, particularly through systematic use-wear analysis and the reconstruction of spatial and temporal activity patterns. Such an approach would support the development of a more differentiated framework for the complex technological landscape of the Late Palaeolithic FMG/Azilian.

## Acknowledgement

Berit is one of those colleagues whose encounter leaves a lasting impression and a lasting mark. She is a guiding and benevolent figure for prehistorians working on the Late Glacial period in northwestern Europe, particularly for the ‘younger generation’. Thank you, Berit, for what you have passed on to us and for your discerning eye on our work.

## References

- Antoine, P., Fagnart, J.-P., Auguste, P., Coudret, P., Limondin-Lozouet, N., Ponel, P., Munaut, A.-V., Defgnée, A., Gauthier, A. and Fritz, C. (eds.) 2012. Conty, vallée de la Selle (Somme, France): séquence tardiglaciaire de référence et occupations préhistoriques. *Quaternaire* Hors-série 5. Paris, Association Française pour l'Étude du Quaternaire.
- Barton, R. N. E. 2015. Regional and chronological patterns in lithic raw material behaviour during the late glacial and some implications for the British Later Upper Palaeolithic. *Lithics* 31, 33–43.
- Barton, R. N. E., Tomasso, S., Rots, V., Stafford, E., Hayden, C. and Thacker, G. 2024. *Guildford Fire Station: excavation of a Late Upper Palaeolithic campsite in the valley of the River Wey, Surrey*. Oxford, Oxford Archaeology.
- Björck, S., Walker, M. J., Cwynar, L. C., Johnsen, S., Knudsen, K. L., Lowe, J. J. and Wohlfarth, B. 1998. An event stratigraphy for the Last Termination in the North Atlantic region based on the Greenland ice-core record: a proposal by the INTIMATE group. *Journal of Quaternary Science* 13(4), 283–292.
- Bodu P. (ed.) 1998. *Le Closeau. Deux années de fouille sur un gisement azilien et belloisien en bord de Seine. Rueil-Malmaison (Hauts-de-Seine), document final de synthèse de sauvetage urgent*. AFAN. Unpublished report.
- Bodu, P. 2000. Que sont devenus les Magdaléniens du Bassin parisien? Quelques éléments de réponse sur le gisement azilien du Closeau (Rueil-Malmaison, France). In: Valentin, B., Bodu, P. and Christensen, M. (eds.), *L'Europe centrale et septentrionale au Tardiglaciaire. Confrontation des modèles régionaux de peuplement*. Mémoires du musée de Préhistoire d'Île-de-France 7. Nemours, APRAIF, 315–339.
- Bodu, P. and Valentin, B. 1997. Groupes à Federmesser ou aziliens dans le sud et l'ouest du Bassin parisien. Propositions pour un nouveau modèle d'évolution. *Bulletin de la Société préhistorique française* 94(3), 341–347.
- Bodu, P., Debout, G. and Bignon, O. 2006. Variabilité des habitudes tardiglaciaires dans le Bassin parisien: l'organisation spatiale et sociale de l'Azilien ancien du Closeau. *Bulletin de la Société préhistorique française* 103(4), 711–728.
- Bodu, P., Olive, M., Valentin, B., Bignon-Lau, O. and Debout, G. 2011. Où sont les haltes de chasse? Discussion à partir des sites tardiglaciaires du Bassin parisien. In: Bon, F., Costamagno, S. and Valdeyron, N. (eds.), *Haltes de chasse en Préhistoire. Quelles réalités archéologiques?* Paléthnologie 3. Toulouse, TRACES - UMR 5608 du CNRS, 231–252.
- Bokelmann, K. 1978. Ein Federmesserfundplatz bei Schalkholz, Kreis Dithmarschen. *Offa* 35, 36–54.
- Bokelmann, K., Heinrich, D. and Menke, B. 1983. Fundplätze des Spätglazials am Hainholz-Esinger Moor, Kreis Pinneberg. *Offa* 40, 199–240.
- Bouziane, S. 2021. *Étude d'une occupation azilienne : le locus 14 du Closeau (Rueil-Malmaison, Hauts-de-Seine)*. Unpublished MA-thesis. Paris, Université Paris 1 – Panthéon-Sorbonne.
- Bouziane, S. 2022. *Le locus 14 au Closeau (Rueil-Malmaison, Hauts-de-Seine): un aperçu technologique sur les activités et leurs instruments au cours de l'Azilien récent*. Unpublished MA-thesis. Paris, Université Paris 1 – Panthéon-Sorbonne.
- Breest, K. 1999. Der spätpaläolithische Oberflächenfundplatz mit Rücken- und Bromme-Spitzen bei Dohnsen-Bratzloh, Ldkr. Celle, (Niedersachsen). In: Cziesla, E., Kersting, T. and Pratsch, S. (eds.), *Den Bogen spannen....* Rahden/Westf., Marie Leidorf, 67–77.
- Burau, T. 2019. Technologische Transformationen am Ende der letzten Eiszeit – Frühe Federmesser-Gruppen in Norddeutschland. Unpublished MA-thesis. Kiel, Christian-Albrechts-Universität zu Kiel.
- Chaussé, C. 2005. Les horizons pédologiques tardiglaciaires du Closeau à Rueil-Malmaison (92). Premiers éléments de diagnose. In: Valentin, B., Bodu, P. and Julien, M. (eds.), *Habitats et peuplements tardiglaciaires dans le Bassin parisien*. Rapport de PCR. Nanterre, CNRS UMR 7041/SRA Île-de-France, 87–93.
- Clausen, I. 1998. Neue Untersuchungen an späteiszeitlichen Fundplätzen der Hamburger Kultur bei Ahrenshöft, Kr. Nordfriesland (ein Vorbericht). *Archäologische Nachrichten aus Schleswig-Holstein* 8, 8–49.
- Clausen, I. 2004. The reindeer antler axe of the Allerød period from Klappholz LA 63, Kreis Schleswig-Flensburg/ Germany. Is it a relict of the Federmesser, Bromme or Ahrensburg Culture? In: Terberger, T. and Eriksen, B.V. (eds.), *Hunters in a changing world. Environment and Archaeology of the Pleistocene - Holocene Transition (ca. 11000 - 9000 B.C.) in Northern Central Europe*. Rahden/Westf., Marie Leidorf, 141–164.
- Coudret, P. and Fagnart, J.-P. 2004. Les fouilles du gisement paléolithique final de Saleux (Somme). *Revue archéologique de Picardie* 1–2, 3–17.
- Coudret, P. and Fagnart, J.-P. 2015. Recent research on the Final Palaeolithic site of Saleux (France, Somme). In: Ashton, N. and Harris, C. (eds.) *No stone unturned. Papers in honour of Roger Jacobi*. Lithic Studies Society Occasional Paper 9. London, Lithic Studies Society, 135–155.
- Coudret, P. and Fagnart, J.-P. 2021. Late Glacial Settlement at the site of Saleux (Somme, France). In: Gaudzinski-Windheuser, S. and Jöris, O. (eds.) *The Beef behind*

- all Possible Pasts. *The Tandem-Festschrift in Honour of Elaine Turner and Martin Street*. Monographien des Römisch-Germanischen Zentralmuseums 157. Mainz, Verlag des Römisch-Germanischen Zentralmuseums, 547–567.
- Cupillard, C. and Richards, A. (eds.) 2000. *Les derniers chasseurs-cueilleurs d'Europe occidentale (13 000–5500 av. J.-C.): actes du Colloque international de Besançon (Doubs, France), Épipaléolithique-Mésolithique, 23–25 octobre 1998*. Annales littéraires, série Environnement, société et archéologie. Besançon, Presses universitaires de Franche-Comté.
- Fagnart, J.-P. 1997. *La fin des temps glaciaires dans le Nord de la France. Approches archéologique et environnementale des occupations humaines au cours du Tardiglaciaire*. Mémoires de la Société Préhistorique Française 24. Paris, Société préhistorique française.
- Fagnart, J.-P. and Thévenin, A. (eds.) 1997. *Le Tardiglaciaire en Europe du Nord-Ouest. Actes du 119e Congrès National des Sociétés Historiques et Scientifiques, Amiens 1994*. Paris, Éditions du CTHS.
- Grimm, S. B. 2019. *Resilience and Re-organisation of Social Systems during the Weichselian Lateglacial in Northwest-Europe. An evaluation of the archaeological, climatic, and environmental records*. Monographien des Römisch-Germanischen Zentralmuseums 128. Mainz, Verlag des Römisch-Germanischen Zentralmuseums.
- Günther, K. 1973. *Der Federmesser-Fundplatz von Westerkappeln, Kr. Tecklenburg*. Bodenaltertümer Westfalens 13. Münster, Aschendorff.
- Heidenreich, S. M. 2008. Late Glacial Hunter-Gatherers in Westphalia – The Final Paleolithic Site of Salzkotten-Thüle (District of Paderborn, North Rhine-Westphalia, Germany). *Archäologische Informationen* 31(1&2), 155–163.
- Holzkämper, J., Maier, A. and Richter, J. 2013. “Dark Ages” illuminated – Rietberg and related assemblages possibly reducing the hiatus between the Upper and Late Palaeolithic in Westphalia. *Quartär* 60, 115–136.
- Ikinger, E.-M. 1998. *Der endeiszeitliche Rückenspitzen-Kreis Mitteleuropas*. GeoArchaeoRhein, 1. Münster, LIT.
- Jacquier, J., Mevel, L. and Bodu, P. 2021. Less simple than expected. New technological and functional insights on the Late Azilian site of Le Closeau (France). *Quartär* 68, 181–214.
- Kaiser, K., Clausen, I. (2005). Palaeopedology and stratigraphy of the late palaeolithic Alt Duvenstedt site, Schleswig-Holstein (Northwest Germany). *Archäologisches Korrespondenzblatt* 35, 447–466.
- Krüger, S. and Damrath, M. 2020. In search of the Bølling-Oscillation: a new high resolution pollen record from the locus classicus Lake Bølling, Denmark. *Vegetation History and Archaeobotany* 29, 189–211.
- Lempcke, K.-H. 1996. Agethorst LA 9, Kreis Steinburg. Ein Federmesser-Fundplatz des Spätglazials. *Offa* 53, 7–26.
- Mevel, L. and Bodu, P. 2018. Le Closeau reloaded. Actualités et perspectives autour des occupations Aziliennes du Closeau (Rueil-Malmaison, Hauts-de-Seine). In: Averbouh, A., Bonnet-Jacquement, P. and Cleyet-Merle, J.-J. (eds.) *L'Aquitaine à la fin des temps glaciaires: les sociétés de la transition du Paléolithique final au début du Mésolithique dans l'espace Nord aquitain*. *Paléo*, numéro spécial. Les Eyzies-de-Tayac, Musée national de Préhistoire, 203–214.
- Mills, G. M. 2022. *Late Glacial Geography of The Channel River Network. Southeastern England and its Central Position in the British Peninsula and Ties with Northwestern Europe*. PhD thesis. Oxford, University of Oxford.
- Naudinot, N., Fagnart, J.-P., Langlais, M., Mevel, L. and Valentin, B. 2019. Les dernières sociétés du Tardiglaciaire et des tout débuts de l'Holocène en France. *Gallia Préhistoire* 59, 4–45.
- Olive, M. and Valentin, B. (eds.) 2006. Variabilité des habitats tardiglaciaires dans le Bassin parisien et ses alentours: quelles significations? Actes de la Table ronde de Paris, 26 novembre 2005. *Bulletin de la Société préhistorique française* 103(4), 665–790.
- Otte, M. (ed.) 1988. *De la Loire à l'Oder. Les Civilisations du Paléolithique Final dans le Nord-Ouest Européen*. British Archaeological Reports International Series 444. Oxford, BAR, 357–398.
- Paddayya, K. 1971. The Late Palaeolithic of the Netherlands – a Review. *Helinium* 11, 257–270.
- Pion, G. (ed.) 2000. *Le Paléolithique supérieur récent: nouvelles données sur le peuplement et l'environnement. Actes de la table ronde de Chambéry (mars 1999)*. Mémoire de la Société Préhistorique Française 28. Paris, Société Préhistorique Française.
- Rasmussen, S. O., Bigler, M., Blockley, S. P., Blunier, Th., Buchardt, S. L., Clausen, H. B., Cvijanovic, I., Dahl-Jensen, D., Johnsen, S. J., Fischer, H., Gkinis, V., Guillevic, M., Hoek, W. Z., Lowe, J. J., Pedro, J. B., Popp, T., Seierstad, I. K., Steffensen, J. P., Svensson, A. M., Vallelonga, P., Vinther, B. M., Walker, M. J. C., Wheatley, J. J. and Winstrup, M. 2014. A stratigraphic framework for abrupt climatic changes during the Last Glacial period based on three synchronized Greenland ice-core records: refining and extending the INTIMATE event stratigraphy. *Quaternary Science Reviews* 106, 14–28.
- Reuter, T. in press. *The Social Significance of Technology in Hunter-Gatherer Communities - An Exploration of Lithic Manufacturing during the Lateglacial in Northern Europe*. Untersuchungen und Materialien zur Steinzeit in Schleswig-Holstein und im Ostseeraum 13.

- Roblin-Jouve, A., Olive, M., Rodriguez, P., Bignon-Lau, O., Chaussé, C., Dumarcay, G., Lejeune, Y., Leroyer, C., Thiébault, S. and Watzet, J. 2016. Les limons fluviatiles du site magdalénien d'Étiolles (Essone, France). Bilan des recherches sur le contexte physique et naturel des occupations humaines à Étiolles. *Revue archéologique d'Île-de-France* 9, 7–58.
- Schwabedissen, H. 1954. *Die Federmesser-Gruppen des nordwesteuropäischen Flachlandes: Zur Ausbreitung des Spät-Magdalénien*. Offa-Bücher 9. Neumünster, Wachholtz.
- Street, M., Baales, M., Cziesla, E., Hartz, S., Heinen, M., Jöris, O., Koch, I., Pasda, C., Terberger, T. and Vollbrecht, J. 2001. Final Paleolithic and Mesolithic research in reunified Germany. *Journal of World Prehistory* 15(4), 365–453.
- Tolksdorf, J. F., Turner, F., Kaiser, K., Eckmeier, E., Stahlschmidt, M., Housley, R. A., Breest, K. and Veil, S. (2013). Multiproxy analyses of stratigraphy and palaeoenvironment of the Late Palaeolithic Grabow floodplain site, northern Germany. *Geoarchaeology* 28, 50–65.
- Tromnau, G. 1975a. Die jungpaläolithischen Fundplätze im Stellmoorer Tunneltal im Überblick. *Hammaburg Neue Folge* 2, 9–20.
- Tromnau, G. 1975b. *Neue Ausgrabungen im Ahrensburger Tunneltal. Ein Beitrag zur Erforschung des Jungpaläolithikums im nordwesteuropäischen Flachland*. Offa-Bücher 33. Neumünster, Wachholtz.
- Valentin, B. 1995. *Les groupes humains et leurs traditions au Tardiglaciaire dans le Bassin parisien. Apports de la technologie lithique comparée*. PhD-thesis. Paris, Université Paris 1 – Panthéon-Sorbonne.
- Valentin, B., Bodu, P. and Christensen, M. (eds.) 2000. *L'Europe centrale et septentrionale au Tardiglaciaire: confrontation des modèles régionaux de peuplement. Actes de la table ronde Internationale de Nemours, mai 1997*. Mémoires du Musée de Préhistoire d'Île de France, 7. Nemours, APRAIF
- Veil, S., Breest, K., Grootes, P., Nadeau, M.-J., Hüls, M. 2012. A 14 000-year-old amber elk and the origins of northern European art. *Antiquity* 86, 660–673.
- Wild, M. and Weber, M.-J. 2017. Ein schräger Typ. Eine Geweihspitze aus Lasbek (Kr. Stormarn) und ihr Verhältnis zum europäischen Jung- und Spätpaläolithikum. In: Eriksen, B.V., Abegg-Wigg, A., Bleile, R. and Ickerodt, U. (eds.), *Interaction without borders. Exemplary archaeological research at the beginning of the 21st century*. Kiel/Hamburg, Stiftung Schleswig-Holsteinische Landesmuseen, 23–34.

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# Taphonomy, stratigraphy, chronology, and settlement choice at the Blätterhöhle

New results and open questions

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## Abstract

At the site of the Blätterhöhle near Hagen-Holthausen, southern Westphalia (western Germany), excavations have taken place since 2006. Until today, an important archaeological record spanning the Neolithic, Mesolithic, and Final Palaeolithic could be documented, including numerous human remains. The archaeological finds are recovered from two spatially distinct and functionally complementary parts: the narrow cave and its wider forecourt. This paper gives a brief overview of Palaeolithic research in Westphalia, discusses the current state of research on the Mesolithic and Final Palaeolithic layers at the Blätterhöhle with a special emphasis on human remains, and presents the results of computer-based analyses advancing our understanding of settlement choice, the correspondence of the cave and the forecourt, and the course, volume, and find distribution of the Lower Mesolithic and Final Palaeolithic occupation layers. We close by highlighting still open questions that remain besides recent advances.

*Keywords: Final Palaeolithic, Mesolithic, human remains, taphonomy, computer-based analyses*

## Palaeolithic research in Westphalia and at the Blätterhöhle

During the winter of 1843/44, the Siegen Mining Authority undertook excavations at the Balver Höhle in the Hönne Valley near the town of Balve (northern Sauerland, Märkischer district) in southern Westphalia (the south-eastern part of the western German federal state of North Rhine-Westphalia). These excavations were motivated by the observation that the cave's infill, which was used as natural, phosphate-rich fertiliser on the surrounding fields (Günther 1964, 5–6), was interspersed with skeletal remains of extinct animals and stones that could not have arrived there naturally. Among these stones, „sharp-edged fragments of lydite and a flint-like mass” were described and in 1866 recognised as “lithic tools of the crudest manufacturing method” (Günther 1988, 12–13), making these finds from Westphalia some of the earliest reported Stone Age lithic artefacts. This important impetus sparked a wider interest in the Sauerland caves, which were visited among others also by Rudolf Virchow

and Hermann Schaaffhausen about two decades later. Until the early 20<sup>th</sup> century, the South Westphalian caves were repeatedly visited by researchers interested in archaeology. In addition to Middle Palaeolithic finds, mainly Final Palaeolithic artefacts were recovered (and have been preserved to this day), while only minor evidence of the Upper Palaeolithic has been found (Baales *et al.* 2023; Günther 1988). In contrast to other regions of Germany, the South Westphalian caves were only rarely subject of modern excavations after the pioneering phase in the late 19<sup>th</sup> and early 20<sup>th</sup> century, but became the target of lootings or private endeavours, tolerated by the heritage authorities and mostly geared towards Iron Age finds and features, such as special burials (Luther 2015; Polenz 1991).

It was only with the exploration of the Blätterhöhle cave near Hagen-Holthausen – situated some 20 km to the West of the Balver Höhle – in 2004 that another long-term, systematic excavation on the Stone Age took place in a northern Sauerland cave. In 1983 speleologists of the Kluterthöhle e.V. working group (Ennepetal, Ennepe-Ruhr district, southern Westphalia) discovered a small

crevice at the southern foot of the Weissenstein dolomite massif, initially named Blätterloch (Leaf Hole) and later Blätterhöhle (Leaf Cave) due to the dense foliage cover. The site is located close to the confluence of the Milchenbach creek and Lenne river (Fig. 1). 21 years later, the town of Hagen commissioned the Kluterthöhle e.V. with further explorations to gain information about the hydrological conditions in the Weissenstein. As agreed with the archaeological heritage authorities, attention was paid to archaeological finds. Over Easter 2004, the narrow cave passage was widened and a considerable amount of sediment was removed and stored. Despite the numerous human bones uncovered in the process – and thus deviating from the agreement with the authorities – the work continued and resulted in the creation of a crawl space of about 15 m in length. Given that the sediments containing the bones and other finds were heavily bioturbated by badgers, the speleological activities have not led to any noteworthy loss of archaeological information, but highlighted the Blätterhöhle as an important Stone Age site (Orschiedt *et al.* 2008; 2012).



Figure 1: Location of the Blätterhöhle at the southern slope of the Weißenstein west of the Lenne valley (Basemap: GeoBasisNRW) (Graphic: F. Gumboldt).

## Two Stone Age sites at the Blätterhöhle—Stratigraphy and human remains at the cave and the forecourt

The site of the Blätterhöhle has two spatially distinct and functionally complementary parts: the narrow cave and its wider forecourt (Fig. 2). Together, both areas have yielded an ample set of finds and features from the Final Palaeolithic to the Neolithic, although in varying quantities. After a first  $^{14}\text{C}$  date of a human skull fragment gave an age of 8700 cal BCE and thus turned out to be unexpectedly old, archaeological work began inside and in front of the cave in 2006 on the initiative of the city of Hagen by one of the authors (J.O.), which continues to this day under various sponsorships.

### The Cave

In 2004, speleologists of the Arbeitskreis Kluterhöhle e.V. discovered human skeletal remains approximately ten metres from the cave entrance. At this location, archaeological excavations initiated in 2006 revealed a groove-like feature within sterile cave clay containing two distinct sedimentary layers.

In the lower, more compact, yellowish deposit, fragments of charcoal, animal bones, and isolated stone artefacts were found in association with human skeletal material. Radiocarbon determinations place these finds

within the Early Mesolithic (9250–8600 cal BCE; Orschiedt *et al.* 2019). To date, the remains of at least five human individuals have been identified. The bones were dispersed throughout the sediment, and no anatomical articulation was observed. Micromorphological analyses indicate limited, small-scale *in situ* bioturbation, but no substantial disturbance, suggesting that the skeletal elements were slightly displaced but already fragmented and isolated at the time of deposition. Consequently, one or more secondary interments are inferred. The human remains were situated within an area delimited by three wild boar crania lacking mandibles and canines. Radiocarbon dates for these range between 9300 and 9000 BP (c. 8500–8200 cal BCE). Although slightly younger than the human remains, their spatial association implies that they were incorporated into the depositional context, possibly marking the termination of the site's use as a burial place. Comparable Early Mesolithic contexts are rare, but parallels are known from Belgium (Grotte Margaux, Abri des Autours, Malonne-Petit Ri) and from England (Aveline's Hole; cf. Orschiedt *et al.* 2012).

Above the Early Mesolithic level, a horizon of dark brown, crumbly, humus-rich sediment was encountered. Within this stratum, more than 400 human bone fragments belonging to at least seven individuals were recovered, together with charcoal, faunal remains, and scattered

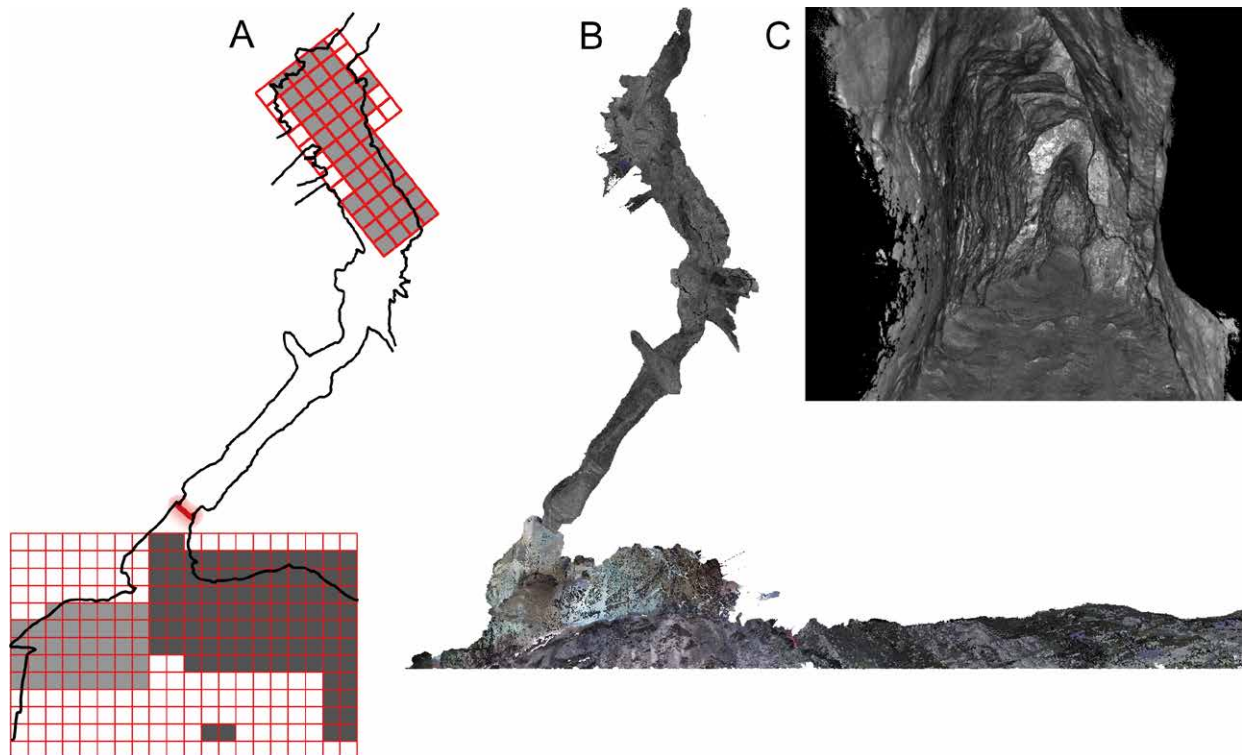


Figure 2: Overall excavation plan with forecourt and cave (A), together with a view of the 3D scan (B) and a glimpse into the scanned cave passage (C) (Graphics: Gumboldt).

lithic artefacts. Radiocarbon dating places these remains within the 4<sup>th</sup> millennium BCE (3900–2900 cal BCE). Again, no anatomical articulation was recorded. Badger activity has led to horizontal displacement of the finds within this layer, preventing the preservation of complete skeletons (Orschiedt *et al.* 2019). In contrast to the Mesolithic assemblage, all anatomical regions – including small bones of the hands and feet – are represented, suggesting that originally articulated primary burials may have been present and subsequently disintegrated through bioturbation and taphonomic processes. It is noteworthy that no grave goods were identified in either the Mesolithic or the Neolithic contexts. The exceptional state of bone preservation enabled both ancient DNA analyses and stable carbon and nitrogen isotope studies. These produced the remarkable finding that during the 4<sup>th</sup> millennium BCE, alongside immigrant farming and herding communities, there also existed a group descended from indigenous Late Glacial hunter-gatherer populations whose subsistence economy was predominantly based on fishing. The evidence from the Blätterhöhle thus provides the first demonstration of the parallel existence of Neolithic and Epimesolithic groups in the 4<sup>th</sup> millennium BCE (Bollongino *et al.* 2013; Orschiedt *et al.* 2014).

### The Forecourt

Originally sheltered under a large broken limestone block that was once part of a rock roof, several find horizons from the Neolithic to the Final Palaeolithic have been preserved, including combustion zones and human remains (Orschiedt *et al.* 2012; 2018). In comparison with the interior of the cave, the former rock-shelter area yielded a considerably smaller quantity of human skeletal material. The finds are concentrated in the immediate entrance zone and consist primarily of fragments of crania and long bones, small complete elements such as hand and foot bones, and isolated teeth. The distribution pattern suggests that taphonomic processes were responsible for the dispersal of the remains in front of the cave. It is therefore plausible that, during the Neolithic, bodies were deposited at or near the cave entrance and that, through decomposition and bioturbation, skeletal elements were transported into the cave interior while other fragments remained on the forecourt. However, given the intense burrowing activity of badgers in the upper cave deposits, it cannot be excluded that these animals displaced skeletal material from the interior to the entrance area. Additional concentrations of human remains occur east of the entrance, directly adjacent to the rock face, as well as in a possible second, largely infilled entrance zone. These remains date to the Early Mesolithic and thus correspond to the Mesolithic layer documented within the cave interior.

Today, the documented stratigraphy on the forecourt, where some 12 m<sup>2</sup> were excavated in detail, comprises eleven sediment layers containing approximately 1750 lithic artefacts, including blanks, tools and debitage measuring a few millimetres in size, and approximately 3950 faunal remains, consisting of partly highly fragmented bones and teeth, which have not yet been studied in detail. The Mesolithic settlement is characterised primarily by several Early Mesolithic hearths, which were discovered in stratigraphic superposition near the cave entrance which is also true for a Late Mesolithic hearth (Heuschen *et al.* 2025). The associated stone artefacts and animal remains, on the other hand, form only vague Early to Late Mesolithic find horizons. The Final Palaeolithic finds, in contrast, form a distinct archaeological horizon which is unique in the region and far beyond, not only because of the human remains (skull parts of a small child and premolar of an adult), but above all because of the unusual lithic assemblage, which – despite several surprisingly old <sup>14</sup>C dates – can be attributed to the Younger Dryas (GS-1) climatic period (Baales *et al.* 2023). During the 2018 and 2019 excavations, six isolated teeth and a mandibular fragment (Fig. 3) were recovered from the Final Palaeolithic strata (Baales *et al.* 2023). Five of the teeth – partly deciduous, partly permanent and not yet fully formed – belong to a child aged approximately seven ( $\pm 2$ ) years in the mixed dentition stage, and could be associated with the mandibular fragment. It cannot be determined, at present, whether these remains originate from a disturbed burial context, but future excavations may unearth further remains. Furthermore, faunal analysis yielded an additional heavily worn human tooth unequivocally attributable to an adult individual. Here, too, the question remains whether other skeletal elements of the same person are preserved. Of particular significance is the fact that the mandibular fragment represents the first Pleistocene human remains been recovered in North Rhine-Westphalia and adjacent regions from an undisturbed stratigraphic context within the framework of systematic excavation. This find thus expands the hitherto extremely limited corpus of human remains dating to the Younger Dryas or Final Palaeolithic in north-western Europe. The taphonomic history of the mandibular fragment, however, remains largely unresolved and requires further investigations.

As suggested by several dated bones and pieces of charcoal from the Final Palaeolithic horizon in front of the Blätterhöhle, there is also evidence of biogenic displacement processes. The remains of wild boar, for example, cannot be assigned to the find horizon with sufficient certainty. In 2024, however, the terminal fragment of a single-row barbed point, which certainly dates from the Upper or Final Palaeolithic period, was found clearly above the Late Mesolithic hearth mentioned above (Heuschen *et al.* 2025).

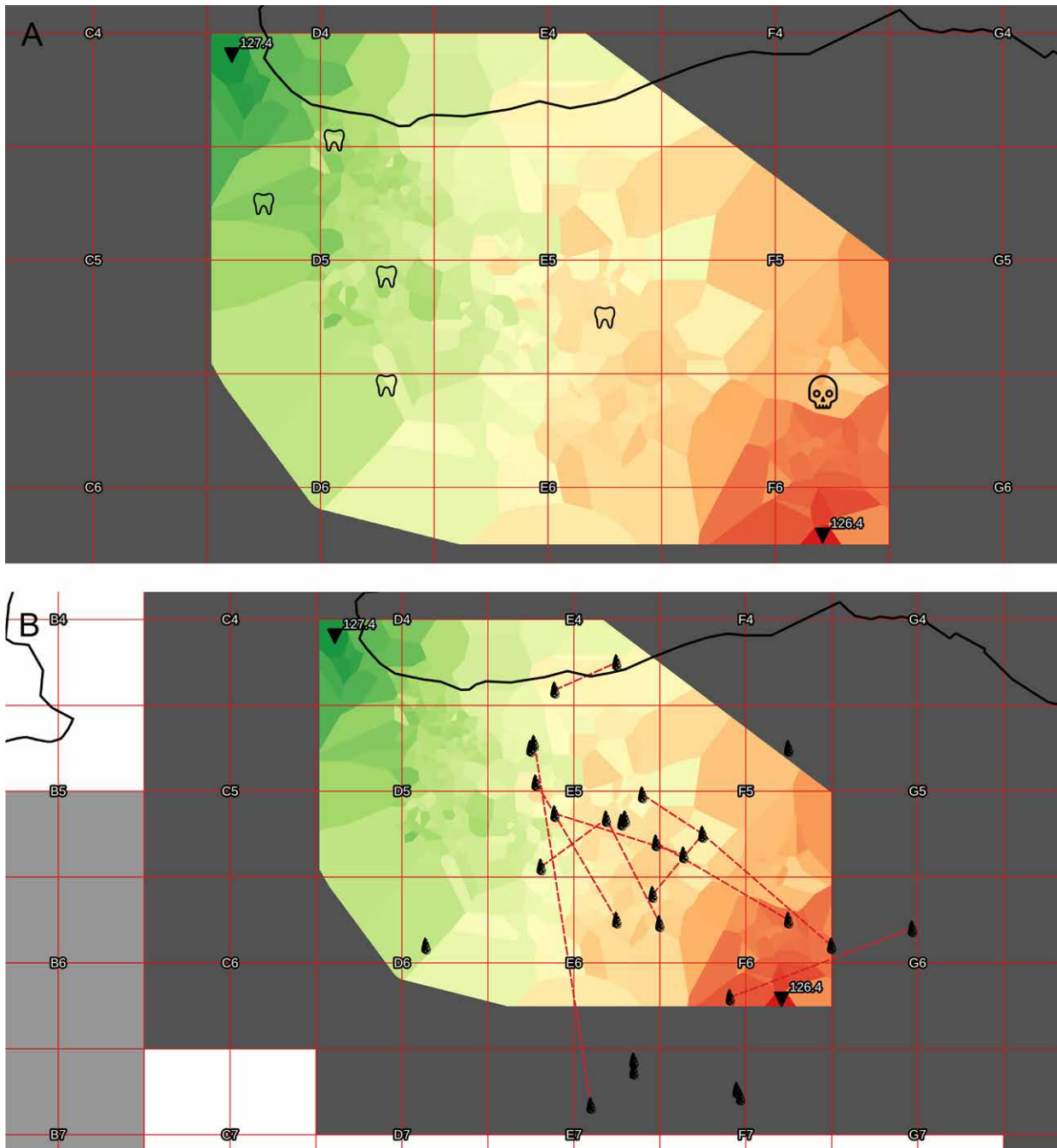


Figure 3: Position of the child's mandible and the associated teeth (A), as well as the position of the refitted flint artefacts from the sediments 6b, 6c and 8 (B) (Graphics: Gumboldt).

A detailed examination of the find area shows that a former badger burrow was present here and that the animals lifted the find from a lower and significantly older level, most likely from the known Final Palaeolithic horizon. Recurrent upward displacement of finds excavated in the horizon is also attested by the tooth fragment of a hyena and a piece of charcoal, radiocarbon dated to the Interpleniglacial (Baales *et al.* 2023).

**Computer-based analyses on current questions of the Final Palaeolithic and Mesolithic occupations**

There are several questions concerning settlement choices, stratigraphy, and taphonomy at the Blätterhöhle. To elucidate factors of settlement choice of the forecourt, a viewshed analysis of the site in comparison to other

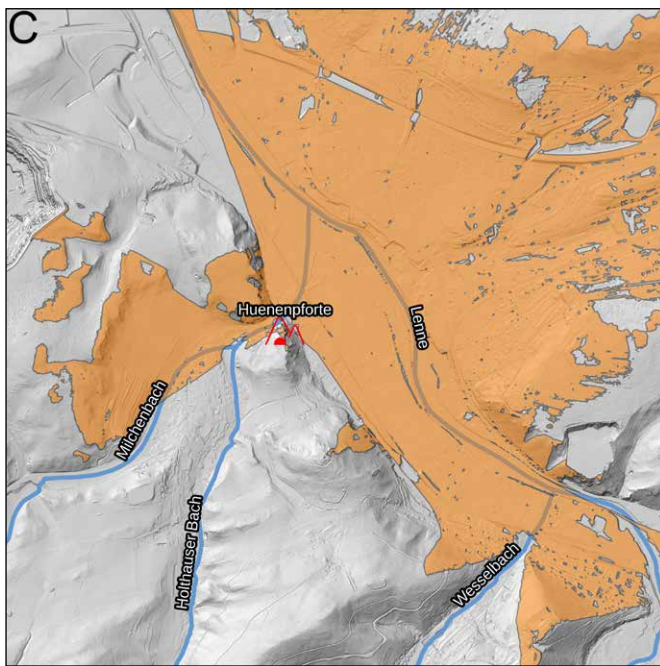
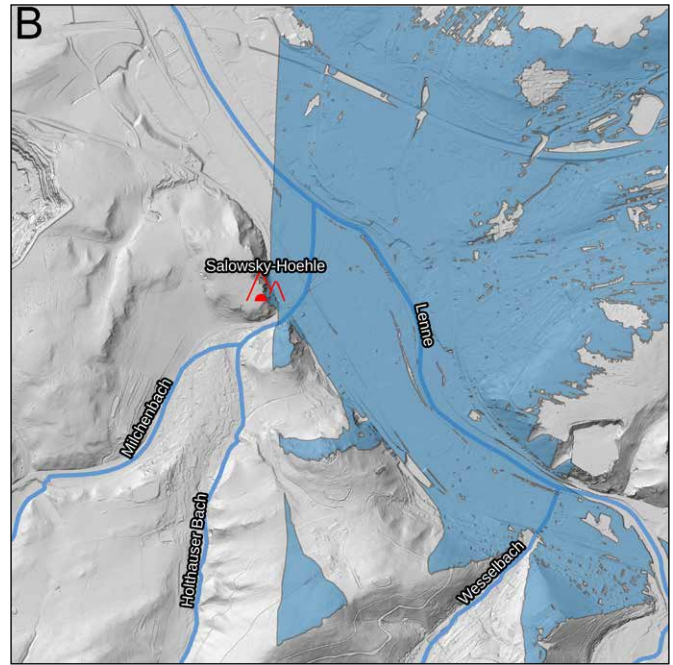
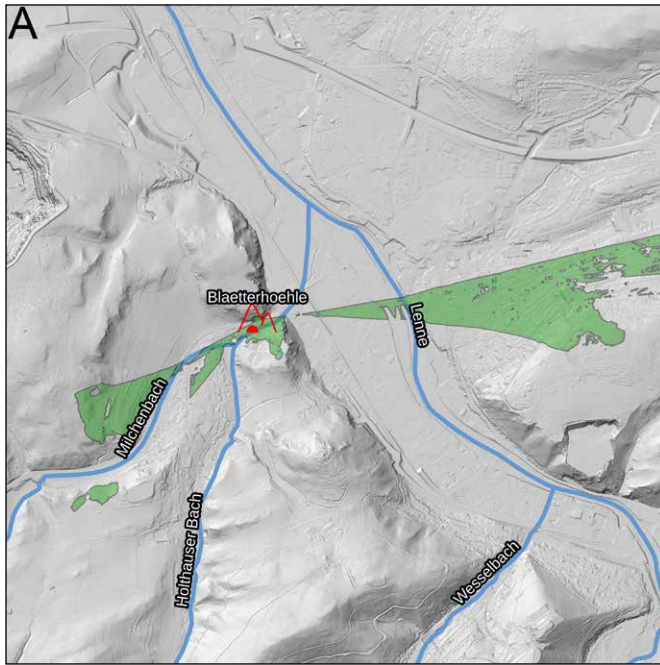


Figure 4: Viewshed analysis of the Blätterhöhle (A), Salowsky cave (B) and Hünenpforte (C) (DEM: GeoBasisNRW; Graphics: Gumboldt).

spots in the landscape is performed. A long-standing problem for jointly documenting and analysing finds and features was the establishment of a combined plan of the narrow cave and the forecourt. Similarly pressing was the establishment of a comprehensive 3D model of the stratigraphy at the forecourt to gain a better understanding of the sloping palaeo-surfaces and find distributions of sediment 6c as well as a reconstruction of sediment volume and inclination in the lower Mesolithic and Upper Final Palaeolithic layers.

In the framework of a master thesis (Noack 2024) and during a three-month project in 2024 (Gumboldt 2024), computer-based analyses were performed for a better understanding of the site's properties and taphonomic history. Some of the results will be presented in the following.

### Viewshed

The repeated occupation of the Blätterhöhle forecourt and its use for different purposes lead to the question as to the reasons for choosing this particular place, e.g.

protection from weather, good overview of the terrain, or good accessibility to resources. To address this question, different area viewshed analyses were performed. In addition to the Blätterhöhle itself, which is located on the southern slope of the Weissenstein, the Salowsky cave, located on the western slope of the same limestone hill, and the Hünenpforte, located on the northern slope of the Milchenbach valley directly opposite the Blätterhöhle were included in the analyses (Fig. 4). The investigated area has a size of nine square kilometres, including a large part of the Lenne valley and its slopes where the caves are located. The analyses were performed using the visibility analysis package in QGIS. As base-map, a digital elevation model (DEM) was used, provided by the state government of North Rhine-Westphalia. Observer locations (viewpoints) were created with an observer height of 1.60 m. The target height was determined as 1.20 m, which corresponds to the average height of reindeer.

The analyses show that the Blätterhöhle clearly provides the smallest area to be observed (0.4 km<sup>2</sup>), while much larger areas can be observed from the Salowsky cave (3.6 km<sup>2</sup>) and the Hünenpforte (4.3 km<sup>2</sup>). Based on these results, it appears highly unlikely that the Blätterhöhle was selected for an advantageous view of the surrounding terrain during forest-free periods. However, compared to the other sites, the south-facing Blätterhöhle was more exposed to sunlight and was probably better protected from weather due to its location in combination with the former rock-shelter which collapsed during the mid-Holocene.

### From 3D-scan to overall plan

Since the beginning of excavation activities in 2006, both excavation areas (forecourt and cave) were excavated separately in local excavation grids without the opportunity to connect both sites in a Cartesian coordinate system and to create overall excavation plans. During the field work in 2023, a 3D-scan was made spanning from the excavation area at the forecourt to the excavation area inside the cave. The georeferenced outline of the cave as well as the excavation grid from inside the cave were extracted from the scan and integrated in a QGIS project which already contained the georeferenced excavation grid of the forecourt as well as the georeferenced contour of the rock face. Based on both excavation grids (forecourt and cave) a custom coordinate system was created using the 'create local CRS'-function in the Geoscience package in QGIS to recalculate the local (find) coordinates in GK3 coordinates (Gauss Kruger zone 3). This allows to create an overall excavation plan including both the forecourt and the cave in a single Cartesian coordinate system, even without the possibility of tachymetric surveying inside the cave due to its narrowness (Fig. 2). The possibility for joint projection of archaeological observations inside and outside of the

Blätterhöhle will contribute to a better understanding of the complex stratigraphy as well as the find distribution at the forecourt and in the cave.

### Find distribution on the forecourt

For documentation during field work, a modified version of the 'Rheinisches Stellenkartensystem' is used. Here, every square metre of the excavation grid represents a Stelle (position), which is subdivided into four quarter square metres. Finds were documented in a database with their Stelle, quarter square metre, and local find coordinates, which can be recalculated in Cartesian coordinates for the combined plan (see above) to plot the finds from the forecourt in planars and profiles (SN and EW) to better understand the complex stratigraphy and the find accumulation, especially of the Late Pleistocene sediment 6c.

Two different approaches were chosen to reconstruct the course of sediment 6c in QGIS, namely Voronoi polygons [height] and Minimum bounding geometry, based on the distribution of finds and planar drawings made during field work. From an input find layer, a corresponding layer of Voronoi polygons was created, whereby the find heights were used as height information for the polygons (QGIS project 2025a). In order to delimit the Voronoi polygons externally, a delimiting polygon was created based on the find distribution (QGIS project 2025b). Then, Kernel density estimations were performed in QGIS for planar and profile views to identify find-clusters within sediment 6c. Larger density values result from higher numbers of finds clustered within a given location (QGIS project 2025c). These clusters may point to possible activity zones or archaeological structures like firepits, not visible during excavation. Both reconstruction attempts (Fig. 5) show that sediment 6c dips by about 1 m from northwest to southeast, which is why erosion and displacement of find material cannot be ruled out. This becomes visible, for instance, when looking at the mandible and its associated teeth, which were found further upslope of the mandible (Fig. 3). Kernel density estimations show that teeth and mandibles were in an area of bone concentrations pointing to shallow troughs or steps in the original surface. A comparable picture emerges when looking at lithic artefacts from sediment 6c, which comprise blanks and tools, e.g. backed and tanged points, as well as debris from blank production. Here, the lighter specimens of refitted pieces were found further down the slope (Fig. 3), which could also point to relocation processes. In addition, the analysis revealed several find clusters of flint artefacts, bones, and charcoals, pointing to possible activity zones or firepits, not visible during excavation. As these are only preliminary results, further studies are necessary to analyse them in more detail.

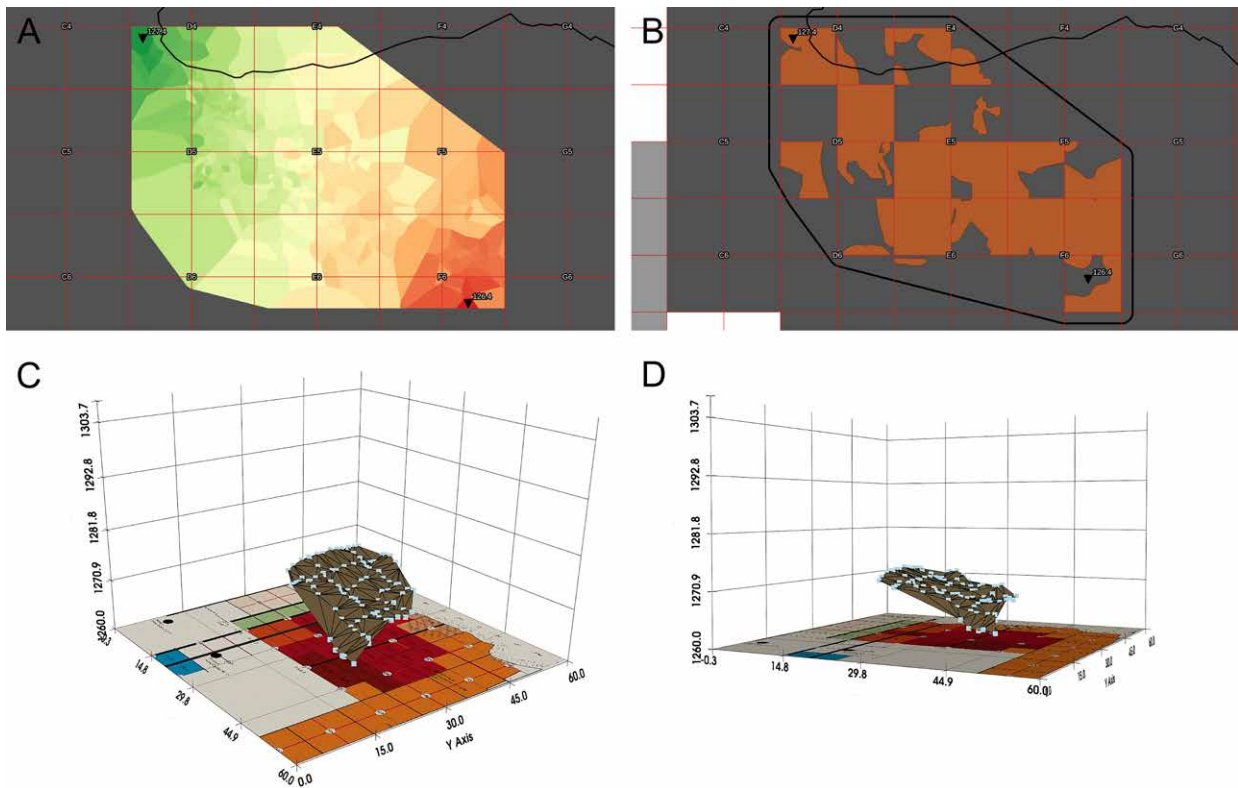


Figure 5: Reconstruction of the sequence of sediment 6c based on the find levels (A), the planar (B) and the profile drawings (C and D) (Graphics: A–B: F. Gumboldt , C–D: Noack).

### Reconstruction of the course of strata at the Pleistocene–Holocene transition

The pronounced slope of the forecourt of the Blätterhöhle cave, combined with the substantial accumulation of rock debris, poses significant challenges for reconstructing the stratigraphy. The sedimentary sequence is heterogeneous, rendering the stratigraphic structure highly complex. To improve understanding of the Final Pleistocene sediment layer 6c, a novel method was developed enabling its three-dimensional reconstruction. The objective was to trace the course of the find layer in order to better contextualise the Final Palaeolithic archaeological deposits.

For the 3D reconstruction, all scanned and digitally available profile drawings depicting layer 6c were utilized. Each profile drawing contained measured elevation data, allowing for accurate three-dimensional placement of the drawings at the correct height and in their proper geographical orientation. The technical implementation was carried out using the Python programming language and the associated libraries PyVista and NumPy (Harris *et al.* 2020; Sullivan *et al.* 2019). NumPy was employed to process supplementary metadata (orientation, elevation, and coordinates from the excavation plan), while PyVista provided the three-dimensional environment for plotting the drawings. The reconstruction process is based on

triangulation. Connecting three defined points yields a triangular surface mesh; adding further points generates multiple interconnected triangles forming a continuous surface. Within the three-dimensional environment, individual points were placed via a graphical user interface and subsequently triangulated. For the reconstruction of sediment layer 6c, points were plotted along the lower boundary of the layer on the profile images, thereby mapping its full extent. Triangulation of these points produced the complete course of the lower boundary (Fig. 5). To reconstruct the upper boundary of layer 6c, the lower course of layer 6b was mapped using the same methodology, as it corresponds to the upper surface of 6c. This procedure resulted in two reconstructed boundary surfaces, the volume between which represents layer 6c.

The average gradient of the lower boundary of layer 6c was calculated at  $-18\%$  ( $-10^\circ$ ), sloping downward from the cave entrance in a south-easterly direction. The upper boundary also slopes in a southeasterly direction, with a gradient of  $-21.2\%$  ( $-12^\circ$ ). As this reconstruction is derived from profile drawings – which themselves represent interpretations of the actual profiles – it can be stated that the two boundaries run approximately parallel. Layer 6c thus extends relatively uniformly from the cave entrance toward the southeast. This reconstruction method, based on interpreted profile

drawings, enabled the identification of a continuous stratigraphic unit, thereby enhancing the understanding of the Final Pleistocene archaeological context.

### Open questions and future works

Although the combination of plans from the cave and the forecourt as well as the modelling of the stratigraphic units markedly enhanced our understanding of the taphonomy and site formation processes at the Blätterhöhle, the Final Palaeolithic find horizon is still riddled with questions regarding its chronological and chorological position. The stratigraphic position directly below Earliest/Early Mesolithic find horizons and some <sup>14</sup>C dates around 10000 cal BCE suggest a chronological attribution to the Younger Dryas (Baales *et al.* 2023). According to current archaeological knowledge, finds from the Younger Dryas in the Sauerland should be attributable to the Ahrensburgian and/or Long Blade industries and accompanied by cold-adapted fauna (Street *et al.* 2019). However, the documented finds from sediment layer 6c do not match these expectations. To the contrary, the lithic assemblage consists of numerous and highly different backed points (and knives), simple microlithic or Zonhoven points, and an untypical tanged point. In the faunal remains, reindeer is missing, but rather temperate species, such as red deer and (perhaps) wild boar is present. Such a combination of fauna and lithic artefacts is unique and highly unusual for the region and beyond. An attribution of these finds to a pre-Allerød context (GI-1 e-b) is supported by the majority of <sup>14</sup>C datings (Baales *et al.* 2023) and the sedimentological classification of the 6c sediment, which, according to Martin Kehl, represents pre-Allerød loess formation, overprinted by human activities in the upper part (cf. Baales *et al.* 2023). Given these contradictory signals, two explanations can be debated:

1. Erosional events have removed the sediments of the Younger Dryas and the Allerød so that pre-Allerød sediments are in direct contact with those from the Earliest/Early Mesolithic. In this case, the Final Palaeolithic assemblage would represent a coherent composition of lithic artefacts and faunal remains of unclear chorological attribution.
2. The assemblage represents a coherent assemblage of the Younger Dryas, but – instead of the Ahrensburgian or Long Blade industries – is directly related to inventories in neighbouring southern and western regions, where the development of the backed point groups continued. The settlement took place on older loess sediment after a phase of erosion had cleared away older Final Pleistocene sediments.

Here, it is interesting to note that until recently there was a perception that the Ahrensburgian was present in this region throughout the entire Younger Dryas as the most recent

expression of the Final Palaeolithic tanged point groups. This picture was ultimately based on only a few Ahrensburgian sites with <sup>14</sup>C ages from the beginning of the Younger Dryas, above all Alt Duvenstedt (LA 121–123) in Schleswig-Holstein and Remouchamps in the southern Belgian Ardennes (Weber *et al.* 2011). A new dating series from this cave has changed the picture. A good two dozen new <sup>14</sup>C ages on reindeer and chamois bones show that the Final Palaeolithic use of the Remouchamps cave area only began around 10200 cal BCE and probably lasted until the end of the Younger Dryas with its accompanying rapid climatic and environmental changes. An early measurement from Oxford of around 10800 cal BCE was also revised by re-dating the corresponding reindeer metacarpus with cut marks (Crombé *et al.* 2024). The few <sup>14</sup>C ages on Ahrensburgian reindeer remains from Hohler Stein near Kallenhardt and the Kartstein located in the northern Eifel (which, together with Remouchamps, represent the three important Ahrensburgian sites with faunal preservation on the northern edge of the Rhenish Massif) also fit into this series (Baales *et al.* 2019; Weber *et al.* 2011). Based on these results, two possible scenarios can be derived concerning our findings in front of the Blätterhöhle, both of which presuppose a high adaptability or mobility of Final Pleistocene human groups:

Due to the low resolution of the Ahrensburgian <sup>14</sup>C ages and the Final Palaeolithic finds of the Blätterhöhle, it cannot be ruled out that in our region, on the northern edge of the Rhenish Massif, there was a rapid succession of the Ahrensburgian (and thus a cold steppe with migrating reindeer herds) to the ‘Blätterhöhle inventory type’ (in a more temperate environment with red deer), representing a continuation of the Allerød (GI-1) backed point groups. The Younger Dryas therefore only had a delayed effect here (despite the collapse in tree pollen levels at the beginning of the Younger Dryas period; cf. Meerfelder Maar; cf. Weber *et al.* 2011) and the Ahrensburgian arrived late, after the resurgence of migrating reindeer herds between the European lowlands in the North and the northern edge of the Rhenish Massif to the South (cf. Baales 2021).

Alternatively, we may take the mean values of the <sup>14</sup>C ages more seriously and expect – analogous to the new results for Remouchamps (Crombé *et al.* 2024) – the presence of the Ahrensburgian in our region a few hundred years earlier. Due to a short, milder phase within the Younger Dryas, there was then a rapid advance of new human groups as carriers of the ‘Blätterhöhle inventory type’ from adjacent southern/western areas, as a temperate environment with an adapted fauna (e.g. red deer) was able to spread in our region and prevailed for a short time (Baales *et al.* 2023), before a subarctic environment with migrating reindeer herds became established again.

Currently, there are indications of biogenic disturbances present in sediment 6c, but the lithic assemblage appears consistent. Open questions remain as to how the sedimentological sequence can be explained and why the <sup>14</sup>C

ages are mostly significantly older than GS-1. As always with such questions and problems, only new research and improved dating results can continue to minimise existing uncertainties. Currently, a series of high-resolution

luminescence dating is underway, and excavations on the Blätterhöhle forecourt will continue in the framework of a project recently funded by the German Science Foundation (DFG).

## References

- Baales, M. 2021. Tracking the reindeer: The Upper and Final Pleistocene record of reindeer in the northern uplands and its seasonal implications. In: Gaudzinski-Windheuser, S. and Jöris, O. (eds.), *The Beef behind all Possible Pasts – The Tandem Festschrift in Honour of Elaine Turner and Martin Street*. Monographien des Römisch-Germanischen Zentralmuseums 157. Mainz, Verlag des Römisch-Germanischen Zentralmuseums, 563–592.
- Baales, M., Birker, S., Kromer, B., Pollmann, H.-O., Rosendahl, W. and Stapel, B. 2019. *Megaloceros*, reindeer and elk – first AMS-<sup>14</sup>C-datings on Final Palaeolithic finds from Westphalia (western Germany). In: Eriksen, B. V., Rensink, E. and Harris, S. (eds.), *The Final Palaeolithic of Northern Eurasia. Proceedings of the Amersfoort, Schleswig and Burgos UISPP Commission Meetings*. Schriften des Museums für Archäologie Schloss Gottorf Ergänzungsreihe 13. Kiel, Ludwig, 137–153.
- Baales, M., Heuschen, W., Kehl, M., Manz, A., Nolde, N., Riemenschneider, D., Rittweger, H. and Orschiedt, J. 2023. Western Visitors at the *Blätterhöhle* (city of Hagen, southern Westphalia) during the Younger Dryas? A new final palaeolithic assemblage type in western Germany. *PLoS ONE* 18(5), e0284479. DOI: 10.1371/journal.pone.0284479
- Bollongino, R., Nehlich, O., Riochards, M. P., Orschiedt, J., Thomas, M. G., Sell, C., Fajkošová, Z., Powell, A. and Burger, J. 2013. 2000 Years of Parallel Societies in Stone Age Central Europe. *Science* 342, 479–481. DOI: 10.1126/science.1245049
- Crombé, P., Pironneau, C., Robert, P., van der Sloot, P., Boudin, M., De Groote, I., Verheyden, S. and Vandendriessche, H. 2024. Human response to the Younger Dryas along the southern North Sea basin, Northwest Europe. *Scientific Reports* 14, 18074. DOI: 10.1038/s41598-024-68686-z
- Gumboldt, F. 2024. Erste GIS-basierte Analysen des Fundmaterials der Blätterhöhle in Hagen. Unpublished project report. Hagen, Stadtarchäologie Hagen.
- Günther, K. 1964. *Die altsteinzeitlichen Funde der Balver Höhle*. Bodenaltertümer Westfalens 8. Münster, Aschendorff.
- Günther, K. (ed.) 1988. *Altsteinzeitliche Fundplätze in Westfalen. Alt- und mittelsteinzeitliche Fundplätze in Westfalen, Teil 2*. Einführung in die Vor- und Frühgeschichte Westfalens 6/2. Münster, Westfälisches Museum für Archäologie.
- Harris, C. R., Millman, K. J., Van Der Walt, S. J., Gommers, R., Virtanen, P., Cournapeau, D., Wieser, E., Taylor, J., Berg, S., Smith, N. J., Kern, R., Picus, M., Hoyer, S., Van Kerkwijk, M. H., Brett, M., Haldane, A., Del Río, J. E., Wiebe, M., Peterson, P., Gérard-Marchant, P., Sheppard, K., Reddy, T., Weckesser, W., Abbasi, H., Gohlke, C. and Oliphant, T. E. 2020. Array programming with NumPy. *Nature* 585, 357–362. DOI: 10.1038/s41586-020-2649-2.
- Heuschen, W., Baales, M., Maier, A. and Orschiedt, J. 2025. Die Spur der Zähne geht weiter – spannende Neuentdeckungen vom Vorplatz der Blätterhöhle. *Archäologie in Westfalen-Lippe* 2024, 11–15.
- Luther, I. 2015. Kultische Nutzung? Eisenzeitliche Hohlen in Südwestfalen. In: Gaffrey, J., Cichy E. and Zeiler, M. (eds.), *Westfalen in der Eisenzeit*. Darmstadt, Philipp von Zabern, 195–197.
- Noack, T. 2024. 3D-Rekonstruktion und Analyse der Stratigraphie auf dem Vorplatz der Blätterhöhle, Stadt Hagen, Westfalen. Unpublished MA-thesis. Cologne, University of Cologne.
- Orschiedt, J., Bollongino, R., Nehlich, O. and Burger, J. 2014. Parallelgesellschaften? Die letzten Jäger und Sammler Mitteleuropas aus der Blätterhöhle. *Archäologie in Westfalen-Lippe* 2013, 43–45.
- Orschiedt, J., Heuschen, W., Gehlen, B., Schön, W., Kehl, M. and Roth, G. 2019. Die Stratigraphie der Blätterhöhle. Schichtenfolge, Datierung, Mikromorphologie und 3D-Funddichteschätzungen. In: Baales, M. and Pasda, C. (eds.), *„All der holden Hügel ist mir keiner fremd...“ Festschrift zum 65. Geburtstag von Claus-Joachim Kind*. Universitätsforschungen zur prähistorischen Archäologie 327. Bonn, Dr. Rudolf Habelt, 501–513.
- Orschiedt, J., Gehlen, B., Schön, W. and Gröning, F. 2012. The Neolithic and Mesolithic cave site Blätterhöhle at Hagen, Germany. *Notae Praehistoricae* 32, 73–88.
- Orschiedt, J., Heuschen, W., Baales, M., Gehlen, B., Schön, W. and Burger, J. 2018. Nacheinander, nebeneinander oder miteinander? Jäger-Sammler und Ackerbauern in der Blätterhöhle. Archäologische und naturwissenschaftliche Erkenntnisse zum spätpaläolithischen, mesolithischen und neolithischen Fundplatz in Hagen, Nordrhein-Westfalen. In: Wemhoff, M. and Rind M. M. (eds.), *Bewegte Zeiten. Archäologie in Deutschland. Begleitband zur Ausstellung im Gropius-Bau, Berlin*. Petersberg, Michael Imhof, 63–71.

- Orschiedt, J., Kegler, J. F., Gehlen, B., Schön, W. and Gröning, F. 2008. Die Blätterhöhle in Hagen (Westfalen) – Vorbericht der ersten archäologischen Untersuchungen. *Archäologisches Korrespondenzblatt* 38, 13–32.
- Polenz, H. 1991. Opferhöhlen der vorrömischen Eisenzeit im südlichen Westfalen. In: Hülsken, T., Niemeyer, J. and Polenz, H. (eds.), *Höhlen. Wohn- und Kultstätten des frühen Menschen im Sauerland*. Münster, Westfälisches Museum für Archäologie, 33–71.
- QGIS project 2025a, August 05. 24.1.23.81. Voronoi polygons. [https://docs.qgis.org/3.40/en/docs/user\\_manual/processing\\_algs/qgis/vectorgeometry.html#voronoi-polygons](https://docs.qgis.org/3.40/en/docs/user_manual/processing_algs/qgis/vectorgeometry.html#voronoi-polygons)
- QGIS project 2025b, August 05. 24.1.23.42. Minimum bounding geometry. [https://docs.qgis.org/3.40/en/docs/user\\_manual/processing\\_algs/qgis/vectorgeometry.html#minimum-bounding-geometry](https://docs.qgis.org/3.40/en/docs/user_manual/processing_algs/qgis/vectorgeometry.html#minimum-bounding-geometry)
- QGIS project 2025c, August 05. 24.1.6.1. Heatmap (kernel density estimation). [https://docs.qgis.org/3.40/en/docs/user\\_manual/processing\\_algs/qgis/interpolation.html#heatmap-kernel-density-estimation](https://docs.qgis.org/3.40/en/docs/user_manual/processing_algs/qgis/interpolation.html#heatmap-kernel-density-estimation)
- Street, M., Baales, M., Gehlen, B., Heinen, M., Heuschen, W., Orschiedt, J., Schneid, N. and Zander, A. 2019. Archaeology across the Pleistocene-Holocene boundary in western Germany: Human responses to rapid environmental change. In: Fagnart, J.-P., Mevel, L., Valentin B. and Weber M.-J. (eds.), *L'Europe du Nord-Ouest autour de 10 000 BP (11 600 cal. BP): Quels changements? XXVIIIe congrès préhistorique de France, Amiens 2016. Volume 2, Session 3*. Paris, Société Préhistorique Française, 491–510.
- Sullivan, C. B. and Kaszynski, A. A. 2019. PyVista: 3D plotting and mesh analysis through a streamlined interface for the Visualization Toolkit (VTK). *Journal of Open Source Software* 4, 1450. DOI:10.21105/joss.01450
- Weber, M.-J., Grimm, S. B. and Baales, M. 2011. Between warm and cold: Impact of the Younger Dryas on human behavior in Central Europe. *Quaternary International* 242, 277–301. DOI:10.1016/j.quaint.2010.12.002

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# Swiderian sites on the shores of Kalviai Lake, southern Lithuania

Tomas Rimkus

## Abstract

The Swiderian culture in the south-eastern Baltic region is considered to comprise the last hunter-gatherer groups of the Final Palaeolithic. In Lithuania, a number of Swiderian sites with tanged or willow leaf-shaped points are known, although most of these have been identified in palimpsest assemblages. In 2020, a new Swiderian site, Vilūnai 4, was located in the western valley of Lake Kalviai in southern Lithuania. 90 flint artefacts assigned to the Swiderian culture were concentrated in lacustrine sediments. The lithic assemblages were dominated by flakes of various stages of core preparation and their further processing, as well as variously sized regular blades and opposite platform cores. The tool category included one dihedral burin and two tanged points. The technological features of the flint tools suggest that the concentration is contemporaneous and provide further insight into the Swiderian culture's flint working industry in Lithuania. In recent years, more prehistoric sites have been discovered on the shores of Lake Kalviai, containing artefacts characteristic for Final Palaeolithic lithic processing traditions. This suggests that the area was frequently visited by Late Glacial hunter-gatherers. This paper aims at providing an initial analysis of the lithic concentration and comparing the results with the broader context. It also provides a brief introduction to the Vilūnai 4 site and its archaeological investigations.

*Keywords: Swiderian culture, lithic technology, tanged points*

## Introduction

The Swiderian culture in the southeastern Baltic region comprised the last group of hunter-gatherers to continue the Final Palaeolithic flint processing traditions. These are typically characterised by opposite platform cores, dihedral burins made on blade edges and large scrapers. The most distinctive artefacts, however, are the tanged and willow leaf-shaped points produced from regular blades (e.g. Berg-Hansen *et al.* 2019a; Šatavičius 2005a; Serwatka 2018; Zagorska 1994; 2012; Zaliznyak 1995).

Swiderian lithic points have been recorded in Lithuania since the late 19<sup>th</sup> and early 20<sup>th</sup> centuries, primarily in publications produced by amateur archaeologists (Gloger 1873; 1903; Szukiewicz 1901). This data later helped to relocate not only the same sites, but also to discover many new Stone Age findspots in southern Lithuania. As archaeological research intensified in the 20<sup>th</sup> century, a considerable number of new Swiderian sites and stray finds were discovered in the region (Butrimas and Ostrauskas 1999; Ostrauskas 1999; Rimantienė 1971; Šatavičius 2016). Currently, there are more than 150 sites in Lithuania

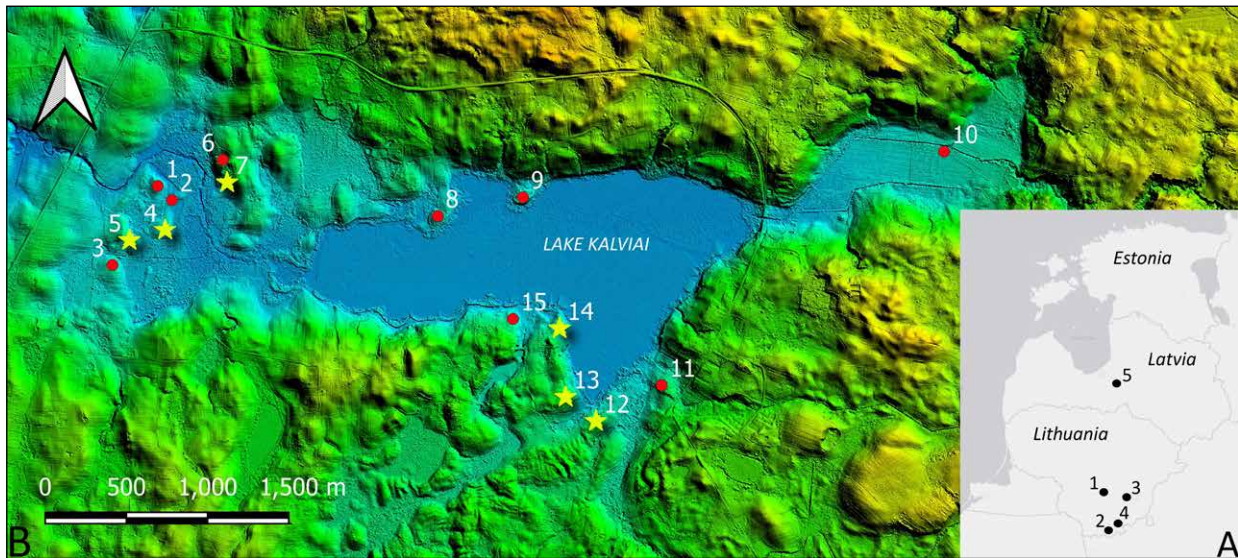


Figure 1: A: Geographical location of Lake Kalviai (1) and key Final Palaeolithic sites mentioned in the text. (2) Kabeliai 2; (3) Pasieniai 1; (4) Titnas 1A; (5) Salaspils Laukskola. B: Stone Age sites distributed around Lake Kalviai. (1) Vilūnai 1; (2) Vilūnai 2; (3) Vilūnai 3; (4) Vilūnai 4; (5) Vilūnai 5; (6) Šventininkai 1; (7) Šventininkai 2; (8) Būtkiemis 1; (9) Būtkiemis 2; (10) Basonys 1; (11) Kalviai 5; (12) Kalviai 4; (13) Kalviai 1; (14) Kalviai 2; (15) Kalviai 3. Sites marked with the yellow star indicate the presence of Final Palaeolithic artefacts at the site (according to Štavičius 2014; Piličiauskas *et al.* 2021; Žilinskaitė *et al.* 2021; Rimkus 2024a).

associated with Swiderian culture lithic finds, which mainly concentrate in the southern and southeastern parts of the country (see discussions by Girininkas 2009; Rimkus 2024b; Štavičius 2005b). However, most of these sites are located within palimpsest sites, where the archaeological material is frequently stratigraphically indistinguishable and mixed with younger material in sandy soils. Nevertheless, there are also Swiderian sites in Lithuania that could be studied in more detail, such as Eiguliai 1, Kabeliai 2, Pasieniai 1 and Titnas 1A. These sites yielded larger lithic assemblages that stand out from the archaeological material of younger periods, thus providing more information about the societies of the Final Palaeolithic (e.g. Gudaitienė 2018; 2020; Ostrauskas 2002a; Rimantienė 1971; Štavičius 2012a; 2012b).

In 2020, an extensive rescue archaeological fieldwork along the course of an international gas pipeline began in the western valley of Lake Kalviai, southern Lithuania. Until then, flint artefacts dating to the Stone Age and other finds from younger archaeological periods had been known to exist around the lake, but only a few sites with a handful of lithics associated with the Final Palaeolithic had been documented (Štavičius 2014). However, in 2020, archaeological excavations in the western part of the lake revealed new sites containing artefacts attributed to the Swiderian. One of these was named Vilūnai 4. The site is located on a small hill in an overgrown part of the area. Although more than 2000 lithic artefacts were found at the site (Rimkus 2024a), only 90 of these were assigned to the Swiderian lithic assemblage, mainly found on the hill slope

in lacustrine sediments. The assemblage is dominated by flakes of various sizes, regular and semi-regular blades, and opposite platform prismatic shaped cores, as well as three diagnostic tool types. This paper presents a case study of the lithic concentration discovered in the wetland part of Vilūnai 4 and focuses on its technological attributes. While the results of the archaeological research conducted at Vilūnai 4 have recently been published in more extensive studies (Rimkus 2024a; Rimkus *et al.* 2025), the data demonstrate that the shores of Lake Kalviai contain more sites where Swiderian lithics have been found. Therefore, this work also briefly discusses Lake Kalviai as a microregion visited by Late Glacial hunter-gatherers.

### Surrounding area and description of site

Lake Kalviai is located in the northern part of southern Lithuania, within the Nemunas basin (the largest river in Lithuania) (Fig. 1). Although there is a lack of data on the development of the lake, geological mapping of the region suggests that it was formed during the Last Glacial. The lake is embedded in a glaciofluvial moraine landscape. Its former western and eastern shores are terrestrialized, but the presence of small elevations suggests that these areas represented islands and small peninsulas when the water level in the lake was higher. The region is characterised by Baltic erratic flint, which was one of the main materials used to make lithic tools (Baltrūnas *et al.* 2006).

Currently, there are 15 sites recorded in the former or existing shorelines of the lake. These sites mostly contain

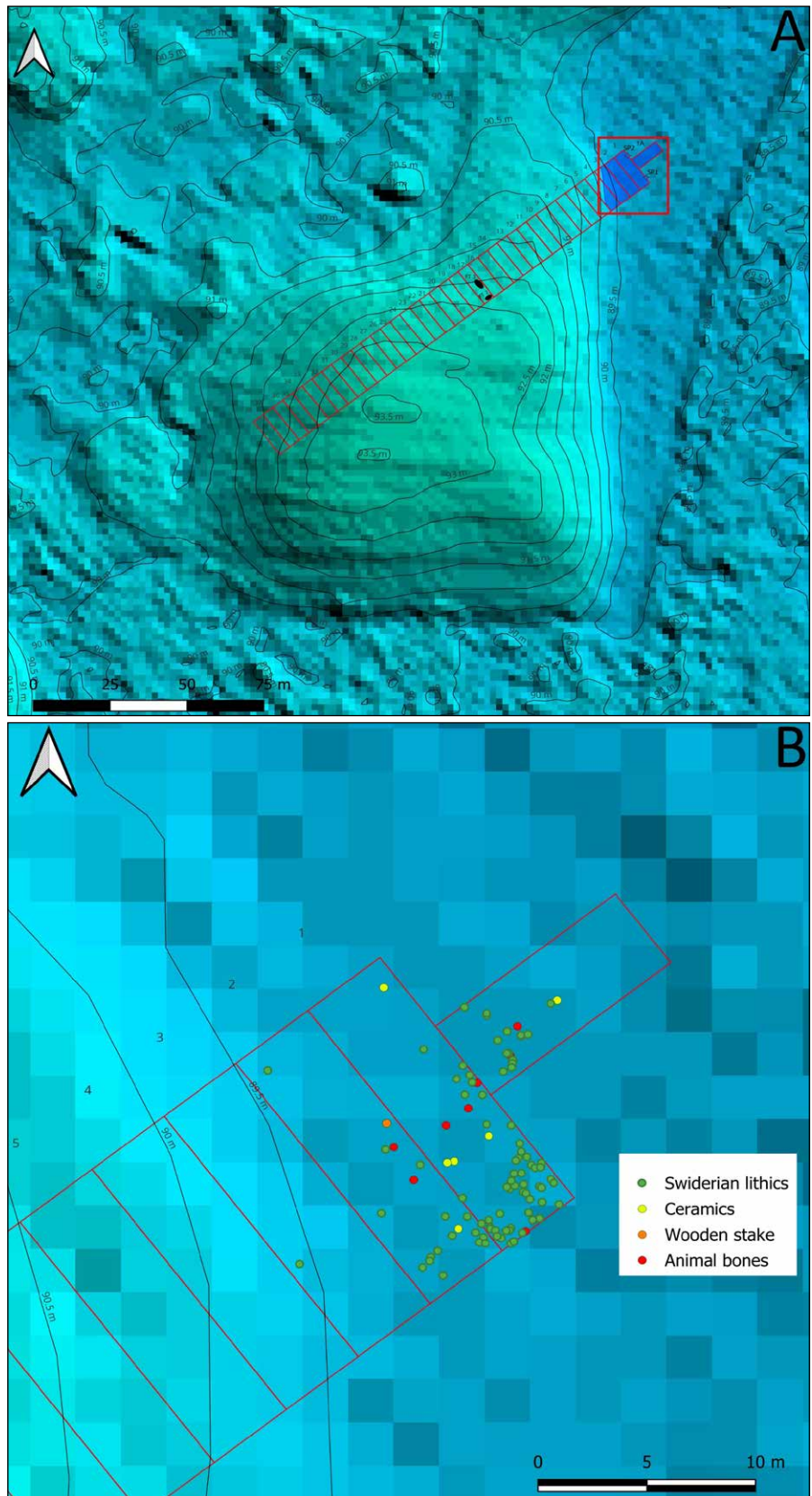


Figure 2: A: General excavation plan of site Vilūnai 4. The dark blue area marks the possible lake shore, whereas the red rectangle indicates trenches 1A-4, where the Swiderian lithic assemblage was located (after Rimkus *et al.* 2025). B: Distribution of Swiderian lithic finds and other artefacts (dated to the Subneolithic and Neolithic) in the excavated trenches (after Rimkus *et al.* 2025).



Figure 3: Wetland stratigraphy of trench 1 at Vilūnai 4 (picture taken by the author).

flint artefacts dating back to various periods of the Stone Age (Šatavičius 2014). Only six of these sites contain flints that can be either typologically or technologically assigned to the Final Palaeolithic (Fig. 1). The Vilūnai 4 site is located on an elevation (54°71'55 N; 24°23'58 E), which rises above a swampy area of the lake (c. 93.5 m a.s.l.) (Fig. 2A). The surrounding landscape suggests that the hill may have been an island at some point when the lake was still present in this area. However, most of the site has been heavily affected by long-term modern agriculture, and no intact layers were found during archaeological excavations in the trenches on higher ground. Nevertheless, hundreds of flint artefacts were found on the ploughed surface, suggesting local human activity during the Stone Age and younger archaeological periods (for more details see Bliujienė *et al.* 2021; Kontrimas 2016; Piličiauskas *et al.* 2021; Rimkus 2024a; Vengalis *et al.* 2016). Five trenches (No. 1A, 1, 2, 3 and 4) were excavated on the northeastern slope of the hill, revealing up to 120 cm thick lacustrine sediments (Fig. 3). Almost all of the trenches, except for trench 4, contained an alluvial layer (up to 10–15 cm) characterised by a mixture of organics and small pebbles at its base. This layer contained flint artefacts (including Swiderian tools, n=124), other rock artefacts (n=2), animal bones (n=10), hunter-gatherer pottery (n=6) and a wooden artefact (n=1). AMS <sup>14</sup>C datings of organics (12 samples) demonstrate that the main phase of human activity dates to the 5<sup>th</sup>–2<sup>nd</sup> millennium BCE (see Rimkus *et al.* 2025 for discussion). This suggests that the finds in the layer may have accumulated during active shoreline erosion by the lake water. Although no animal bones or other organic material related to the Swiderian lithic assemblage were found here, 90 flint artefacts associated with the Swiderian were recorded.

### The Swiderian lithic assemblage

The Swiderian flint finds were concentrated in the southeastern part of the excavated trenches. Their types and general statistical information are presented in Tab. 1.

Type	Number of pieces
<b>Debitage</b>	
Blades	25
Cortical blades	2
Blades with edge damage	5
Flakes	33
Cortical flakes	14
Flakes with edge damage	3
<b>Cores</b>	
Opposite platform	4
Irregular	1
<b>Tools</b>	
Tanged points	2
Burins	1
<b>Total</b>	<b>90</b>

Table 1: A list of flint artefact types related to the Swiderian lithic assemblage found in trenches 1A, 1, 2 and 3 at Vilūnai 4.

Flakes dominate the flint finds (n=50), 14 of which contain cortex, suggesting that they were primary flakes. Three of the flakes reveal minor damage at the edges. However, due to the absence of diagnostic forms and the fact that no use-wear analyses were conducted, the flakes could not be associated with artefacts at this stage.

The second largest group comprises blades (n=32). Only two of them were primary blades, while five specimens had damaged edges. However, for the same reasons described above, these blades were not linked with diagnostic artefact types.

Four prismatic shaped opposite platforms and one irregular core were identified in the assemblage. Three diagnostic artefact types were identified in the

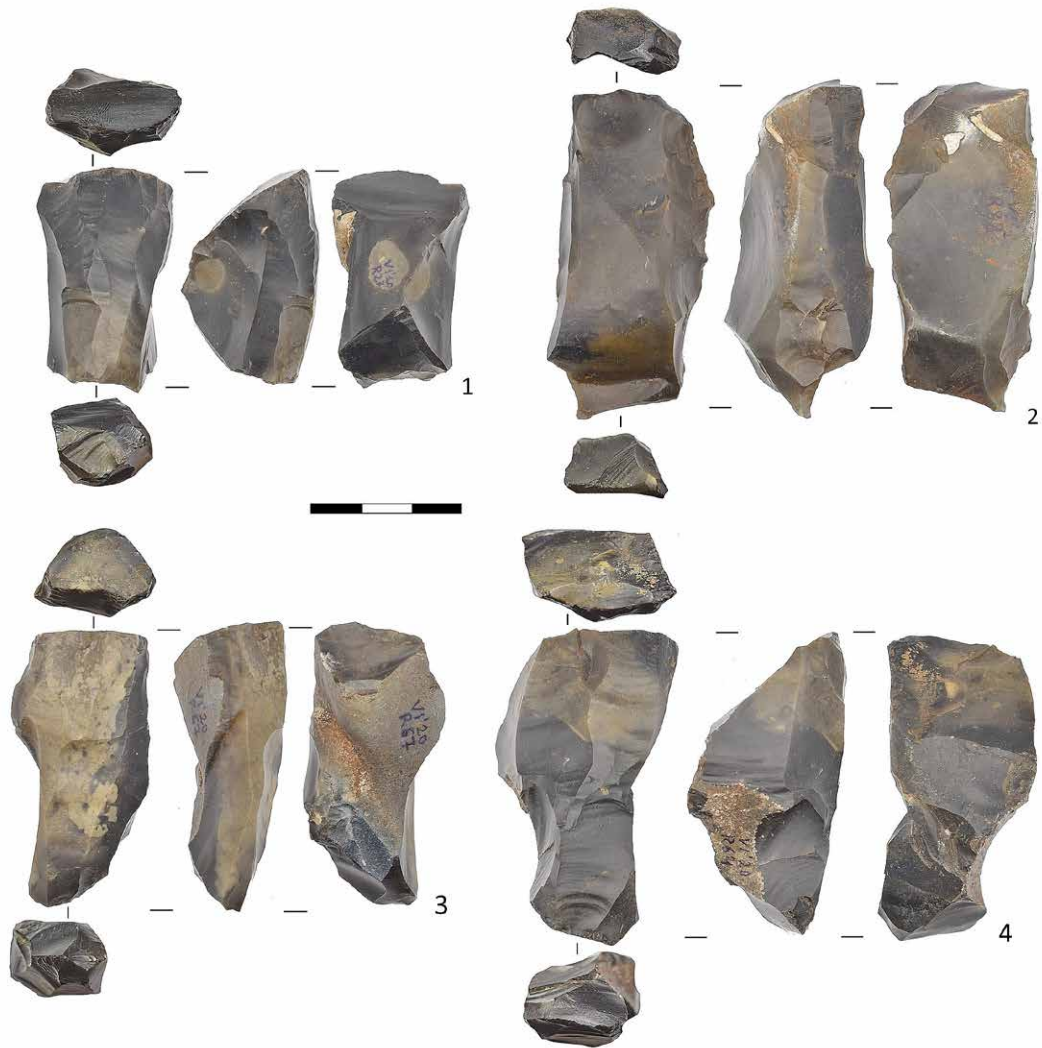


Figure 4: Opposite platform cores from the Swiderian lithic concentration (pictures taken by the author).

lithic concentration – two tanged points and one large dihedral burin.

The flints identified in the Swiderian lithic assemblage demonstrate that good quality dark grey coloured flint with light brown patches was processed at the site. The finds are in a good state of preservation, *i.e.* they are not patinated and show no signs of overheating. Refitting was successfully applied to eleven specimens, however, the refitted flakes do not add much to the knowledge of flint processing at the site at this stage, as more refitting would be needed to better understand the separate stages of core preparation and exploitation (Rimkus 2024a). The entire collection of archaeological finds from Vilūnai 4 is stored at the National Museum of Lithuania.

### Cores

All four opposite platform cores have their platforms bevelled at an angle of approximately 45° (Fig. 4). As can

be seen from the remaining negatives, the cores were used to produce regular blades of various sizes. It is likely that the blades were produced by direct percussion with a softer hammer, as observed at most Swiderian sites with tanged points (*e.g.* Gruzdź 2018). Another interesting feature of the cores is that platforms vary in size. This is because one platform was dominant and blades were more frequently struck from it, while the other was used less and was intended to control the correct exploitation of blades (*e.g.* Pyżewicz *et al.* 2019). Examples of cores at Vilūnai 4 show that one platform was exploited with a flat surface, while the other was faceted. Three cores demonstrate a tendency for larger platforms to be unfaceted and smaller platforms at the opposite end (used for control) to be faceted (Fig. 4: 1–3). One specimen demonstrates the opposite case, with flaking on the larger platform (Fig. 4: 4).

The final core from this concentration is irregular. It has a flat platform. Perhaps, an attempt was made to form

a core from the flint nodule, or maybe the aim was simply to find ways to fully exploit the piece of flint. Nonetheless, the core shows signs of exploitation for short flakes.

### Blade processing

The blades vary in size and state of preservation (Fig. 5: 4–14). Fully preserved blades are 40–80 mm long and mostly 10–20 mm wide, although wider ones exist too. They are usually 3–10 mm thick. The proximal parts of the blades demonstrate a very small part of a preserved core platform. A typical blade has a slightly curved profile at the bottom or top, although the curvature is more often visible at the top. The size of the bulbs varies too, but they are usually small. These features suggest that the flakes could have been formed by a direct blow with a soft hammerstone, but it must be mentioned that no hammerstones were found in this part of the site. The use of soft hammerstone is typical in Swiderian lithic assemblages (Berg-Hansen *et al.* 2019a; 2019b; Dziewanowski 2011; Migal 2007; Pyżewicz *et al.* 2019). A hard or soft hammer was also used to trim the flaking edge. Other researchers further argue that the use of blade technology in the Swiderian should be studied in more detail to understand how the technique of blade manufacturing has changed, in addition to the different types of projectiles and their possible chronological stages (Gruzdź 2018). This would perhaps allow for a better understanding of different technological stages and their development (e.g. Przeździecki 2019; Szymczak 1992).

Upon examining the flakes and blades found in the concentration, no special retouching was observed that would suggest these finds could be attributed to a specific type of tool or indicate their use. The sporadic damage to the edges of several flakes and blades could have been caused by post-depositional factors, such as the flints being affected by shoreline erosion of the lake. This could have resulted in sporadic damage to the edges that may resemble use-wear. Therefore, a microscopic study of debitage should be the succeeding step in future investigations. No evidence of special breaking or other deliberate processing was found on the flints. Only three diagnostic artefacts with clear characteristic techniques were found in the concentration (see below). Cases where blades are not treated with retouching and show no visible signs of use do occur at Swiderian sites. Scientists studying such flakes have recently determined that flakes with signs of use were mainly intended for processing harder materials, such as antler, bone, or wood. In contrast, blades without signs of use could have been prepared for transport, exchange, or as a stock of raw materials (Pyżewicz *et al.* 2024). While traceological studies of the material found at Vilūnai 4 would be a beneficial supplementary study, preliminary analysis of the available data suggests that the finds may be related to a specialised place used to prepare cores and blades. A similar situation can be seen when

comparing the archaeological material with concentrations attributed to site Titnas 1A in southern Lithuania. These concentrations clearly demonstrate the production of cores and blades, with only a few diagnostic artefacts among a large amount of debitage (Šatavičius 2012a).

### Tool categories

Two tanged points were identified among the flint finds discovered in the concentration. The first is a tanged point measuring 50 mm in length, 12 mm in width and 5 mm in thickness, made from a regular blade struck from an opposite platform core (Fig. 5: 1). The point has a pointy tang shaped by retouch on both edges. On the right side of the dorsal surface, near the top of the artefact, a deliberately formed fine retouch can be seen. It is likely that this continued to the tip of the point, which is broken off. On the ventral side, the lower part of the projectile has been retouched by flat retouch. One of the edges on this side of the tang is also partially retouched.

The second tanged point was made using a slightly wider blade (Fig. 5: 2). It measures 44 mm in length, 36 mm in width, and 2 mm in thickness. The tip of the artefact is broken off. Compared to the previously discussed specimen, the tang of this artefact is wider and was formed by retouching both edges from the sides. More noticeable technological changes are visible in the ventral part of the tang, where there is a flat retouch. Both projectiles exhibit all characteristics typical for Swiderian tanged points. Using analogies from other countries, Lithuanian archaeologists have often linked this type of points to the Younger Dryas period (e.g. Šatavičius 1998).

The third and final diagnostic type tool found in the concentration is a dihedral-type burin. It is made of a large blade measuring 80 mm in length, 20 mm in width and 6 mm in thickness, which is produced from an opposite platform core (Fig. 5: 3). Its cutting edge is formed at the distal end of the blade, at the very tip. This was achieved by pressing both sides of the blade tip. A review of published archaeological material from the Eastern Baltic region reveals that characteristic Swiderian burins are often formed on the edges and tips of long blades. Sometimes, they are also made on the edges of the broken arrowheads. Examples can be found at sites such as Eiguliai 1A, Ežerynas 1, 8, 14 and 17, Netiesai 1, Pasieniai 1C, Puvočiai 1A, Salaspils Laukskola and Skaruliai in Latvia and Lithuania (Berg-Hansen *et al.* 2019a; Rimantienė 1971; Šatavičius 2005a; Zagorska 1994; 2012).

### Chronological uncertainties

One of the most distinctive types of artefacts and the main chronological indicator among Swiderian lithic assemblages are projectiles. Two types of arrowheads are traditionally attributed to the Swiderian: 1) those with a distinct tang (tanged points), and 2) those without a distinct tang (willow

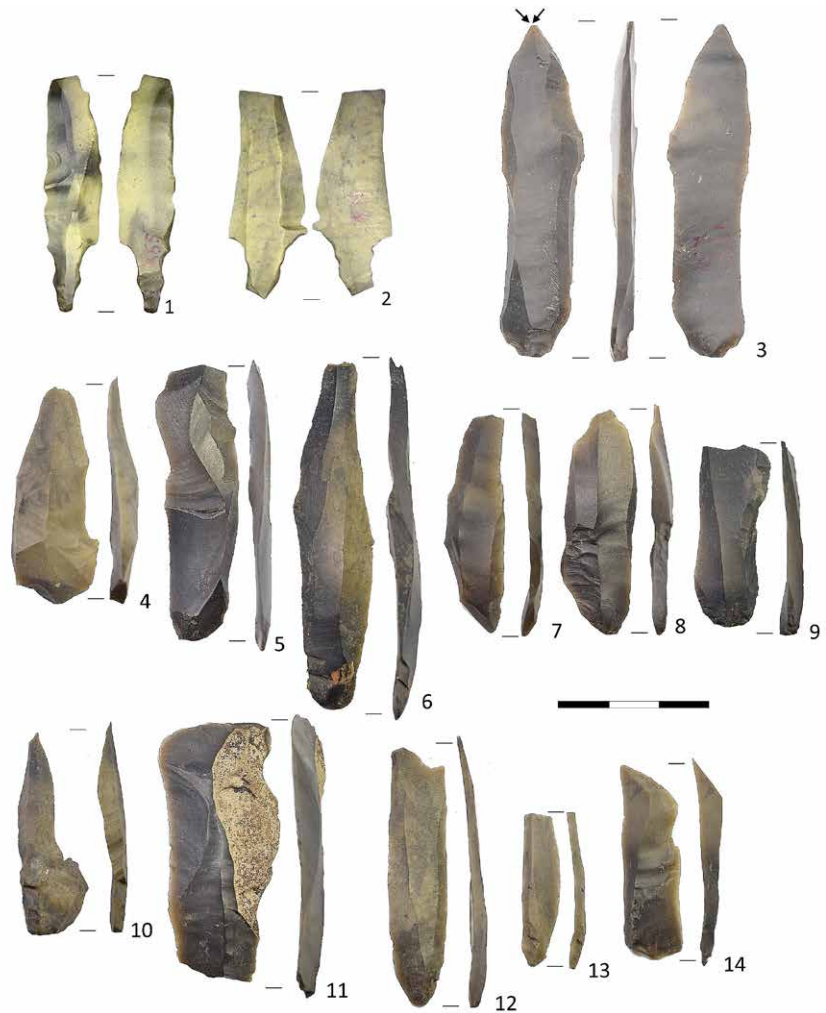


Figure 5: Tanged points (1 and 2), dihedral burin (3) and selected examples of blades from the Swiderian lithic concentration (pictures taken by the author).

leaf-shaped points) (e.g. Grużdź 2018; Sulgostowska 1999). It is traditionally assumed that the tanged point type dates back to the Younger Dryas period, while the willow leaf-shaped type marks changes in shape and was used at the beginning of the Preboreal period. However, it is difficult to rely on this typo-chronological concept without reliable radiocarbon data, which is scarce compared to the abundance of Swiderian assemblages in Latvia, Poland, and Lithuania. Currently, samples dated from Final Palaeolithic sites in Poland are the most important reference point for the chronology of the Swiderian (Płonka *et al.* 2020; Schild *et al.* 1999; 2011; Winkler 2019). The dated samples confirm that Swiderian material culture dates to the Late Glacial, with the latest dates correlating to the Preboreal period (Schild 2014).<sup>1</sup> In the middle of the Preboreal period, the characteristic Swiderian lithic types seems to disappear as the people start to adapt new lithic processing techniques,

1 It should also be noted that some interpretations suggest that Swiderian leaf-shaped points may have persisted until the Boreal period (e.g. Gudaitienė *et al.* 2019; Stefański 2017).

*i.e.* the pressure blade technology (e.g. Damlien *et al.* 2018). Thus, in the Early Mesolithic period, small blades and microliths emerged, while large tanged points, often associated with the terms of Kunda, Pulli, or post-Swiderian, still persisted (e.g. Grużdź *et al.* 2025; Ostrauskas 2002b; Rankama and Kankaapää 2011; Sulgostowska 1999; Zagórska 2019). Therefore, it can be assumed that, while hunting techniques of the Early Mesolithic inhabitants were changing, the Final Palaeolithic tradition of using large tanged points still persisted at the beginning of the Early Holocene.

Only a few radiocarbon dated complexes are associated with the Swiderian in the Eastern Baltic. A notable exception is the site Kabeliai 2 in southern Lithuania, but it is difficult to determine which of the obtained dates should be associated with the flint inventory found there (Ostrauskas 2002a). Radiocarbon dates have also been obtained from stray osseous artefacts, a considerable number of which are resembling types of the Final Palaeolithic (e.g. Zagórska 2006). While the dates fall well within the Swiderian chronology, the dated material is not

linked to any flint artefact complexes (Rimkus *et al.* 2019; Zagorska *et al.* 2019).

The question of dating the Swiderian flint concentration found at Vilūnai 4 remains relevant. Three animal bones (belonging to *Capreolus capreolus*, *Cervus elaphus* and *Sus scrofa*), a wooden stake (*Alnus* sp.) and three fragments of porous pottery fragments were dated by AMS <sup>14</sup>C from the same layer as the Swiderian lithics (Rimkus *et al.* 2025). Ages of these samples range from the Subneolithic to the Neolithic, however, the dating of charcoal and plant macrofossils found in the layer yielded three dates of Final Palaeolithic and Mesolithic age. One piece of charcoal was dated to 11788–11423 cal BCE (KIA-57801: 11670 ± 55 BP), which is the only date representing the Final Palaeolithic from the find layer in wetland trenches (Rimkus 2024a).<sup>2</sup> However, it is significantly older than the supposed dating of the Swiderian and thus cannot be correlated with it.

All AMS <sup>14</sup>C dates available from the find layer are distributed over a wide chronological interval. The flint finds discovered during the excavations did not differ stratigraphically from the Subneolithic pottery or animal bones recorded in the same layer. Therefore, based on the currently available data, it is likely that this layer, due to intense shoreline erosion, at some point displaced artefacts and ecofacts from various Stone Age periods from their original positions and accumulated them into a single layer. During different stages of the Stone Age, as the lake water level fluctuated and the shoreline was shifting, people could have carried out activities at the foot of the hill or slightly higher (depending on the lake water level). In this case, the transgression of the basin's water would have washed away not only the archaeological finds that indicate human activity at the foot of the hill, but shoreline displacement might also have eroded much older human-made tools, for instance, those dating to the Late Glacial. This could have caused an admixture of younger and older artefacts in the same layer. It would indicate that in order to obtain more accurate chronological data from the organic artefacts found in this later, each of the finds must be dated directly. The concentration of flint finds attributed to the Swiderian is more complicated as for now it can only be dated based on typology. However, considering the distribution of lithics, it can be assumed that their distribution may continue towards the east-southeast direction of the excavated trenches (Fig. 2B). Continuing the field research here may be one of the options to unearth datable organic material.

2 Another date attributable to the Final Palaeolithic was obtained during the excavation of trench No. 17 in the upper part of the hill, where a thin layer of organic matter was discovered. A piece of charcoal found within this layer was dated to 11446–11214 cal BCE (FTMC-YY40-7: 11388 ± 50 BP). However, archaeobotanical studies of the layer indicate that this date is most likely related to the higher water level of the lake during the Late Glacial (see Rimkus *et al.* 2025 for discussion).

## Final Palaeolithic sites around the shores of Lake Kalviai

Flint artefacts characteristic of the Final Palaeolithic have been recorded at six locations around Lake Kalviai (Fig. 1). Much of the data is fragmentary, in some cases consisting only of a few surface finds. Some of the archaeological material has also been published only in short reports. Therefore, this comparative analysis may be supplemented with new data in the future when more comprehensive studies of some of the newly excavated sites from the region are published.

Among the published material, some flint artefacts from Kalviai 2 and 4 were found on the soil surface as well as in trenches. They are preliminarily associated with the Final Palaeolithic (Štavičius 2014). Association is based on the argument that they are covered with a thick whitish patina. However, no diagnostic Final Palaeolithic types of artefacts have been found at these sites, nor has the technology of the lithics been discussed. Therefore, dating remains very preliminary.

More extensive data on the Final Palaeolithic flint finds from the area originates from site Kalviai 1. Archaeological research was conducted there in 1999 and 2000. During these investigations, 850 flint artefacts were discovered which typologically cover several Stone Age periods. The discovery of an opposite platform core and several blades bearing distinctive technological marks allowed one of the site's chronological stages to be correlated with the Final Palaeolithic – with possible attribution to the Swiderian (Štavičius 2014). Kalviai 1 is located in the south-eastern part of the lake, approximately 2.6 km southeast of Vilūnai 4.

As for the western part of Lake Kalviai, single opposite platform cores were recorded in Vilūnai 5 (also identified in 2020), which is adjacent to Vilūnai 4. Evidence of human activity dating back not only to the Stone Age, but also to the early Metal Ages was identified here (Piličiauskas *et al.* 2021; Rimkus and Zabiela 2024; Vengalis *et al.* 2022). However, no lithic concentrations or any other diagnostic artefact types (other than cores) characteristic to the Swiderian or other Final Palaeolithic technocomplexes have been identified.

Another important site is Šventininkai 2, which is likewise located very close to Vilūnai 4. In 2020, blades struck off from opposite platform cores and six tanged points with ventral retouch on the tangs were found here (Žilinskaitė *et al.* 2021). While detailed typological and technological analyses of the arrowheads have yet to be published, site Šventininkai 2 currently contains the largest number of Swiderian flint projectiles in the Stone Age sites known on the shores of the lake.

## Conclusions

Excavations carried out in 2020 in the western part of Lake Kalviai revealed new information on the Final Palaeolithic

hunter-gatherer groups that inhabited the shores of the formerly larger lake. Currently, there is very little data on the natural environment or the development of the lake's water level. Consequently, any broad conclusions about the conditions of human life or the local fauna during the Late Glacial period cannot be drawn at the moment. However, the available data indicates that groups of Final Palaeolithic hunter-gatherers occupied the area. The rich lake ecosystem was probably a pull factor for these people, and good quality flint for tool production was likewise available locally. The location of Vilūnai 4 indicates that people chose a lower lying area of the landscape for occupation. This is an interesting and still little studied aspect, given that most Final Palaeolithic sites in Lithuanian territory are located on elevated river or lake terraces (e.g. Rimantienė 1971; Šatavičius 2014).

At the moment, the site is the sole example of a homogenous Final Palaeolithic lithic concentration in the micro-region of Lake Kalviai. Its characteristics suggest that specialised flint processing and tool production may have taken place here. However, compared to similar structures in the Eastern Baltic region (e.g. Zagorska 2010), significantly more types of domestic tools would be required for this activity to be considered as the domestic unit (e.g. Zagorska

and Winiarska-Kabacińska 2019). In the future, use-wear analyses on artefacts from the Vilūnai 4 flint concentration would be crucial.

Currently, it is difficult to date the concentration of the flint artefacts found at the site with higher precision. Based on the types of projectiles and opposite platform cores, the finds could be attributed to the Younger Dryas, but further research is required. Analysis of the distribution of the artefacts indicates that they are likely spread beyond the excavated area. Thus, further field archaeological research could provide additional data and more accurate dating of the concentration, as well as the discovery of further artefacts to conduct more refittings.

## Acknowledgements

The idea to write this paper emerged during my postdoctoral research from 2021 to 2023, which was funded by the Alexander von Humboldt Research Foundation. I would like to express my gratitude to Berit V. Eriksen for her support and supervision during this period. Editors of this volume are thanked for the invitation to publish my research, and lastly, I am grateful to two anonymous reviewers for their positive comments.

## References

- Baltrūnas, V., Karmaza, B., Kulbickas, D. and Ostrauskas, T. 2006. Distribution of raw material for prehistoric flint artefacts in South Lithuania. *Geografija* 42(2), 41–47.
- Berg-Hansen, I., Damlien, H. and Zagorska, I. 2019a. The northern fringe of the Swiderian technological tradition: Salaspils Laukskola revisited. *Archaeologia Baltica* 26, 12–31.
- Berg-Hansen, I., Damlien, H., Kalniņš, M., Zagorska, I., Schülke, A. and Bērziņš, V. 2019b. Long-term variation in lithic technological traditions and social interaction: the Stone Age of the eastern Baltic (Latvia), 10500–2900 CALBC. *Fennoscandia Archaeologica* XXXVI, 6–32.
- Bliujienė, A., Petrauskas, G., Bagdzevičienė, J., Babenskas, E. and Rimkus, T. 2021. Essential changes in the composition of copper alloys reveal technological diversities in the transition from the Earliest Iron Age to the Early Roman period in Lithuania. *Archaeologia Baltica* 28, 39–62.
- Butrimas, A. and Ostrauskas, T. 1999. Tanged points cultures in Lithuania. In: Kozłowski, S. K., Gurba, J. and Zaliznyak, L. L. (eds.). *Tanged points cultures in Europe. Read at the International Archaeological Symposium, Lublin, September, 13–16, 1993*. Lublin, Maria Curie-Skłodowska University Press 267–271.
- Damlien, H., Berg-Hansen, I. M., Zagorska, I., Kalniņš, M., Nielsen, S. V., Koxvold, L. U., Bērziņš, V. and Schülke, A. 2018. A technological crossroads: exploring diversity in the pressure blade technology of Mesolithic Latvia. *Oxford Journal of Archaeology* 37/3, 229–246.
- Dziewanowski, M., 2011. On the classification of by-products of the reduction for blades – some aspects of technology in Swiderian assemblages. *Światowit IX (L)/B*, 223–233.
- Girininkas, A. 2009. *Akmens amžius* (Lietuvos archeologija vol. 1), Vilnius, Versus Aureus.
- Gloger, Z. 1873. Osady nad Niemnem i na Podlasiu z czasów użytku krzemienia. *Wiadomości Archeologiczne* 1, 97–124.
- Gloger, Z. 1873. Osady nad Niemnem i na Podlasiu z czasów użytku krzemienia. *Wiadomości Archeologiczne* 1, 97–124.
- Gloger, Z. 1903. *Dolinami rzek. Opisy podróży wzdłuż Niemna, Wisły, Bugu i Biebrzy*. Warszawa, Nakład Ferdynanda Hosicka.
- Gruzdź, W. 2018. An examination of theories on lithic reduction methods in Swiderian technology. In: Knutsson, K., Knutsson, H., Apel, J. and Glørstad, H. (eds.), *Technology of early settlement in northern Europe. Transmission of knowledge and culture*. Sheffield/Bristol, Equinox Publishing, 47–61.
- Gruzdź, W., Groß, D., Pyżewicz, K. and Vashanau, A. 2025. Continental European plain. In: Nilsson Stutz, L., Peyroteo Stjerna, R. and Törv, M. (eds.), *The Oxford handbook of Mesolithic Europe*. Oxford, Oxford University Press, 213–235.

- Gudaitienė, G. 2018. *The first inhabitants in the western part of the Neris River basin in Lithuania*. Doctoral dissertation. Vilnius, Vilnius University.
- Gudaitienė, G. 2020. Eiguliai, one of Rimutė Rimantienė's first excavations – a revised interpretation. *Lietuvos Archeologija* 46, 33–63.
- Gudaitienė, G., Šapolaitė, J. and Ežerinskis, Ž. 2019. The last Swiderians in Lithuania. *Archaeologia Baltica* 26, 32–49.
- Kontrimas, D. 2016. Vilūnų senovės gyvenvietė. *Archeologiniai tyrinėjimai Lietuvoje 2016 metais*, 44–47.
- Migal, W., 2007. On preferential points of the Final Paleolithic in the Central European Lowland. In: Kobusiewicz, M. and Kabaciński, J. (eds.), *Studies in the Final Palaeolithic settlement of the Great European Plain*. Poznań, Institute of Archaeology and Ethnology, Polish Academy of Sciences, 185–200.
- Ostrauskas, T. 1999. Vėlyvasis paleolitas ir mezolitas Pietų Lietuvoje. *Lietuvos Archeologija* 16, 7–17.
- Ostrauskas, T. 2002a. Kabeliai 2 Stone Age site. *Archaeologia Baltica* 5, 51–82.
- Ostrauskas, T. 2002b. Kundos kultūros tyrinėjimų problematika. *Lietuvos Archeologija* 23, 93–106.
- Piličiauskas, G., Vengalis, R., Kalinauskas, A. and Minkevičius, K. 2021. Vilūnų senovės gyvenvietės. *Archeologiniai tyrinėjimai Lietuvoje 2020 metais*, 34–38.
- Płonka, T., Bobak, D. and Szuta, M. 2020. The dawn of the Mesolithic on the plains of Poland. *Journal of World Prehistory* 33, 325–383.
- Przeździecki, M. 2019. Studium technologiczne materiałów krzemianych ze stanowiska Wołkusz 3 w Północno-Wschodniej Polsce. Koncepcja produkcji ostrzy preferencyjnych. *Archeologia Polski* LXIV, 39–71.
- Pyżewicz, K., Gruzdź, W., Serwatka, K., Sobkowiak-Tabaka, I. and Stefański, D. 2019. Swiderian lithic assemblages from Poland – some new observations and ideas. In: Montoya, C., Fagnart, J.-P. and Locht, J.-L. (eds.), *Préhistoire de l'Europe du Nord-Ouest. Mobilités, climats et identités culturelles. XXVIIIe Congrès préhistorique de France, Amiens 30 mai – 4 juin 2016*. Paris, Société Préhistorique Française, 511–528.
- Pyżewicz, K., Przeździecki, M., Gruzdź, W., Kozak, B., Płaza, D. K. and Sobko, B. 2024. Biographies of Swiderian blades – various examples from the Polish territory. *Sprawozdania Archeologiczne* 76/1, 187–204.
- Rankama, T. and Kankaapää, J. 2011. First evidence of eastern Preboreal pioneers in arctic Finland and Norway. *Quartär* 58, 183–209.
- Rimantienė, R. 1971. *Palaeolit i mezolit Lity*, Vilnius, Mintis.
- Rimkus, T. 2024a. *Nuo vėlyvojo ledynmečio iki pirmųjų metalų. Priešistorės bendruomenių tyrimai Kalvių apyžerėje, Pietų Lietuvoje*. Archeologinės vertybės Lenkijos-Lietuvos dujotiekio trasoje 1. Klaipėda, Klaipėda University Press.
- Rimkus, T. 2024b. Archäologische Forschung im Augstumaller Moor – Fundplätze der Endpaläolithischen Jäger- und Sammlerkulturen im Memeldelta an der litauischen Küste. *Acta Praehistorica et Archaeologica* 56, 65–90.
- Rimkus, T. and Zabiela, G. 2024. Vilūnai 5: a Stone Age and Early Metal period site in the western part of Kalviai Lake valley (southern Lithuania). *Archaeologia Baltica* 31, 7–28.
- Rimkus, T., Butrimas, A., Iršėnas, M. and Meadows, J. 2019. The decorated spindle-shaped bone dagger from Šarnelė: the earliest example of hunter-gatherer mobile art in Lithuania. *Archaeologia Baltica* 26, 50–63.
- Rimkus, T., Kisielienė, D., Piličiauskienė, G., Rumbutis, S. and Peseckas, K. 2025. Hunter-gatherer interaction in a dynamic lake shore landscape during the Late Pleistocene–Late Holocene in southern Lithuania. *Journal of Wetland Archaeology* 24(1-2), 31–53.
- Schild, R., Pazdur, M. F. and Vogel, J. C. 1999. Radiocarbon of the tanged point technocomplexes in Poland. In: Kozłowski, S. K., Gurba, J. and Zaliznyak, L. L. (eds.), *Tanged points cultures in Europe. Read at the International Archaeological Symposium, Lublin, September, 13–16, 1993*. Lublin, Maria Curie-Skłodowska University Press, 13–15.
- Schild, R., Królik, H., Tomaszewski, A. J. and Ciepielewska, E. 2011. *Rydno. A Stone Age red ochre quarry and socioeconomic center. A century of research*. Warsaw, Institute of Archaeology and Ethnology, Polish Academy of Sciences.
- Schild, R. 2014. Geomorphology, stratigraphy, paleoecology and radiochronology. In: Schild, R. (ed.), *Całowanie. A Final Palaeolithic and Early Mesolithic site on an island in the ancient Vistula channel*. Warsaw, Institute of Archaeology and Ethnology, Polish Academy of Sciences, 17–57.
- Serwatka, K. 2018. What's your point? Flexible projectile weapon system in the Central European Final Palaeolithic. The case of Swiderian points. *Journal of Archaeological Science: Reports*, 17, 263–278.
- Stefański, D. 2017. Tanged point technocomplex – Swiderian, but what else? New findings from Kraków region, southern Poland. *Quartär* 64, 241–264.
- Sulgostowska, Z. 1999. Final Palaeolithic Masovian cycle and Mesolithic Kunda culture relations. In: Kozłowski, S. K., Gurba, J. and Zaliznyak, L. L. (eds.), *Tanged points cultures in Europe. Read at the International Archaeological Symposium, Lublin, September, 13–16, 1993*. Lublin, Maria Curie-Skłodowska University Press, 85–92.
- Szukiewicz, W. 1901. Poszukiwania archeologiczne w powiatach Lidzkim i Trockim (gub. Wileńska). *Światowit* 3, 3–29.

- Szymczak, K. 1992. *Północno-Wschodnia prowincja Surowcow a kultury Świderskiej*. Folia Archaeologica 15. Łódź, Wydawnictwo Uniwersytetu Łódzkiego.
- Šatavičius, E. 1998. The Early Mesolithic site of Pasieniai 1. *PACT* 54, 157–169.
- Šatavičius, E. 2005a. Svidrų kultūra Lietuvoje. *Lietuvos Archeologija* 29, 133–170.
- Šatavičius, E. 2005b. Lietuvos vėlyvojo paleolito kultūrų periodizacija. *Archaeologia Lituana* 6, 49–82.
- Šatavičius, E. 2012a. Titnago kasimo ir apdirbimo dirbtuvės prie Titno ežero. *Archaeologia Lituana* 13, 66–83.
- Šatavičius, E. 2012b. Pasieniai 1 settlement. In: Zabiela, G., Baubonis, Z. and Marcinkevičiūtė, E. (eds.), *Archaeological investigations in independent Lithuania 1990–2010*. Vilnius, Society of the Lithuanian Archaeology, 21–26.
- Šatavičius, E. 2014. Ankstyvosios priešistorės objektų tyrimai Kalvių apyžemyje. *Archaeologia Lituana* 15, 7–20.
- Šatavičius, E. 2016. The first Palaeolithic inhabitants and the Mesolithic in Lithuanian territory. In: Zabiela, G., Baubonis, Z. and Marcinkevičiūtė, E. (eds.), *A hundred years of archaeological discoveries in Lithuania*. Vilnius, Society of the Lithuanian Archaeology, 8–39.
- Vengalis, R., Piličiauskas, G. and Rutavičius, J. 2016. Dujotiekių jungties tarp Lenkijos ir Lietuvos pakartotiniai žvalgymai. *Archeologiniai tyrinėjimai Lietuvoje 2015 metais*, 458–465.
- Vengalis, R., Minkevičius, K., Valančius, M. and Piličiauskas, G. 2022. Hidden landscapes of the earliest Iron Age: excavations at Kakliniškės 7 reveal an overlooked settlement phase in southern Lithuania. *Archaeologia Baltica* 29, 119–148.
- Winkler, K. 2019. *Ahrensburgien und Swidrien im mittleren Oderraum. Technologische und typologische Untersuchungen an Silexartefakten der jüngeren Dryaszeit*. Untersuchungen un materialien zur Steinzeit in Schleswig-Holstein und im Ostseeraum, Band 11. Kiel/Hamburg, Wachholtz.
- Zagorska, I. 1994. Salaspils Laukskolas akmens laikmeta apmetne. *Archeologija un Etnogrāfija* XVI, 14–28.
- Zagorska, I. 2006. The earliest antler and bone harpoons from the East Baltic. *Archaeologia Baltica* 7, 178–186.
- Zagorska, I. 2010. Dzīves telpas organizācija Salaspils Laukskolas vēla paleolita apmetnē. *Archeologija un Etnogrāfija* XXIV, 183–201.
- Zagorska, I. 2012. *Senie ziemeļbriežu mednieki Latvijā*, Rīga, Zinātne.
- Zagorska, I. 2019. The Early Mesolithic bone and antler industry in Latvia, eastern Baltic. In: Groß, D., Lübke, H., Meadows, J. and Jantzen, D. (eds.), *Working at the sharp end: from bone and antler to Early Mesolithic life in northern Europe*. Untersuchungen und Materialien zur Steinzeit in Schleswig-Holstein und im Ostseeraum 10. Kiel/Hamburg, Wachholtz Verlag, 305–318.
- Zagorska, I. and Winiarska-Kabacińska, M. 2019. A first glimpse of the organisation of space in the Late Palaeolithic of Latvia. In: Eriksen, B. V., Rensinks, E. and Harris, S. (eds.), *The Final Palaeolithic of Northern Eurasia. Proceedings of the Amersfoort, Schleswig and Burgos UISPP commission meetings*. Schriften des Museums für Archäologie Schloss Gottorf 13. Kiel, Ludwig Verlag, 329–341.
- Zagorska, I., Eriksen, B. V., Meadows, J. and Zelčs, V. 2019. Late Palaeolithic settlements of Latvia confirmed by radiocarbon dating of bone and antler artefacts. In: Eriksen, B.V., Rensinks, E. and Harris, S. (eds.), *The Final Palaeolithic of Northern Eurasia. Proceedings of the Amersfoort, Schleswig and Burgos UISPP commission meetings*. Schriften des Museums für Archäologie Schloss Gottorf 13. Kiel, Ludwig Verlag, 343–362.
- Zaliznyak, L. L. 1995. *The Swidrian reindeer-hunters of eastern Europe*. Wilkau-Hasslau, Beier & Beran Archäologische Fachliteratur.
- Žilinskaitė, A., Brazaitis, Dž., Pilkauskas, M. and Poška, T. 2021. Šventininkų akmens amžiaus gyvenvietė. *Archeologiniai tyrinėjimai Lietuvoje 2020 metais*, 56–63.

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# From Ice Age to Insight

The study of the Ahrensburg Tunnel Valley  
through time

Moiken Hinrichs and Katja Winkler

## Abstract

The Ahrensburg tunnel valley in Schleswig-Holstein, Germany, is renowned for its numerous key archaeological sites from the Late Palaeolithic period. These sites were first documented through pioneering surveys and excavations carried out by Alfred Rust in the 1930s. Long inaccessible for research, the area has recently become the focus of renewed interest due to planned railway expansion, which threatens parts of the site but also offers opportunities for archaeological rescue excavations. Early investigations, stimulated by private collectors and confirmed by Rust's groundbreaking fieldwork, provided evidence of human presence shortly after the last glaciation. After decades of inactivity, targeted research resumed in 2008 under the direction of Ingo Clausen, aiming to relocate Rust's original trench and assess preservation. While some shoreline deposits have degraded, deeper central lake sediments exhibit intact stratigraphy, high artefact density, and excellent organic preservation. The interplay of infrastructure development and heritage protection now drives the urgent need to document, preserve, and further study this culturally significant landscape.

*Keywords: Late Palaeolithic, Research History, Hamburgian, Ahrensburgian*

## Introduction

The Ahrensburg tunnel valley is one of the most intriguing archaeological site ensembles in Schleswig-Holstein. Although it preserves some of the oldest evidence for bow-and-arrow hunting in human history (Hartz *et al.* 2019; Rust 1943), it remains largely unknown outside Late Palaeolithic research. It is the eponymous site to two cultural groups – the Hamburgian and the Ahrensburgian – yet, apart from strong local commitment, it has attracted little wider public attention.

Over the past decade, this has begun to change. Infrastructure development has placed the railway line along the Ahrensburg tunnel valley in the spotlight of expansion planning. The German Railway (DB) intends to extend the existing railroad embankment and replace the current road crossing with a bridge. This poses, first and foremost, a threat to the archaeological monument which is at risk of being damaged or destroyed during construction. At the same time, it offers a significant opportunity for research: excavations must be conducted to rescue those parts of the site that would otherwise be lost.

As final decisions on the implementation of the railway expansion draw closer, it is time to review achievements so far, to identify opportunities, and to assess the problems

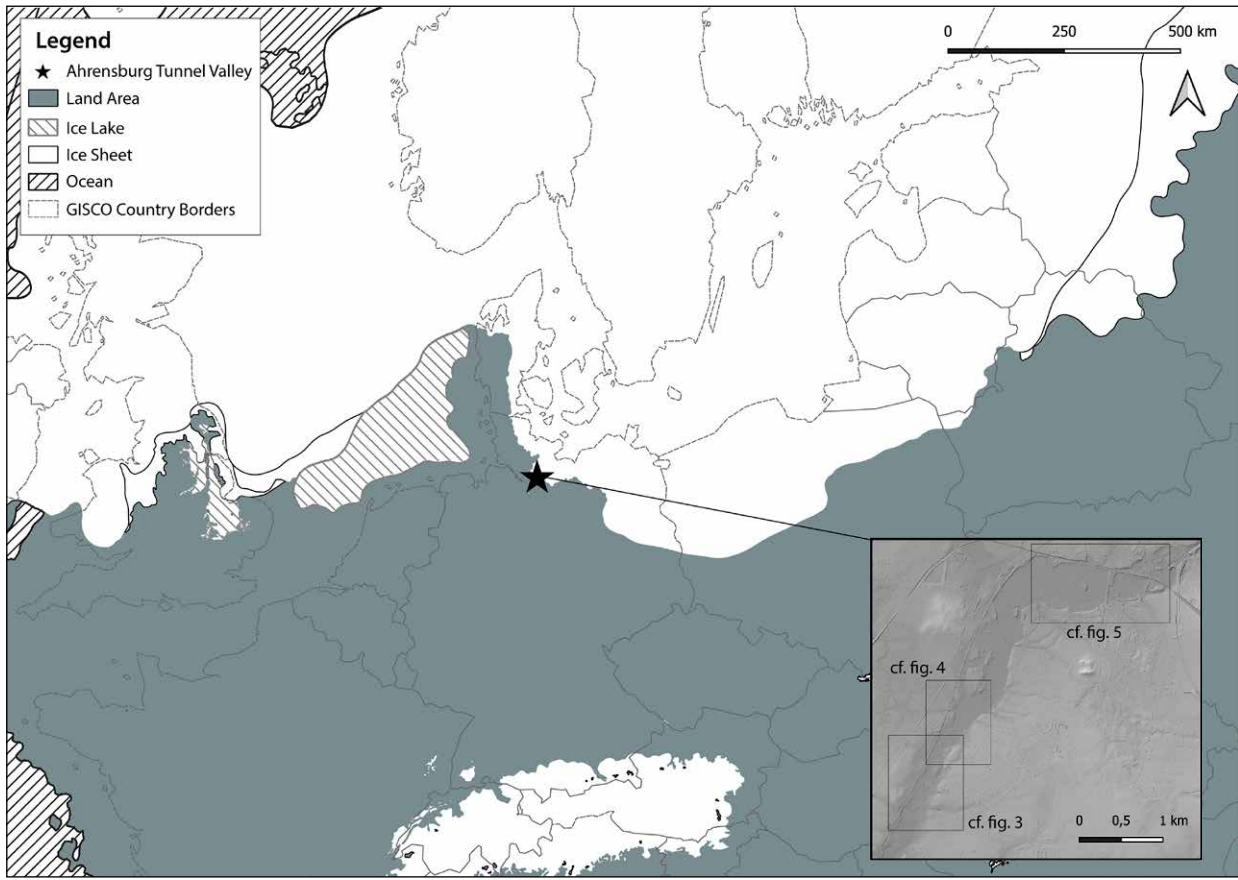


Figure 1: Map of the Ahrensburg tunnel valley in relation to the LGM (26500–19500 cal BP). The digital terrain model (DTM) is super-elevated twice. The extent of landmasses and ice sheet (EPHA) compiled by ZBSA (after: Buoncristiani and Campy 2004; Calvet *et al.* 2011; Caille *et al.* 2013; Clark *et al.* 2004; Gibbard and Clark 2011; Gobejishvili *et al.* 2011; Harff *et al.* 2017; Hughes *et al.* 2016; Lambeck and Purcell 2005; Larsen *et al.* 2014; Lericolais 2017; Matoshko 2011; Rinterknecht *et al.* 2018; Seguinot *et al.* 2018; Sejrup *et al.* 2016; Urdea *et al.* 2011; Westley and Edwards 2017; Zasadni and Kłapyta 2014). Geographic Information System of the Commission (GISCO) country borders: © EuroGeographics for the administrative boundaries.

and challenges ahead. This article aims to: (1) provide a brief summary of research related to the tunnel valley, (2) outline the planning process and related challenges and (3) offer a short outlook into the future.

## Geology

One of the defining characteristics of the Ahrensburg tunnel valley is its geological positioning (see Fig. 1). Situated at the margin of the Last Glacial Maximum (LGM), the valley remains remarkably well-preserved. Tunnel valleys form in glacial margin zones where meltwater erodes sediments beneath the ice (Gripp 1964, 237) and are typified by their elongated, hollow structures, lacking the slip faces or impact slopes characteristic of fluvial valleys. Following the retreat of the ice sheet, these valleys were infilled with dead ice, which melted slowly and shaped the valley while creating slowly silting freshwater lakes (Cimiotti 1987, 173; Gripp 1964, 184–186). Most tunnel valleys were eroded during deglaciation and are no longer visible. In contrast, the Ahrensburg

tunnel valley remains in an excellent state of preservation, maintaining its original form as created roughly 20000 years ago (Cimiotti 1987, 173; Hughes *et al.* 2016).

South of the Hamburg-Schleswig-Holstein border, the Ahrensburg tunnel valley adjoins the Wandse tunnel valley, which today suffers from extensive anthropogenic degradation. Coring activities have revealed substantial peat and mud strata, facilitating the reconstruction of various lacustrine environments (Cimiotti 1987, 173–174; Tromnau 1975, 94–98). Throughout the Late Glacial, the dead ice lakes underwent periodic changes in size and depth due to subsidence, with a notable episode of desiccation during the Allerød (Cimiotti 1987, 174–177).

One prominent feature is the bottleneck at the so-called *Brauner Hirsch*, near the Hamburg border, where the tunnel valley narrows to just 70 m (cf. Fig. 4). Today, it remains the only possible crossing point in this section of the valley – and the area that poses particular challenges for the planned construction work.

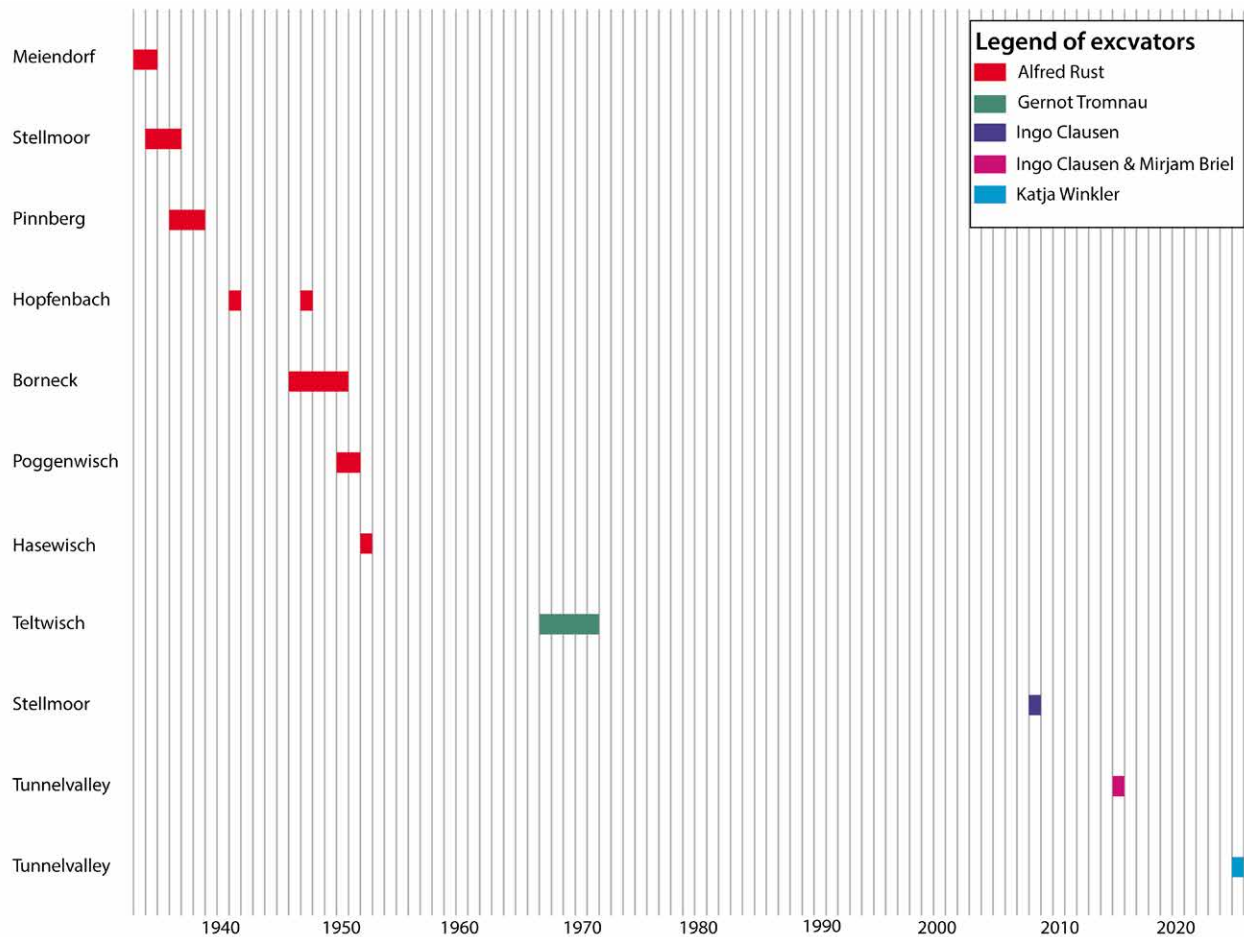


Figure 2: Overview of excavations carried out in the Ahrensburg Tunnel Valley.

## Excavation History

The Ahrensburg tunnel valley has long been recognised as an archaeological locality, though its scientific significance was not immediately appreciated. The first recorded finds were made 1906 by state geologist Wilhelm Wolff, who discovered flint tools on Stellmoor Hill during geological mapping and reported them to the Museum of National Antiquities in Kiel. Reflecting the prevailing state of research at the time, these artefacts were classified as Neolithic in origin (Rust 1943, 123; Tromnau 1975, 11), as the possibility of human occupation so far north during the last Ice Age was not yet widely accepted. A proposal to initiate excavations in the bog at the base of Stellmoor Hill was not pursued for lack of funding.

Six years later, the first organic remains from the valley were unearthed during construction of the *Walddörfer Bahn* in the northern section of the tunnel valley. These finds were transferred to the State Institute of Mineralogy and Geology in Hamburg but subsequently destroyed during World War II (Tromnau 1975, 11).

Credit for stimulating the sequence of later, ground-breaking discoveries is due in large measure to numerous

private collectors who persistently explored Stellmoor Hill and its surroundings. Notably, finds made by Chr. Laage provided persuasive evidence that humans had been present in Schleswig-Holstein shortly after the last glaciation (Rust 1943, 123; Tromnau 1975, 11). Alfred Rust substantiated this claim in a dramatic fashion. Having been shown Late Palaeolithic tools from the Alster near Wellingsbüttel, Hamburg, in the early 1930s, he recalled encountering similar artefacts in the Ahrensburg tunnel valley. A brief survey yielded further material, which he presented to Gustav Schwantes, then Director of the Museum of National Antiquities in Kiel and Professor of Prehistory at the University of Kiel (Schäfer 2007). Rust had attended Schwantes's lectures since being a student at the University of Hamburg and was granted permission to excavate (Fig. 2).

In 1933, excavations commenced at the Meiendorf site (Rust 1937, 74; Tromnau 1975, 12). Rust's principal objective was to recover organic material in order to establish the chronological position of the stone tools beyond dispute. Having first excavated the settlement area on the mineral slope, he proceeded to investigate

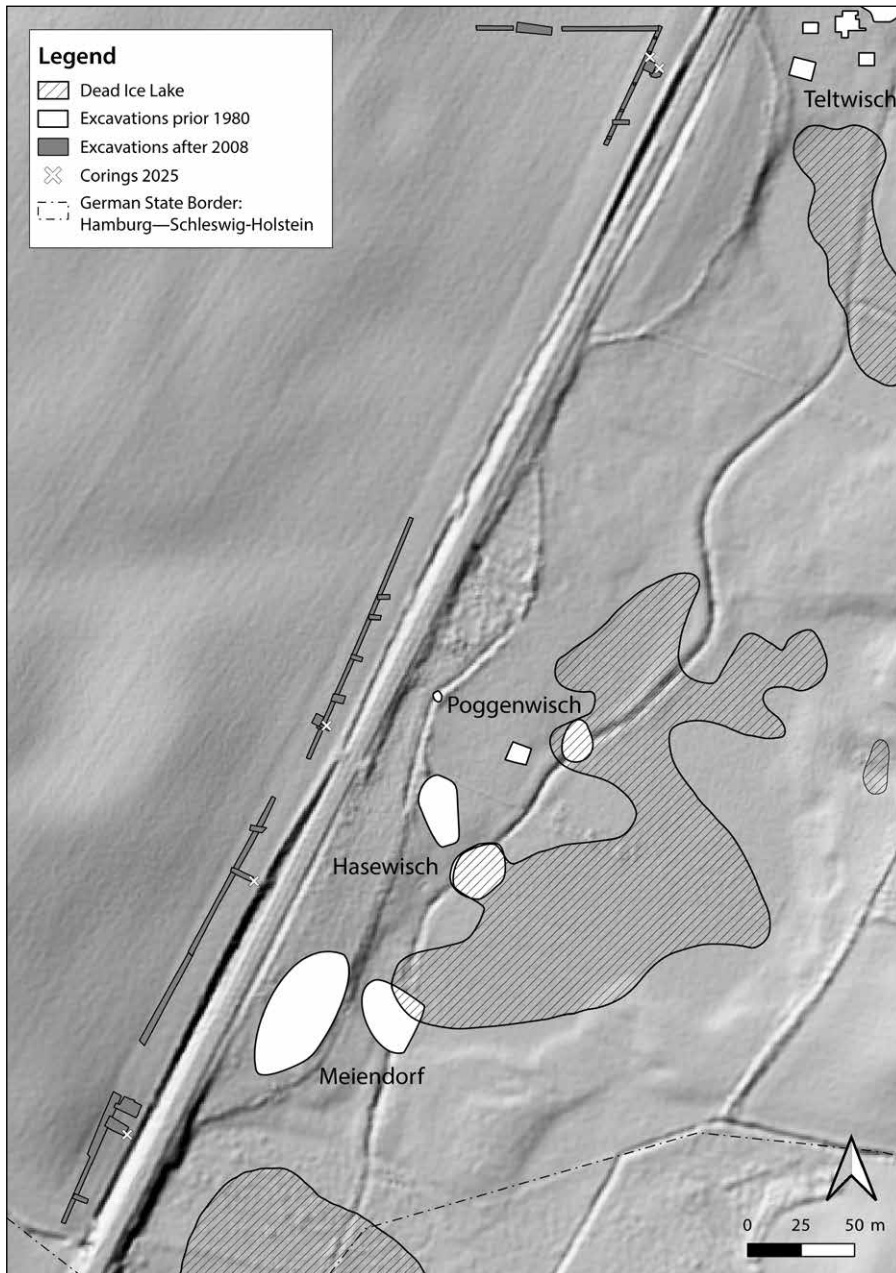


Figure 3: Southern part of the Ahrensburg tunnel valley and related excavations. The DTM is superelevated twice. German state borders: Regionalatlas Deutschland, Data licence Germany – attribution – Version 2.0.

the adjacent former dead-ice lake (Fig. 3). Here, he recovered a wealth of organic material, including antler, bone, complete to nearly complete reindeer skeletons, and organic tools. Buoyed by this success, Rust turned to Stellmoor Hill, focusing work on the former dead-ice lake basin (Fig. 4). This yielded an equally rich assemblage of organic remains, which remain exceptional even today (Clausen 2010; Rust 1943).

These excavations also decisively established the stratigraphic relationship between the two distinct cultural groups. The lowermost layer contained Hamburgian material, while overlying strata – at least two distinguishable

layers – were attributable to the Ahrensburgian, separated from the Hamburgian by a soil formation horizon corresponding to the Allerød interstadial (Rust 1943, 6–13). This confirmed the chronological precedence of the Hamburgian culture. Among the most remarkable finds were the remains of approximately 100 arrow shafts in the Ahrensburgian layer, which were unfortunately lost in the destruction of the Kiel collections during World War II. A chance discovery, in 2011, led to the recovery of a few arrow fragments from Rust’s estate, which were subsequently attributed to the Ahrensburgian through radiocarbon dating, thereby conclusively resolving any

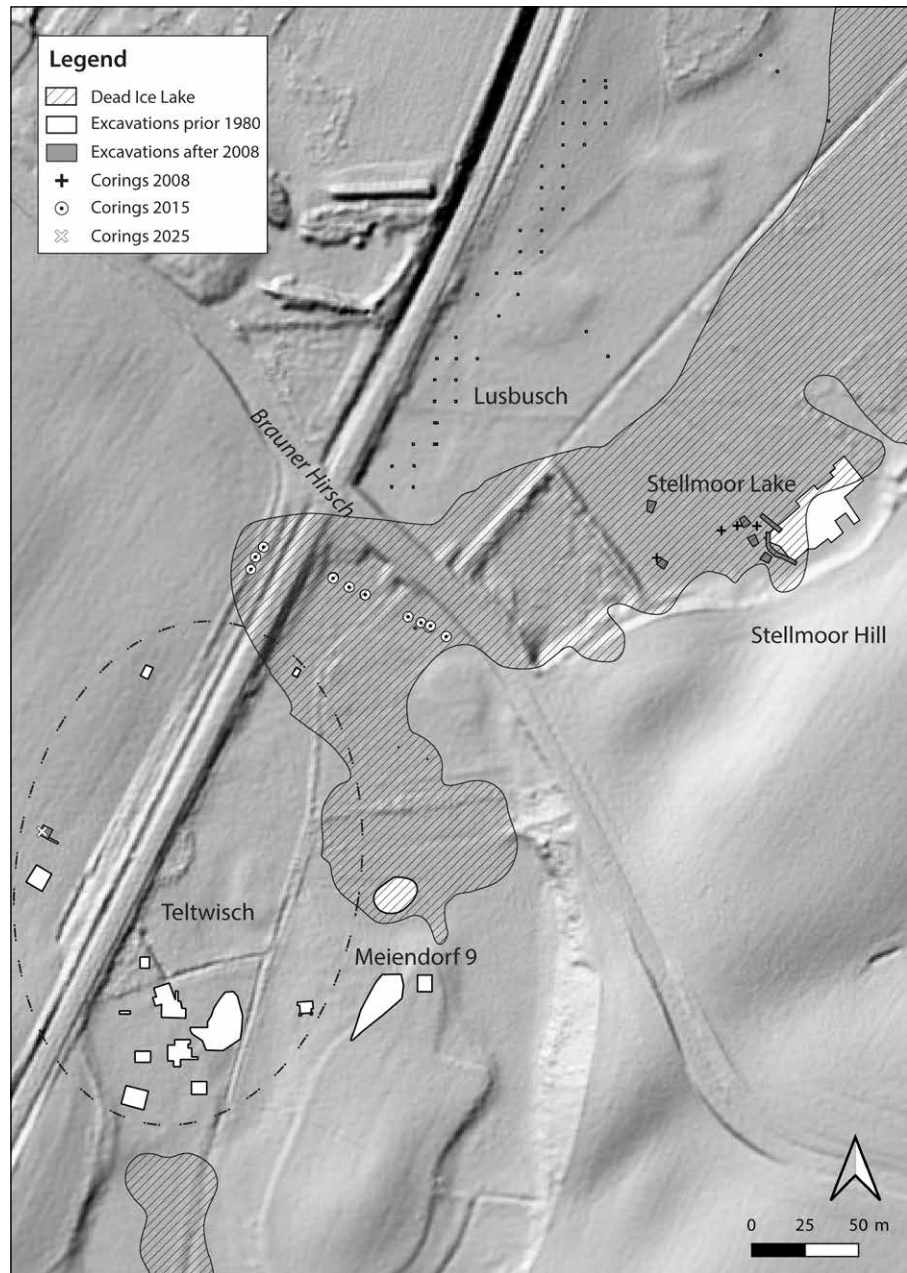


Figure 4: The Ahrensburg tunnel valley at the road crossing *Brauner Hirsch* and related excavations. The DTM is superelevated twice.

uncertainties regarding the chronological attribution of these artefacts (Hartz *et al.* 2019).

Following his work in the southern reaches of the tunnel valley, Rust shifted his attention northwards (Fig. 5). Between 1936 and 1956, he identified four additional sites in waterlogged contexts, dating from the Late Palaeolithic to the Neolithic. The Neolithic site of Seehases Moorkoppel was left largely unexamined, as Rust's focus at the time was on locating Mesolithic deposits (Bötel 1950). The Hopfenbach site, discovered accidentally during culvert construction in 1941, underwent a brief test excavation that revealed a 3.5 m wooden object. In 1947, while excavating at Borneck, Rust revisited Hopfenbach and found two

further wooden artefacts nearby. He interpreted this group as idols originally standing in the lake, later destroyed by a falling tree (Rust 1958a, 121–129).

Investigations at Borneck uncovered concentrations of finds ranging from the Hamburgian to the Mesolithic, along with what were interpreted as tent structures. However, excavations into the associated dead-ice lake proved disappointing: while organic artefacts were recovered, clear spatial correlations with the settlement areas could not be established (Hinrichs 2019; 2021; Rust 1958a, 29–92). Excavations at Pinnberg revealed Mesolithic occupation sites and burials that had remained undisturbed by modern activity (Rust 1958b). The Pinnberg was situated in the deepest



Figure 5: Northern part of the Ahrensburg tunnel valley and related excavations. The DTM is superelevated twice.

sector of the former lake system. It appears that the northern portion of this basin did not fully dry out during the Allerød period, thereby limiting opportunities for human settlement. Only during the Boreal period water levels decreased sufficiently to allow at least temporary access to the island.

Rust's final excavations took place at Hasewisch and Poggenwisch (Fig. 3), both of which produced significant results (Rust 1958a, 93–121). At Hasewisch, only the settlement area was excavated, though corings in the lake yielded reindeer bones (Clausen and Guldin 2017, 17). Poggenwisch was investigated in the same manner as Meiendorf and Borneck: first the settlement zone on mineral soil, followed by examination of lacustrine deposits. Poggenwisch in particular is renowned for the so-called Poggenwisch Staff – a 14.8 cm long, highly decorated artefact of reindeer antler, attributed to the Hamburgian.

It is important to note that Rust's excavations were financed by the *SS-Ahnenerbe* (Clausen 2010, 16; Ickerodt 2016; Rust 1943, 60). Scholarly debate continues as to whether Rust was simply a beneficiary of the system or an active adherent (Ickerodt 2016; Tromnau 2015).

Excavations ceased after Rust's campaigns until plans for a new road through the tunnel valley necessitated

archaeological intervention (Tromnau 1975). This led to Gernot Tromnau's excavation of the Teltwisch sites (Fig. 4) and the eventual designation of the valley as a *Grabungsschutzgebiet* (protected excavation zone) in 1977. At Teltwisch, several campsites ranging from the Hamburgian to the Mesolithic were recorded; seven were excavated in detail and others preliminarily assessed. Corings and test pits were also undertaken in the adjacent dead-ice lake (Tromnau 1975). Although the proposed road was never built, its route is again under consideration today. During Tromnau's work, Friedrich Grube and Hussein Homci conducted geological studies that were the basis for reconstructions of the former dead-ice lakes (Bokelmann 1991, 72–73; Tromnau 1975, 94–98).

Since 1982, the tunnel valley has been part of a designated nature reserve and, since 2007, integrated into the Natura-2000 network. While these measures have afforded substantial protection to the archaeological resource, they have also imposed severe restrictions on new research, with investigations effectively prohibited unless prompted by unavoidable development.

No further archaeological fieldwork occurred until 2008, when Ingo Clausen initiated targeted excavations

aimed at relocating Rust's original trench (Fig. 4). Rust had left no measured coordinates, and the only available data comprised site descriptions, photographs, one rough map, and an excavation plan published in the contributions by Karl Gripp and Rudolf Schütrumpf (Rust 1943, I, Fig 1; 8, Fig. 1). A secondary aim of Clausen's work was to assess both the preservation conditions in the former lake and the presence and extent of archaeological deposits (Clausen 2010, 17). The results were highly promising; however, the stratigraphy recorded in three test pits near Rust's trench differed from that reported by Rust, and the preservation of bone and antler was poorer. Drill core data suggested post-depositional disturbance and redeposition of layers. Rust had likely benefited from excavating in a small shoreline bay with unusually favourable conservation conditions – conditions not found nearby (Clausen 2010, 17–18). A further test pit in the deeper central area of the lake northwest of Rust's trench confirmed intact stratigraphy and excellent organic preservation, with indications of high artefact density to depths of 7 m (Clausen 2010, 18).

Nearly a decade later, renewed focus came with plans to extend the S4 railway from Hamburg to Ahrensburg. The current embankment runs along the western edge of the tunnel valley, crossing known sites and – given the absence of archaeological monitoring in 1884 – likely obliterating others. Notably, it intersects part of the former dead-ice lake at the *Brauner Hirsch* road overpass, where unstable peat layers prompted the 19th-century engineers to construct a floating foundation. Subsidence continues to affect the road structure today.

The planned railway expansion will require reconstruction of the overpass and the upgrading of the embankment to support two tracks. Pre-investigations in 2015 (Figs. 3, 4) were limited to the western side of the embankment, as excavation was not permitted within the Fauna-Flora-Habitat-protected area (FFH). No definitive settlement site was identified, despite glacial sediments being exposed and a few stray finds being made. North of the road overpass, in the Lusbusch area west of Rust's excavations, a grid of small test pits yielded dense flint debitage and tools, demonstrating intensive Late Palaeolithic occupation on the opposite shore of the lake (Clausen and Guldin 2017).

Within the projected bridge crossing zone, conventional pre-investigation was impossible. Instead, large-diameter coring was employed to assess the existence, composition, and preservation state of archaeological deposits (Fig. 4). The results were striking: projections estimated that approximately 260000 preserved artefacts could be recovered from the crossing area – an even greater quantity than Rust obtained in the 1930s (Clausen and Guldin 2017, 15–16). This underlines the enormous significance, yet also the practical difficulty, of any future excavation in the Ahrensburg tunnel valley. To avoid disturbing the deposits, the original

engineering plan favoured a network arch bridge, thereby spanning the archaeological layers without penetration.

However, in the decade since the pre-investigations, project planning has evolved. A decision has now been taken to replace the network arch design with a pillar-supported bridge. This alternative would necessitate peat removal for stable foundations, entailing major disturbance to both the archaeological and ecological environment. Negotiations between the Archaeological State Department of Schleswig-Holstein (ALSH), the Lower Nature Conservation Authority (UNB), and DB are currently exploring the possibility of relocating the crossing approximately 350 m to the south, between former dead-ice lakes. This route, first considered in the 1960s and previously leading to the Teltwisch excavations, would avoid wetland areas with high organic preservation. While legal obstacles to building a new road through an existing FFH-area remain significant, relocation would reduce archaeological damage, mitigate environmental destruction, simplify excavation on mineral soils, and lower construction costs.

Irrespective of final bridge design, it is highly probable that the embankment expansion will proceed. Accordingly, in summer 2025, excavations were carried out along the embankment. Four areas, selected from earlier test trench results, were opened, with smaller trenches positioned in zones offering the highest preservation potential for settlement deposits. No intact archaeological layers were encountered, but the geological findings were illuminating. Within a small area, sediment profiles revealed a highly complex depositional history, including periglacially superimposed meltwater channels and fluvial sand deposits. Artefacts recovered from these layers were heavily abraded and in many cases the distinction between artefact and geofact was uncertain, necessitating the retention only of unequivocal artefacts. Glacial sediments were found directly beneath the plough layer, indicating erosion of Holocene and, in some locations, Younger Dryas soil horizons. The causes and sediment transport pathways remain unclear, though the profiles contribute to refining the reconstruction of ice sheet advance–retreat dynamics following the LGM. Notably, despite decades of research, the precise margin of the former ice sheet in this area remains largely undetermined. Additional corings conducted in conjunction with the trench excavations have, however, yielded further insights into the local moraine formation.

## Critical assessment

The Ahrensburg tunnel valley is unique in Schleswig-Holstein and arguably one of the most important Late Palaeolithic sites in Europe. Its preservation of organic artefacts, combined with a well-documented cultural sequence from the Hamburgian to the Ahrensburgian, makes it indispensable for understanding the final stages of the last Ice Age.

Legal protections as a *Grabungsschutzgebiet*, nature reserve, and Natura-2000 site have safeguarded the valley from large-scale destruction, but they have also made systematic excavation nearly impossible. This means that research typically occurs only when infrastructure projects, like the current S4 railway expansion, provide both the legal grounds and funding for archaeological intervention. Another critical issue is the site's visibility. Outside specialist circles, the tunnel valley remains little known, despite its significance for the history of human adaptation to extreme climates. Public engagement has been limited beyond the local scale and a significant portion of material from private collections has neither been published nor subjected to the degree of analysis warranted.

Although Alfred Rust employed methodologies that were innovative for his time – such as botanical and zoological analyses – the documentation produced during his excavations does not meet the level of detail expected in contemporary archaeological practice. Comprehensive sediment descriptions were prepared only sporadically and were largely confined to the dead-ice lake contexts. Neither artefacts nor excavation trenches were systematically georeferenced, and, in the case of artefacts, neither depth measurements nor precise layer assignments were consistently recorded. Where stratigraphic attribution is provided, it is often vague and open to interpretation. Moreover, adverse field conditions – particularly the recurrent intrusion of rising groundwater and the collapse of excavation profiles – further compromised data accuracy. In some instances, artefacts were removed from the sediments only seconds before encroaching groundwater forced termination of work (e.g. Rust 1958a, 82; 125). While such circumstances make for compelling personal narratives, they resulted in an incomplete contextual record from a scientific perspective. Advances in analytical techniques and archaeological science have since revealed both errors and misinterpretations in Rust's conclusions; however, without new excavations there is no means to revise or correct these aspects (e.g. Bokelmann 1981; Clausen 2010, 16; Price *et al.* 2015).

Comparable limitations are evident in Rust's excavations on mineral soils. Here, fieldwork was conducted using a one-square-metre grid system, with artefacts recorded by grid square but with minimal information on their depth or stratigraphic provenance. This level of resolution precludes reliable analysis of activity zones and renders the verification of postulated tent structures impossible (Hinrichs 2019; 2021). Later critical examination of Rust's reconstruction methodology for tent rings has further cast doubt on their existence (Hinrichs 2021, 7). The available data are simply insufficient to substantiate such interpretations. Similar issues affect Gernot Tromnau's Teltwisch excavations. While not all areas were documented to the level of quarter-square precision, the overall information quality surpasses

Rust's work. Nevertheless, the absence of detailed sediment drawings remains a significant limitation, although layer descriptions were at least provided for contexts yielding artefacts (Tromnau 1975).

Research on the material from the Ahrensburg tunnel valley has continued to the present day (e.g. Bratlund 1996; Drucker 2011; Grimm and Weber 2008; Grimm *et al.* 2021; Grønnow 1985; Meadows *et al.* 2018; Riede *et al.* 2010; Weber 2013; Wild 2020) and has provided significant insights into the palaeoenvironment and human life at the end of the last Ice Age, as for example the Cluster B1: *Pioneers of the North* of the DFG funded CRC 1266 – Scales of Transformation. However, considerable scope for further discovery remains. As previously noted, more recent analyses indicate that not all original interpretations were correct, and that modern methodologies could produce substantially more detailed and reliable results. Unfortunately, existing collections are often unsuitable for re-analysis, owing to incomplete contextual documentation, post-excavation mixing of material, and, in some cases, total artefact loss during World War II (e.g. Riede *et al.* 2010). This makes a renewed, methodologically rigorous investigation of the site highly desirable to advance our knowledge of the Late Palaeolithic and Early Mesolithic in northern Germany.

It is at this juncture, however, that conflicting priorities become apparent. On one hand, archaeological research demands new data to correct past inaccuracies and enhance understanding of prehistoric lifeways; on the other hand, heritage management seeks to protect the site and its stratigraphic integrity *in situ*, provided that preservation is not directly threatened. In addition, environmental protection authorities in the Ahrensburg tunnel valley rightly oppose any intervention that could compromise existing ecological conditions. These competing objectives have historically generated tensions among stakeholders, and it is likely that not all decisions made by any party have been strictly solution oriented. Nevertheless, all involved share the ultimate goal of preserving the site, advancing scholarship, and communicating its significance.

The urgency of resolving these tensions is heightened by the imminent infrastructure developments. The originally proposed network arch bridge was intended to minimise impacts on both the nature conservation area and the archaeological monument. However, due to local opposition and, above all, financial considerations, a decision was taken to opt for a smaller, less expensive pillar bridge. This design change entails significant adverse consequences for both archaeology and environmental preservation. Retaining the current road alignment would require construction directly over – and through – the sediments of the former dead-ice lake. In this location, up to four metres of peat overlie substantial layers of organic mud containing archaeological remains. A pillar bridge

would necessitate foundations reaching depths of at least ten metres to ensure stability. Archaeological excavation in this context would require recovery and documentation of materials from depths of up to eight metres, under conditions of continuous groundwater intrusion. Achieving this would necessitate groundwater lowering, a process that threatens not only the surrounding natural environment but also untouched archaeological layers. Lowering the groundwater table would also cause peat subsidence, in turn jeopardising the stability of the nearby railway embankment, which in places was originally constructed without deep foundations. Excavation on the scale and in the manner undertaken by Rust is no longer feasible under present conditions, but any future intervention in such deposits will inevitably encounter these same severe technical challenges.

### Future plans

Although the network arch bridge design was initially considered as a means to avoid disturbing archaeological layers during construction at the crossing point, no analogous solution is feasible for the adjacent railway embankment. As noted above, the embankment at the *Brauner Hirsch* traverses portions of the former dead-ice lake (cf. Fig. 4). In this section, the existing structure rests on a floating foundation; however, any extension of the railway line would necessitate a different approach to ensure long-term stability. Undertaking archaeological excavations in such proximity to the embankment is deemed unsafe. The risks are twofold: firstly, the danger posed to workers excavating at significant depth beneath an active railway; and secondly, the potential for further subsidence of the underlying sediments during excavation, which could in turn endanger rail operations. Given these hazards, the archaeological layers beneath the embankment are considered irretrievably lost.

In accordance with the principle that archaeological excavations are undertaken when preservation *in situ* is impossible, a strategy of compensatory excavation was adopted. The objective is that, if deposits cannot be safeguarded, their loss can at least be offset by fully documenting the site. In the case of the Ahrensburg tunnel valley, direct excavation beneath the embankment is unfeasible; the knowledge potential of these inaccessible layers will therefore be permanently lost once construction is complete. This loss will be mitigated by undertaking a scientifically rigorous excavation at a nearby, analogous location. This entails the disadvantage that the loss of the archaeological monument is effectively doubled, as both the area affected by the construction work and that encompassed by the excavation trench have been destroyed. The extent of potential archaeological losses at the construction site remains unknown. Such excavations should be regarded strictly as a measure of last resort and

employed only under exceptional circumstances. Their implementation requires thorough evaluation of both purpose and potential benefits and can be justified solely in heritage contexts of outstanding significance, such as the Ahrensburg tunnel valley.

The site selected for this compensatory work, as proposed in a specialist report on the planned construction, lies in the vicinity of Alfred Rust's original excavation, between the test pits investigated by Ingo Clausen in 2008 (Guldin 2017). The technical challenges are considerable: the high groundwater table and water-saturated sediments create extremely difficult working conditions. To meet contemporary documentation standards while ensuring safety, the intervention would necessitate the construction of a sheet pile caisson equipped with a sealed bottom plug, installed using either jet grouting or soft gel injection techniques. Such a system would entirely isolate the excavation area from external groundwater and thereby prevent the collapse of profile walls or the loss of stratigraphic layers. It would also ensure that only the sediments within the caisson are dewatered, avoiding any lowering of the surrounding groundwater table – a measure essential to prevent subsidence of the nearby railway embankment and associated safety hazards.

However, constructing such a caisson within a designated nature conservation area poses significant regulatory and logistical difficulties. These include restrictions on permissible construction materials, seasonal limitations on activity, and the challenging terrain required for heavy equipment deployment. The unstable ground conditions represent one of the most pressing uncertainties in the project planning. While a caisson remains the only viable method for conducting excavations under these circumstances, the technical feasibility of constructing such a structure safely within the tunnel valley has yet to be fully assessed. Comprehensive pre-construction geotechnical investigations will therefore be required before any work in the former dead-ice lake areas can proceed.

Currently, the DB planning process is evaluating four potential crossing solutions: the aforementioned network arch bridge, a pillar bridge, a relocated crossing, and an embankment bridge. The latter option can be regarded without exaggeration as the most detrimental from both heritage preservation and environmental standpoints. Not only would it entail extensive and difficult-to-quantify encroachment, but it would also result in the near-total destruction of the Ahrensburg tunnel valley as a cultural and natural asset.

From a heritage management perspective, the only defensible option is the relocation of the crossing. While such a change in road alignment would affect a greater portion of the FFH-area –requiring a longer route through currently undisturbed land – the environmental impacts would still be considerably reduced compared

with the significant disruption to wetland ecosystems inevitable at the *Brauner Hirsch* site. Consequently, from a nature conservation standpoint, relocation and reconstruction of the crossing is likewise the preferable solution. The legal obstacles to this approach, however, are substantial, and a final decision on the chosen option is yet to be reached.

More than nine decades after Alfred Rust's pioneering discoveries in the Ahrensburg tunnel valley, archaeological research is prepared to return to the site, equipped with modern analytical methods and excavation techniques. While it remains impossible to predict the full extent of potential new discoveries, such investigations hold the promise of transformative insights into the Late Palaeolithic in northern Germany. Although the past decade has tempered expectations for rapid commencement of construction, recent developments – particularly the cooperative efforts of DB, the UNB, and the ALSH – suggest that a consensus balancing the diverse interests involved may soon be achieved. Should this occur, a decision and subsequent initiation of construction work may be anticipated within the next several years.

However, time pressure will be a decisive factor. Rescue excavations must be completed before construction begins, which limits the possibility for long-term, interdisciplinary research. There is also the challenge of balancing archaeological goals with nature conservation

requirements under Natura-2000 regulations, which may restrict access and methods.

Looking beyond the S4 project, the Ahrensburg tunnel valley would benefit from an integrated research strategy combining a wide range of sciences such as archaeology, palaeoecology, and geoscience. Such an approach should also include public outreach – through exhibitions, educational programmes, and digital platforms – to bring the site's significance to a wider audience.

## Acknowledgements

The authors wish to express their gratitude to Dr. Alf Grube for his generous contribution of time and expertise in elucidating the complex sedimentary sequences within the excavation trenches, as well as for his valuable support in the interpretative process through the provision of additional core samples.

We would further like to express our deepest gratitude to Berit V. Eriksen, whose constant support, thoughtful guidance, and invaluable advice have been vital throughout our career. Her encouragement extended beyond the boundaries of our dissertations, as she generously shared her knowledge and experience on all aspects of the scientific profession. Her patience, wisdom, and unwavering belief in our abilities have not only shaped the quality of our work but have also significantly influenced our development as researchers.

## References

- Bokelmann, K. 1981. Rentierjäger am Gletscherrand in Schleswig-Holstein? Ein Diskussionsbeitrag zur Erforschung der Hamburger Kultur. *Offa* 36(1979), 12–22.
- Bokelmann, K. 1991. Some new thoughts on old data on humans and reindeer in the Ahrensburgian tunnel valley in Schleswig-Holstein, Germany. In: Barton, R. N. E., Roberts, A. J. and Roe, D. A. (eds.), *The Late Glacial in northwest Europe: human adaptation and environmental change at the end of the Pleistocene*. London, Council for British Archaeology 77, 72–81.
- Bötel, E.-W. 1950. Kartei der Landesaufnahme Schleswig-Holstein: *Information zur Fundstelle STO/Ahrensburg/62-001-000-00085*.
- Bratlund, B. 1996. Hunting strategies in the Late Glacial of northern Europe: A survey of the faunal evidence. *Journal of World Prehistory* 10(1), 1–48.
- Buoncristiani, J.-F. and Campy, M. 2004. Palaeogeography of the last two glacial episodes in the Massif Central, France. In: Ehlers, J. and Gibbard, P. L. (eds.), *Developments in Quaternary Sciences* 2. Amsterdam, Elsevier, 111–112.
- Calvet, M., Delmas, M., Gunnell, Y., Braucher, R. and Bourlès, D. 2011. Recent Advances in Research on Quaternary Glaciations in the Pyrenees. In: Ehlers, J., Gibbard, P. L., and Hughes, P. D. (eds.), *Developments in Quaternary Sciences* 15. Amsterdam, Elsevier, 127–139.
- Caulle, C., Penaud, A., Eynaud, F., Zaragosi, S., Roche, D. M., Michel, E., Boulay, S. and Richter, T. 2013. Sea-surface hydrographical conditions off South Faeroes and within the North-Eastern North Atlantic through MIS 2: the response of dinocysts. *Journal of Quaternary Science* 28(3), 217–228.
- Cimiotti, U. 1987. Gutachtliche Stellungnahme zur Bedeutung und Wertigkeit des Meiendorf-Stellmoor-Ahrensburger Tunneltales. In: Cimiotti, U. (ed.), *Beiträge zum Quartär in Holstein*. Berlin, Technische Universität Berlin, 167–205.
- Clark, C. D., Evans, D. J. A., Khatwa, A., Bradwell, T., Jordan, C. J., Marsh, S. H., Mitchell, W. A. and Bateman, M. D. 2004. Map and GIS database of glacial landforms and features related to the last British Ice Sheet. *Boreas* 33(4), 359–375.
- Clausen, I. 2010. Auf den Spuren von Alfred Rust und seinen Rentierjägern. *Archäologische Nachrichten aus Schleswig-Holstein* 2010, 15–19.
- Clausen, I. and Guldin, A. 2017. Die spätjungpaläolithischen Stationen des Ahrensburger

- Tunneltals in neuen Kartenbildern (Gem. Ahrensburg, Kr. Stormarn). In: Eriksen, B. V., Abegg-Wigg, A., Bleile, R. and Ickerodt, U. (eds.), *Interaktion ohne Grenzen. Beispiele archäologischer Forschungen am Beginn des 21. Jahrhunderts*. Schleswig: Stiftung Schleswig-Holsteinische Landesmuseen, 11–21.
- Drucker, D. G., Kind, C.-J. and Stephan, E. 2011. Chronological and ecological information on Late-glacial and early Holocene reindeer from northwest Europe using radiocarbon (14C) and stable isotope (13C, 15N) analysis of bone collagen: Case study in southwestern Germany. *Quaternary International* 245(2), 218–224.
- EPHA: European Prehistoric and Historic Atlas, Last Glacial Maximum. <https://zbsa.eu/en/last-glacial-maximum/> [accessed: 24.11.2025]
- Gibbard, P. L. and Clark, C. D. 2011. Pleistocene Glaciation Limits in Great Britain. In: Ehlers, J., Gibbard, P. L. and Hughes, P. D. (eds.), *Developments in Quaternary Sciences 15*. Amsterdam, Elsevier, 75–93.
- GISCO: <https://ec.europa.eu/eurostat/web/gisco/geodata/administrative-units/countries> [accessed: 24.11.2025]
- Gobejishvili, R., Lomidze, N. and Tielidze, L. 2011. Late Pleistocene (Würmian) Glaciations of the Caucasus. In: Ehlers, J., Gibbard, P. L., and Hughes, P. D. (eds.), *Developments in Quaternary Sciences 15*. Amsterdam, Elsevier, 141–147.
- Grimm, S. B. and Weber, M.-J. 2008. The chronological framework of the Hamburgian in the light of old and new 14C dates: Der chronologische Rahmen der Hamburger Kultur angesichts alter und neuer 14C-Daten. *Quartär* 55, 17–40.
- Grimm, S. B., Eriksen, B. V., Krüger, S., Reuter, T., Wild, M. and Weber, M.-J., 2021. Late Glacial Occupation of Northern Germany and Adjacent Areas. In: Gaudzinski-Windheuser, S. and Jöris, O. (eds.), *The Beef behind all Possible Pasts – The Tandem Festschrift in Honour of Elaine Turner and Martin Street*. Monographien des Römisch-Germanischen Zentralmuseums 157. Mainz, Verlag des Römisch-Germanischen Zentralmuseums, 433–457.
- Gripp, K. 1964. *Erdgeschichte von Schleswig-Holstein*. Neumünster, Wachholtz.
- Grønnow, B. 1985. Meiendorf and Stellmoor Revisited: an Analysis of Late Palaeolithic Reindeer Exploitation. *Acta Archaeologica* 56, 131–166.
- Guldin, A. 2017. *Neubau S-Bahnlinie S4 (Ost) Hamburg – Bad Oldesloe*. *Archäologischer Fachbeitrag (PFA 2 und PFA 3)*. Fachbeitrag Unterlage 25. Neumünster, Archäologisches Landesamt Schleswig-Holstein.
- Harff, J., Flemming, N. C., Groh, A., Hünicke, B., Lericolais, G., Meschede, M., Rosentau, A., Sakellariou, D., Uścinowicz, S., Zhang, W. and Zorita, E. 2017. Sea Level and Climate. In: Flemming, N. C., Harff, J., Moura, D., Burgess, A. and Bailey, G. N. (eds.), *Submerged Landscapes of the European Continental Shelf*. Newark, John Wiley & Sons, 11–49.
- Hartz, S., Weber, M.-J., Meadows, J. and Klooff, S. 2019. One in a hundred – the rediscovery of a potential arrow shaft from Stellmoor (Schleswig-Holstein, Northern Germany). In: Eriksen, B. V., Rensink, E. and Harris, S. (eds.), *The Final Palaeolithic of Northern Eurasia. Proceedings of the Amersfoort, Schleswig and Burgos UISPP Commission meetings*. Kiel, Ludwig, 155–168.
- Hinrichs, M. 2019. *Die Ahrensburger von Borneck, Kreis Stormarn: Das Erkenntnispotential von Altgrabungen am Beispiel der Inventare von Borneck-Nord und -Ost*. MA-thesis. Christian-Albrechts-Universität zu Kiel, Kiel.
- Hinrichs, M. 2021. Re-evaluating the Ahrensburgian Find Concentrations from Borneck-North and -East, District of Stormarn, Schleswig-Holstein, Germany. *Offa* 73-77(2016-2020), 5–22.
- Hughes, A. L. C., Gyllencreutz, R., Lohne, Ø. S., Mangerud, J. and Svendsen, J. I. 2016. The last Eurasian ice sheets – a chronological database and time-slice reconstruction, DATED-1. *Boreas* 45(1), 1–45.
- Ickerodt, U. 2016. Ein notwendiger Kommentar zu Gernot Tromnaus Würdigung von Alfred Friedrich Wilhelm Rust (1900–1983). *Archäologische Informationen* 39, 227–238.
- Lambeck, K. and Purcell, A. 2005. Sea-level change in the Mediterranean Sea since the LGM: model predictions for tectonically stable areas. *Quaternary Science Reviews* 24(18), 1969–1988.
- Larsen, E., Fredin, O., Jensen, M., Kuznetsov, D., Lyså, A. and Subetto, D. 2014. Subglacial sediment, proglacial lake-level and topographic controls on ice extent and lobe geometries during the Last Glacial Maximum in NW Russia. *Quaternary Science Reviews* 92, 369–387.
- Lericolais, G. 2017. Late Pleistocene Environmental Factors defining the Black Sea, and Submerged Landscapes on the Western Continental Shelf. In: Flemming, N. C., Harff, J., Moura, D., Burgess, A. and Bailey, G. N. (eds.), *Submerged Landscapes of the European Continental Shelf*. Newark: John Wiley & Sons, 479–495.
- Matoshko, A. V. 2011. Limits of the Pleistocene Glaciations in the Ukraine: A Closer Look. In: Ehlers, J., Gibbard, P. L. and Hughes, P. D. (eds.), *Developments in Quaternary Sciences 15*. Amsterdam, Elsevier, 405–418.
- Meadows, J., Heron, C., Hüls, M., Philippsen, B. and Weber, M.-J., 2018. Dating the lost arrow shafts from Stellmoor (Schleswig-Holstein, Germany): Datierung der verlorenen Pfeilschäfte aus Stellmoor (Schleswig-Holstein, Deutschland). *Quartär* 65, 105–114.
- Price, T. D., Meiggs, D., Weber, M.-J. and Pike-Tay, A. 2015. The migration of Late Pleistocene reindeer: isotopic

- evidence from Northern Europe. *Archaeological and Anthropological Sciences* 2019(9), 371–394.
- Riede, F., Grimm, S. B., Weber, M.-J. and Fahlke, J. M. 2010. Neue Daten für alte Grabungen - Ein Beitrag zur spätglazialen Archäologie und Faunengeschichte Norddeutschlands. *Archäologisches Korrespondenzblatt* 40, 297–316.
- Rinterknecht, V., Hang, T., Gorlach, A., Kohv, M., Kalla, K., Kalm, V., Subetto, D., Bourlès, D., Léanni, L. and Guillou, V. 2018. The Last Glacial Maximum extent of the Scandinavian Ice Sheet in the Valday Heights, western Russia: Evidence from cosmogenic surface exposure dating using <sup>10</sup>Be. *Quaternary Science Reviews* 200, 106–113.
- Rust, A. 1937. *Das altsteinzeitliche Rentierjägerlager Meiendorf*. Neumünster, Wachholtz.
- Rust, A. 1943. *Die alt- und mittelsteinzeitlichen Funde von Stellmoor*. Neumünster, Wachholtz.
- Rust, A. 1958a. *Die jungpaläolithischen Zeltanlagen von Ahrensburg*. Neumünster, Wachholtz.
- Rust, A. 1958b. Die Funde vom Pinnberg. Vor- und frühgeschichtliche Untersuchungen aus dem Schleswig-Holsteinischen Landesmuseum für Vor- und Frühgeschichte in Schleswig und dem Institut für ur- und Frühgeschichte der Universität Kiel 14. Neumünster, Wachholtz.
- Schäfer, S. 2007. Schwantes, Gustav. *Neue Deutsche Biographie*. 790–791.
- Seguinot, J., Ivy-Ochs, S., Juvet, G., Huss, M., Funk, M. and Preusser, F. 2018. Modelling last glacial cycle ice dynamics in the Alps. *The Cryosphere* 12(10), 3265–3285.
- Sejrup, H. P., Clark, C. D. and Hjelstuen, B. O. 2016. Rapid ice sheet retreat triggered by ice stream debulking: Evidence from the North Sea. *Geology* 44(5), 355–358.
- Tromnau, G. 1975. *Neue Ausgrabungen im Ahrensburger Tunneltal: ein Beitrag zur Erforschung des Jungpaläolithikums im Nordwesteuropäischen Flachland*. Neumünster, Wachholtz.
- Tromnau, G. 2015. 'Eine notwendige Stellungnahme'. Der mutige Aufsatz des Ahrensburger Archäologen Alfred Rust aus dem Jahr 1942. *Jahrbuch Stormarn* 2015, 48–53.
- Urdea, P., Onaca, A., Ardelean, F. and Ardelean, M. 2011. New Evidence on the Quaternary Glaciation in the Romanian Carpathians. In: Ehlers, J., Gibbard, P. L. and Hughes, P. D. (eds.), *Developments in Quaternary Sciences* 15. Amsterdam, Elsevier, 305–322.
- Weber, M.-J. 2013. Late Upper and Late Palaeolithic reindeer hunting in the Ahrensburg tunnel valley – Differences between Hamburgian and Ahrensburgian hunting tactics. In: Grimm, O. and Schmölcke, U. (eds.), *Hunting in northern Europe until 1500 AD. Old traditions and regional developments, continental sources and continental influences. Papers presented at a workshop organized by the Centre for Baltic and Scandinavian Archaeology (ZBSA) Schleswig, June 16th and 17th, 2011*. Neumünster, Wachholtz, 75–90.
- Westley, K. and Edwards, R. 2017. Irish Sea and Atlantic Margin. In: Flemming, N. C., Harff, J., Moura, D., Burgess, A. and Bailey, G. N. (eds.), *Submerged Landscapes of the European Continental Shelf*. Newark, John Wiley & Sons, 241–279.
- Wild, M. 2020. *Coping with risk through seasonal behavioral strategies: Technological analysis of selected late upper palaeolithic antler assemblages from northern Germany, southern Scandinavia and the Paris Basin*. Untersuchungen und Materialien zur Steinzeit in Schleswig-Holstein und im Ostseeraum 12. Kiel/Hamburg, Wachholtz.
- Zasadni, J. and Kłapyta, P. 2014. The Tatra Mountains during the Last Glacial Maximum. *Journal of Maps* 10(3), 440–456.

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# Not just red

## Identification of red Heligoland Flint by macroscopic and microscopic characteristics

Hauke Jürgens, Sönke Hartz and Joachim Schönfeld

### Abstract

The island of Heligoland, German Bight, North Sea, was the source of a special red flint variety. With the exception of the Mesolithic period, this unique raw material was in use to make tools from the Late Palaeolithic to the Bronze Age. Artifacts of red Heligoland Flint were occasionally found in western and northern Europe. The confined provenance may provide clues about migration, exchange and trade routes. However, as similar reddish-coloured flint artefacts from other sources were also found, it is essential to identify red Heligoland Flint with the highest possible certainty. In this study, macroscopic aspects, microscopic characteristics, and fossil content are described, which clearly distinguish red Heligoland Flint from similar reddish erratic Scandinavian flint that has been secondarily patinated by iron oxides.

*Keywords: Heligoland, red flint, reddish iron oxide patination, microfossils, microscopic differentiation*

### Introduction

Gray, brownish, or black flint with a whitish cortex is the classic raw material used by Stone Age tool makers in northern Germany and beyond. It derived from Campanian, Maastrichtian and Danian chalk formations in Denmark, northern Germany and the western Baltic region. The chalk and embedded flint nodules were eroded during the Pleistocene glaciations, transported and deposited as erratics in moraines and glacio-fluvial sediments. It is commonly assumed that these nodules were collected during the prehistory from beaches, cliffs, or riverbeds and used for tool making. Högberg and Olausson (2007) distinguished thirteen kinds of cretaceous Scandinavian flint, which mostly date from the Maastrichtian to Danian stage. Only the Kristianstad Flint dates geologically to the previous Campanian stage, but this flint was extremely rarely used to make stone tools. With a few exceptions, no Scandinavian flint older than the Campanian stage has yet been found (Högberg and Olausson 2007). A flint variety of the previous Turonian period characterized by its brown-red colour rather than its endurance or physical properties was only found on the island of Heligoland. For decades, Heligoland flint was the starting point for discussions about Late Glacial hunter-gatherer migration and Neolithic trade routes (Fries and Veil 2014; Terberger *et al.* 2020). In addition to the unique brown-red flint, four more types of Heligoland flint were found on the island. These include yellow-brown flint, brown or grey scar flint, dark grey to black chunk or bone flint, and grey to grey-black dotted tabular flint (Schmid and Spaeth 1981). So far, only brown-red flint and tabular flint have been found in archaeological assemblages (Beuker 2014). The brown-red



Figure 1: Red coloured flint: a) reddish iron patinated glacial erratic flint pebble from northern Germany; b) crosscut of a); c) crosscut of red Heligoland Flint pebble; d) thermal alteration revealing original colour of flint (blade Groß Offenseth-Aspern site, Offenau 2, SH1995-166.37).

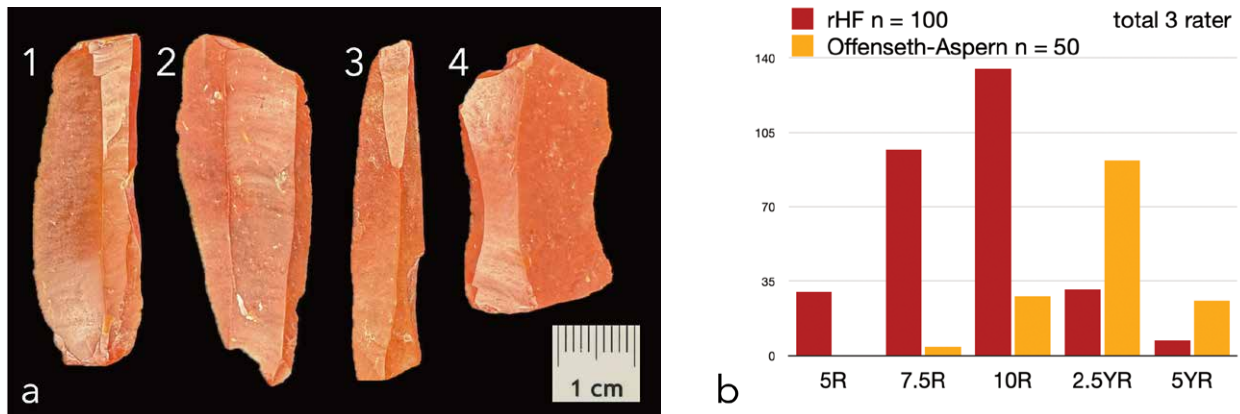


Figure 2: Colour comparison of reddish flint: a) iron patinated reddish flint artifacts (redIPF) from Late Palaeolithic open air site Offenseth-Aspern (1-3); red Heligoland Flint (redHF) neolithic artifact, Drelsdorf (4); b) frequency distribution of Hue values obtained from comparison with MSCC (Munsell Soil Color Charts) of redHF reference collection with blades from Late Palaeolithic site Groß Offenseth-Aspern, Offenau 2; each sample was independently evaluated by three persons.

Heligoland flint used is characterized by its red hues, often with yellow-brown bands, and haze (Fig. 1c). In the following, we apply the term ‘red Heligoland flint’ (hereinafter referred to as redHF), as it is commonly used in the literature. The other flint types from Heligoland are beyond the scope of the present paper. So far no other primary sources of red flint are known.

Nowadays, the redHF can be found in primary position only on the rocky intertidal shoal around Heligoland Dune at extremely low tide, or by diving (Schmidt and Spaeth 1991). In secondary position, redHF can be collected these days transported by currents and waves on the beaches of the Heligoland Dune isle. There is no evidence of glacial transport to areas beyond the island. It is not

known how the raw material was obtained in prehistoric times. As the sea level was significantly lower, it is likely that the flint was quarried locally from a chalk outcrop on an ancient cliff. Although the red colour is the most distinctive feature of an artifact or a geological sample to attribute it to Heligoland, one must be careful not to rely on this characteristic alone. In particular, some reddish iron patinated artifacts made from Scandinavian flint show *prima vista* a very similar surface colour (Fig. 1a). It is impossible to identify the true primary colour of this flint without destructive technologies (Fig. 1b,d; Fig. 2a,b).

The aim of this paper is to establish microscopic criteria for the identification of red Heligoland Flint (redHF), which facilitate a secure discrimination from other, reddish

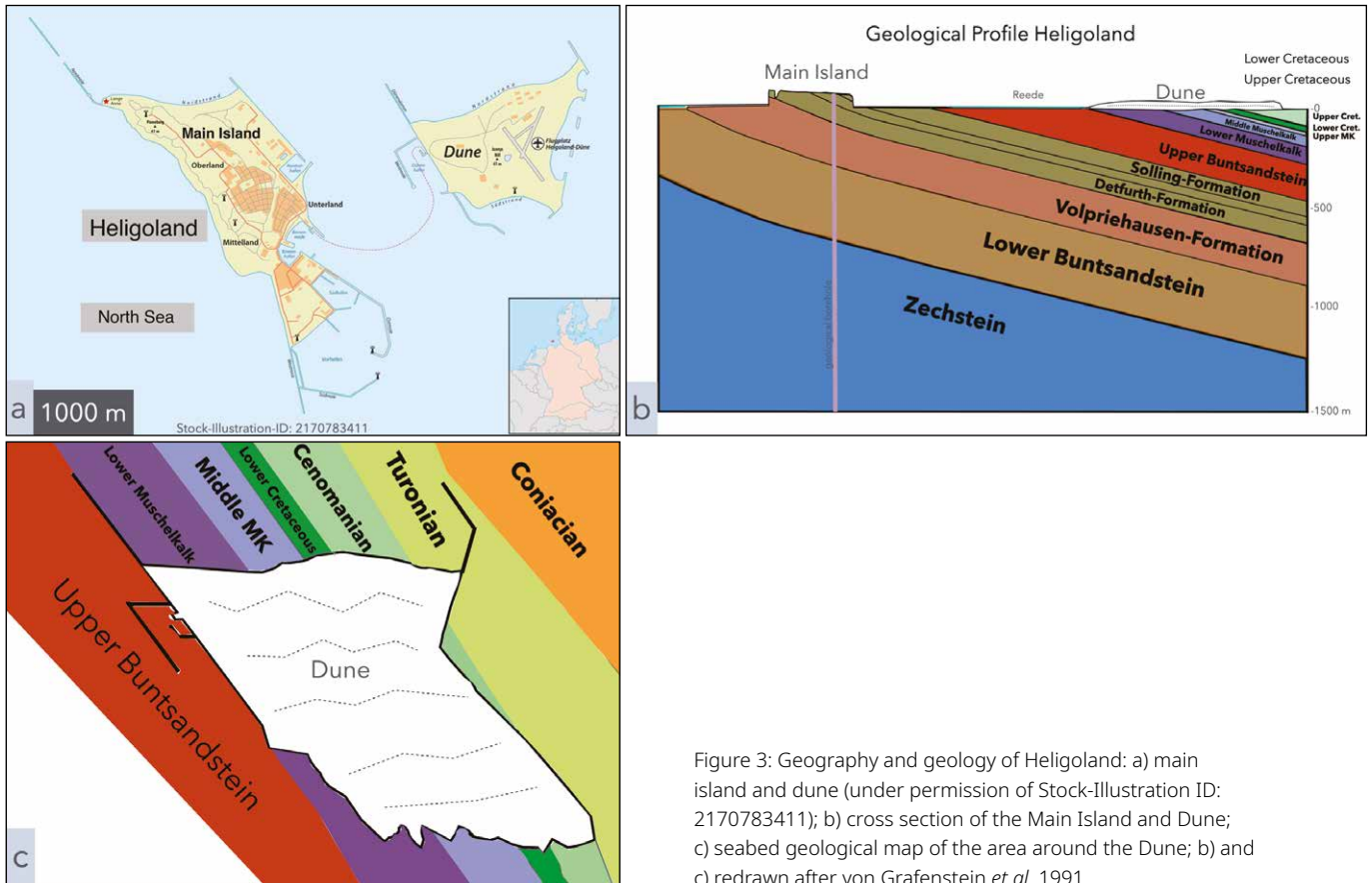


Figure 3: Geography and geology of Heligoland: a) main island and dune (under permission of Stock-Illustration ID: 2170783411); b) cross section of the Main Island and Dune; c) seabed geological map of the area around the Dune; b) and c) redrawn after von Grafenstein *et al.* 1991.

iron patinated Scandinavian flint (hereinafter referred to as redIPF) when the macroscopic aspect is ambiguous. First, we investigated a reference collection of 100 redHF pebbles collected from the Heligoland Dune isle to identify microstructural and micropaleontological characteristics. In a second step we compared these results with a set of 50 redIPF artefacts from the Late Palaeolithic open air site Groß Offenseth-Aspern, Offenau 2, Pinneberg district, northern Germany. The assemblage of this site consists of 900 items including approximately 300 blades, 65 tools, and 42 cores (Plath 2024). The majority of these artefacts exhibit a reddish or brown patina. Out of the 300 blades and 65 tools, 50 reddish blades or blade tools were selected. Fourteen of these 50 implements showed edge damage, fractures or thermally induced flaking and revealed the grey to grey-brown original colour of the flint (Fig. 1d). Therefore, we assume that the assemblage from the Offenseth-Aspern site consists of Scandinavian flint.

## Materials and Methods

### Geographical setting

Heligoland is located about 48 km west of the German mainland and covers a total area of 4.2 km<sup>2</sup>. The island consists of two separate isles, the rocky mainland and the flat dune with sandy beaches (Fig. 3a). The main island, known as the 'red rock' forms a two-step platform, which is 50–61 m

high, and shows steep cliffs at the northern, western, and southwestern sides. The shoreline is enforced by walls and breakwaters, which also protect a large, artificial harbor. About 800 m east of the mainland, the dune is located, which was connected to the main island by a dam until 1721, when a storm surge separated these two parts.

### Geology

The Triassic to Late Cretaceous formations exposed at Heligoland were uplifted and deformed into a horst and graben structure by halokinesis of an underlying Permian salt dome (Fig. 3b).

The spectacular 'Red Cliff' of Heligoland exposes the Buntsandstein Group and iron-rich, red-coloured sandstone with interbedded clay and whitish sand layers. These rocks form the geological base of the island and are generally inclined at 16–20° towards the Northeast (Spaeth 1990). Lower, Middle, and possibly also parts of the Upper Muschelkalk subgroups follow on top. They are covered by the dune and are only exposed in underwater outcrops. The Upper Cretaceous is exposed on the rocky shoal to the north of the dune island (Fig. 3c) (Schmid and Spaeth 1991).

Today, the redHF can only be found as small, wave battered well-rounded nodules about 5–10 cm in size on the northern and eastern side of the dune. Larger, subangular pieces of up to 25 cm in diameter are very rare.

They originate from an underwater outcrop of Turonian chalk. A late Turonian age of the redHF was established with the known stratigraphic ranges of echinoids that were preserved as silicified internal mold of red flint, and with nanofossils from chalk particles adhering to the flint pebbles or from cavities inside the flint nodules (Krüger 1980; Kulhanek, pers. comm., 2025; Schmid and Spaeth 1978; 1981; Wood and Schmid 1991). Also the microfossil record of Heligoland facilitated a correlation with international biozones of the Upper Cretaceous and has contributed to a detailed subdivision of the Cenomanian to Santonian stages in the North Sea region (Schönfeld and Mücke 1991). During an extreme low tide in 1986, Hans Stühmer observed red flint, exposed in cretaceous chalk outcropping of the dune beach (Stühmer 1991). He recognized three flint layers in indurated beds, each about one meter apart. The flint-bearing succession thus comprised a section interval of c. 0.6 m in thickness. The basal flint layer contained large, irregular white-red nodules, the middle layer red bone-shaped flints, and the upper layer showed spherical nodules (Stühmer, pers. comm., 2025). In 1987, Spaeth located the red flint in submarine chalk outcrops by diving. The red flint was also found in a borehole drilled north of Heligoland (Schmid and Spaeth 1991).

### Flint formation

Flint is a fine-grained siliceous (up to 99%) microcrystalline sedimentary quartz that was formed in chalk or limestone. In a generally accepted model for flint formation in chalk it is assumed that flint generated through maturation of opal-A via opal-CT to  $\alpha$ -quartz (Madsen and Stemmerik 2010). The precipitation of opal-A in the porewater was facilitated by dissolution of silicate fossil remains, mainly diatom frustules, radiolarians, and sponge spicules. During periods of low accumulation or even omission at the seabed, the redox boundary and the microbial metabolic zones were fixed at specific depths below the sediment-water interface (Madsen and Stemmerik 2010). Bacterial reduction created a more acidic environment at the redox boundary where carbonate started to dissolve. Simultaneously, sedimentary biogenic opal was dissolved and precipitated at the redox boundary as silica gel or opal-CT. The precipitation was possibly aided by sulphide-oxidizing bacteria.

In a different concept, Jurkowska and Swierczewska-Gładysz (2020) proposed that the formation of siliceous nodule horizons was related to direct quartz precipitation. Spatial and temporal fluctuations in the silica cycle were triggered by large-scale hydrothermal and volcanic activity. During phases of high activity, a vast amount of dissolved silica would have been released into the seawater and transported to the European Basin via oceanic inflow. The elevated silica concentration in this shelf basin triggered the abiotic precipitation of siliceous nodules during early diagenesis. Mortimore (2020) concluded that both models may apply and contribute to flint formation at different times.

### Colour of flint

Embedded in Maastrichtian chalk or Danian limestone, Scandinavian flint exists in different colours ranging from white, grey, light grey, light brownish grey to dark brownish grey. Material properties of flint nodules were related to the physico-chemical properties of the host rock and the geochemistry of the pore water. Dark brownish grey colours of flint generally reflect a more silicified matrix dominated by microcrystalline quartz with a smaller grain size (Aliyu 2016). When impurities are absent or leached out, the flint appears white or pale grey. Depending on the content of organic carbon or pyrite, the colour reaches from dark grey to black. Chlorite or glauconite in the flint matrix produce green hues. Manganese oxides contribute to greyish, purple or bluish tones, whereas yellow, red and brown colours are caused by iron oxides (Brandl *et al.* 2018). Heat exposure can also cause embedded iron oxides to turn an intense red, but this can be distinguished by typical cracking patterns (Fiers *et al.* 2021).

### Macroscopic analyses of flint

All 100 redHF pieces of the reference collection were collected from the Heligoland dune isle. The 50 implements of the comparison sample from the Offernseth-Aspern site were examined in exactly the same way.

Macroscopically we assessed the following characteristics: Munsell colour of matrix, surface size of polished red flat part, the presence of white cortex, a black layer, percussion marks, macro inclusions > 1 mm, visible aureoles around macro inclusions and visible yellow-brown bands, circles, streaks or haze. Lustre and granularity are not considered in this paper as our reference sample has cut and polished surfaces.

We used the Munsell Soil Color Chart (MSCC) system to describe the colours of the flint matrix. The term 'matrix' refers to the basic composition or groundmass of the rock within lithic raw materials including all rock-forming constituents up to a size of 50  $\mu\text{m}$  (Brandl 2014).

Luedtke (1992) suggested that 'cortex' refers to the layer that forms on the outer surface of a nodule during diagenesis and is essentially a transition zone between the flint and its surrounding matrix. In contrast, 'weathering rind' or 'patina' describes the layer that forms in a secondary context as a result of chemical and/ or mechanical surface changes (Luedtke 1992). Patinated surfaces exhibit colour and surface modifications due to  $\text{SiO}_2$ -interference or enrichment notably by oxides of the elements Al, K, Cl, Ti and particularly Fe.

### Microscopic analysis of flint

#### Technical equipment

Microscopic analysis was conducted with a Keyence digital microscope using a magnification of 100x to 800x and incident light. Although the reference pieces are ground

flat and polished, we applied Zeiss Immersol 518F oil immersion for the best possible presentation of the fossil inclusions. The immersion oil can be removed without any visible residue using Benzinum DAB.

The optical quality of water immersed slides is slightly worse compared to immersion oil but for artifact surfaces it may be advisable to use distilled water or, better water gradient HPLC grade, to avoid any chemical contamination. Covering even imperfectly flat artifact surfaces with cover glasses delays evaporation of the water and thus extends the usable time under the microscope.

### Microscopic characteristics

One hundred pieces of the reference collection were examined under a digital microscope over its entire red coloured cut and polished surface. We documented the translucency, presence of disseminated red-brown or black dots in red matrix, yellow-red-brown dots on white inclusions, chalcedony void fill, yellow-orange bands, circles, streaks or haze, manganese dendrites, calcic halos around micro inclusions and different taxa of microfossils: sponge, dinoflagellate cysts, calcispheres, bryozoans, ostracods, brachiopods, echinoderms, trochites, pollen, ichnofossils, bioclastic halos, framboids and different benthic and planktonic foraminifera. Fifty implements of the Offenseth-Aspern site were examined for the same characteristics.

## Results and discussion

### Macroscopic analysis

The apparent colour of red Heligoland flint often consists of heterogeneous coloured areas and dots of different sizes and therefore corresponds more to integrative colour perception. In some cases, it is necessary to choose between several options. The iron-patinated flint of Offenseth-Aspern site was generally more uniformly coloured. The two samples showed slightly different colour distributions in MSCC but clearly had a common intersection (Fig. 2a,b).

Seventy-three percent of the redHF dune pebbles had a white cortex or remnants. Forty-two percent of the pebbles had no black layer and appeared white or red. Fifty-eight percent displayed a black layer of different thicknesses around the red core. Thirty-five percent of the flint had a rounded, Wallstein-like shape and surface, displaying crescent-shaped, circular, or irregular percussion marks. The original colour zoning of these stones in primary deposition remains unclear. Overall, 88 % showed evidence of significant mechanical stress and material loss due to massive wave transport. Today, very rare large nodules up to 25 cm in length exhibiting either white-black-red colour zonation or consisting solely of red flint with a very thin cortex are found on the dune beach. It is not known what kind of pebbles were preferably used as raw material in prehistoric times.

### Microscopic analysis

#### Petrologic aspects

The total area of the red ground and polished flint surface screened at 100x magnification was 634 cm<sup>2</sup>. The translucency, as measured by shifting the focal plane, ranged from 50 to 80 µm, with an average of 56 µm. Erratic Scandinavian flint showed translucency up to 150 µm. Sixty-four pieces of the reference sample showed three-dimensional yellow-orange structures in the form of bands, circles, streaks, or haze (Figs. 1c, 4a–d). Of these, 41 were detectable macroscopically and 23 only microscopically. 37 pieces show yellow-orange circles with central, mostly brown-blackish dendrites. Dendrites form as fern- or tree-like branched crystallizations of manganese oxides. The dendrites often occur in the centre of yellow-orange circles or together with yellow-orange bands, streaks, or haze, which may consist of goethite (Scheinost and Schwertmann 1999). These structures represent typical Liesegang patterns. Liesegang patterns occur when a periodic precipitation reaction is coupled to the mass transport (diffusion) of reagents in solid hydrogels driven by the diffusively moving reaction-diffusion front ending in an equilibrium state (Nabika *et al.* 2020). The Liesegang phenomenon has been observed in a variety of precipitation reactions involving metal cations (such as Fe<sup>2+</sup>, Ca<sup>2+</sup>, Mg<sup>2+</sup>) and their precipitate counteranions (such as S<sup>2-</sup>, OH<sup>-</sup> and SO<sub>4</sub><sup>2-</sup>). Mostly the metal cations are the centre and reservoir of precipitation rings and anions are homogeneously distributed in a gel (Nabika *et al.* 2020). These yellow-orange patterns may have formed during the early stages of diagenesis, while the flint was still in a gel state.

Cracks, density differences and inhomogeneities can promote or inhibit the progression of Liesegang patterns. Heat cracks can be distinguished by rectangular or scaly crack patterns and stylolites can be distinguished by their irregular and often jagged shape (Magni *et al.* 2025). Based on the microscopic image of a double-coloured foraminifera, it can be assumed that the Liesegang patterns formed once the flint had at least consolidated into a gel state and had been stained by iron oxides (Fig. 4d). However, it is rarely possible that Liesegang patterns can form in solid rock if pores or micro permeability are present. Significant compaction of the flint did not occur after the formation of the Liesegang patterns. None of the pieces showed healed tectonic fractures.

Bluish-coloured chalcedony void fill-ups of cavities such as dissolved microfossils occur to varying degrees in nearly all samples of the redHF. The yellow-red-brown iron oxide particles of the remaining flint matrix are never found within the fill-ups. This may be an indication that the fill-ups have arisen diagenetically after the iron oxides were deposited. (Fig. 5f,g,p-3). The colour of the void fill-ups in redIPF is always more brownish. Polarization microscopic

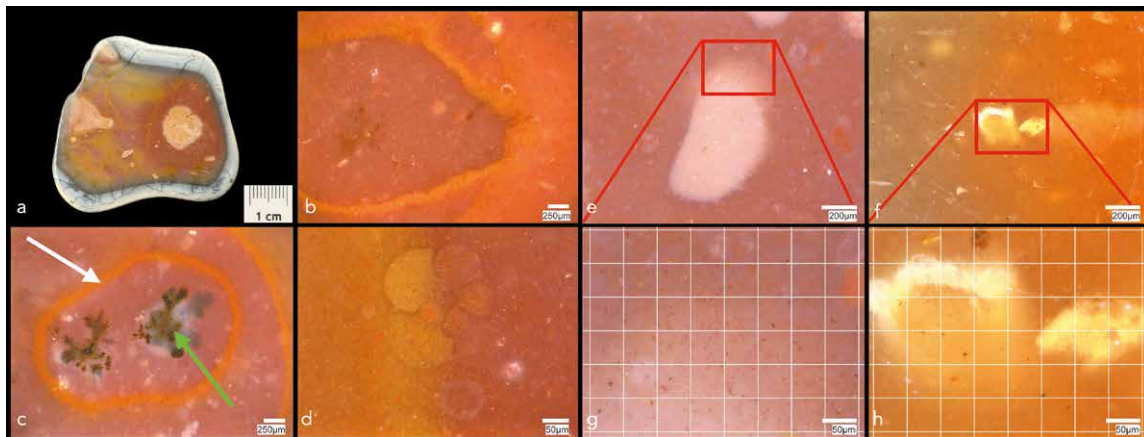


Figure 4: Matrix coloration of flint: a) crosscut of Heligoland pebble; b) yellow orange Liesegang pattern (redHF); c) Manganese dendrite (green arrow) and Liesegang ring (white arrow) (redHF); d) foraminifer half coloured of Liesegang ring (redHF); e) red dots on white ground (redHF); f) red dots on white ground (redIPF); g) and h) enlarged section of e) and f).

examinations to differentiate between quartz polymorphs were not performed.

RedHF contains a significant amount of iron, which clearly distinguishes it from Scandinavian flint (Högberg *et al.* 2014). The red color of the matrix in redHF is primarily caused by the complex distribution of iron oxides, most likely hematite, due to the particles being very fine and distributed uniformly (RAMAN-spectroscopy, Engesser, pers. comm., 2025). The red colour is associated with iron-oxide particles measuring less than 0.2  $\mu\text{m}$  in size (Schwertmann and Cornell 2000). The presence of authigenic iron oxides indicates oxidizing conditions during early flint diagenesis in a marine environment (Krüger 1980). Cai *et al.* (2009) suggest that some of the iron was distributed homogeneously within the matrix. It was also suspected that this form of iron were clusters of several tens of nanometres sized lattice iron, which was introduced into the structure during the formation of the sediment. Zhang *et al.* (2022) concluded that the Fe isotopic composition indicates that the Fe sources and origin of hematite in red chalks of England are not of marine or hydrothermal but of sedimentary origin. Coexisting secondary red and white chalk strata are described from the Mid Cretaceous Hunstanton Formation at Norfolk, England. They are formed at inclined or vertical fractures of the red chalk (Zhang *et al.* 2022). The phenomenon of red flint in white limestone can be observed in the Turonian formation of Scaglia Rossa, Italy (Diaz General 2013). Heligoland red flint is also embedded in white chalk. It is still a matter of debate whether the Heligoland white chalk layers were originally red and underwent some kind of a pedogenic alteration.

In contrast the red colour of the redIPF can be explained by post genetic alteration or weathering and patination. The rock surface significantly changes the

chemical composition by depletion or enrichment of elements due to transport via humidity depending on pH value of the surrounding environment. This mechanism may change the surface colour perceived as a reddish colour patina notably in regard to enriched iron-oxides. The original colour of the flint remains unchanged at most a few millimetres below the surface (Fig. 1b.d). Own Fe-extraction experiments with oxalic acid have shown after some months that these processes are partly reversible and especially yellow-brown coloured flint turned pale again due to dissolution of iron oxides. Pores, cracks and cavities are susceptible structural conduits for alteration (Fig. 1b).

In addition to the homogeneously red-coloured matrix, yellow, red, or brown ferrite oxide particles with sizes of approximately up to 5  $\mu\text{m}$  are ubiquitous disseminated in the redHF, some of them as framboids with sizes of up to 15  $\mu\text{m}$ . These particles are found in high density (> 30 per 50  $\mu\text{m}^2$ ) on 98% of all examined pieces in the reference collection (Fig. 4g). The optimal method of observing these particles is under a microscope, where a white background is present, for example due to a whitish fossil inclusion. We called this feature *red dots on white inclusions* (Fig. 4e.f).

In redIPF yellow, red, or brown particles are either absent or occur rarely, with a maximum frequency of 10 particles per 50  $\mu\text{m}^2$  (Fig. 4h). In our experience, the characteristic *red dots on white inclusions* is highly effective in distinguishing between redHF and redIPF. However, since counting the red dots is considerably subjective, we have refrained from using this data for statistical purposes.

### Micro-palaeontologic aspects

Fossil preservation in flint is strongly controlled by the original skeletal composition. Low-Mg calcite organisms such as foraminifera, brachiopods, bivalves, coccoliths,

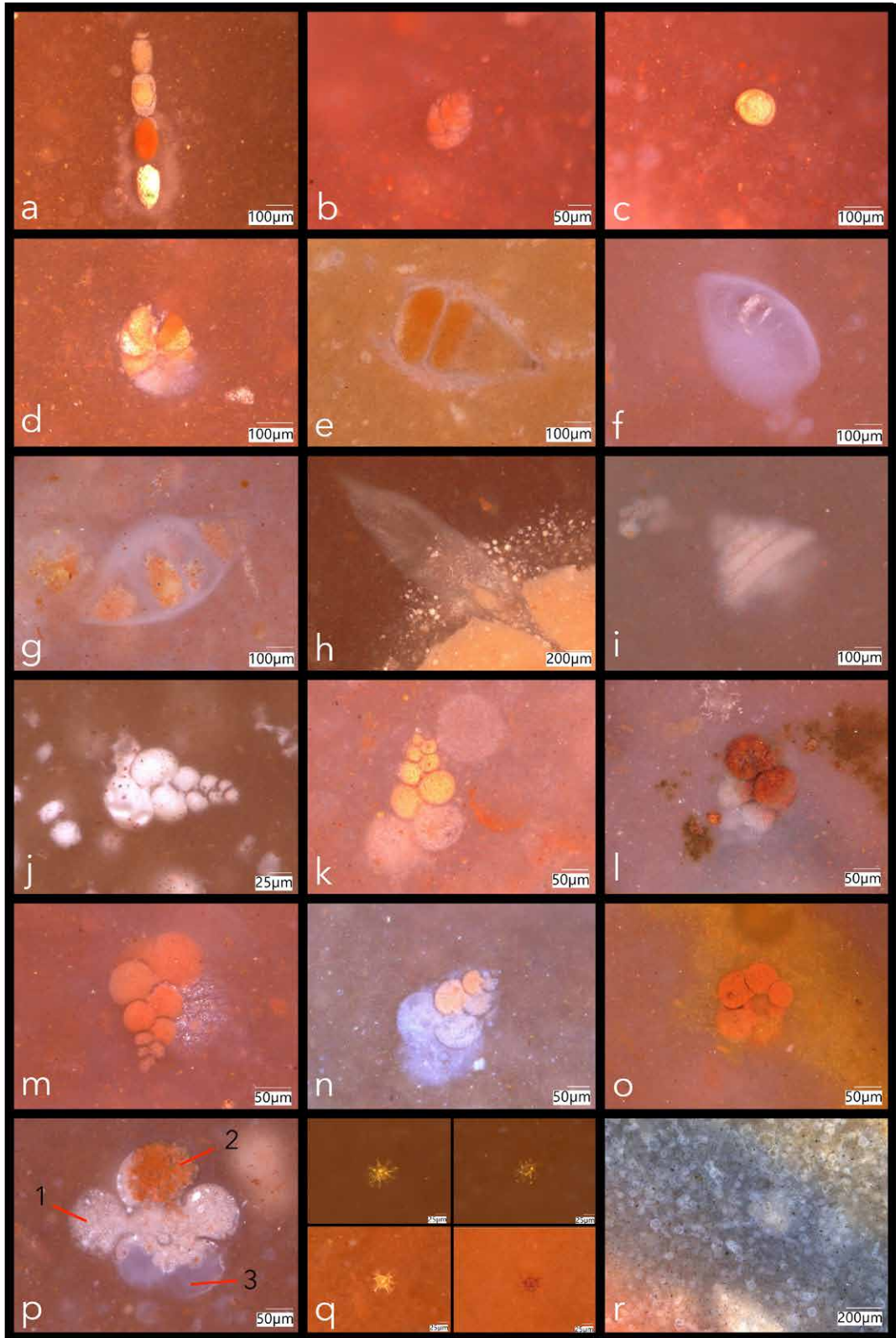


Figure 5: Examples of microfossils: a – i) benthic foraminifera (redHF); j – p) planktonic foraminifera (redHF); p) foraminifer with silicified part (1), iron oxide pseudosomatosis (2) and blue chalcedony fill-up (3) (redHF); q) four examples of dinoflagellate cysts (redIPF); r) calcispheres in flint matrix (redHF).

calcspheres and bryozoans are usually present only as silicified ghost structures, while High-Mg calcite echinoderms are even more prone to dissolution and are often poorly preserved. Siliceous organisms such as radiolarians and hexactinellid or demosponge spicules show excellent primary preservation, whereas calcareous sponges largely disappeared. Purely organic remains are almost never preserved. They were probably destroyed during diagenesis. Overall, flint predominantly contains a mixture of silica-replaced carbonate fossils ('ghosts') and authentically preserved siliceous skeletons. The non-destructive method applied in this study enabled the identification of several higher taxonomic groups, while determinations on species level were ambiguous.

Planktonic foraminifera are zooplanktonic protists inhabiting the upper water column, whose rapid evolutionary turnover and sensitivity to surface-water parameters render them key tools for biostratigraphy and palaeoceanographic studies. Planktonic foraminifera were generally frequently to very frequently identified (Fig. 5j–p), as do calcspheres (Fig. 5r).

Benthic foraminifera are sediment-dwelling protists whose assemblages reflect bottom-water oxygenation, organic flux, and substrate conditions, making them reliable proxies for paleoenvironmental reconstructions of the seafloor. Benthic foraminifera are common and show a wide variety of taxa (Fig. 5a–i), but they are generally observed in much lower numbers than planktonic foraminifera.

Fossil remnants such as ostracods, brachiopods, echinoid spines, trochites, organic remains and spherical structures such as pollen are rarely visible in the redHF. Echinoderm plates or tests, spicules of sponges (megascleres), partly preserved as spiculate networks, and indeterminate remains of siliceous sponges were common. This also includes a regularly occurring calcite diffusion halo around microfossils. This halo could only have formed during the early diagenetic stage, when the flint was still in a gel state following the dissolution of the calcium from the tests. Diatoms, silicoflagellates and radiolaria were rarely identifiable.

The listed taxa and morphologies cannot be clearly differentiated at species level hampering a biostratigraphic assignment. Nevertheless, quantitative analysis can provide valuable information for distinguishing between redHF and redIPF. In the redHF, only one of 100 specimens contained a single dinoflagellate cyst (Fig. 5q). Microscopically disaggregated or disarticulated remains of bryozoans were found in 15 % of the redHF samples. These are very poorly preserved and cannot be identified macroscopically.

The redHF is characterized by a vivid display of microfossils, which underwent various recrystallisation and metasomatism processes. These include crystalline silicified 'ghost' structures, exemplified here by

Planoheterohelix (Fig. 5n–j), which contain iron-oxides ranging in colour from yellowish (goethite) and reddish to brown (hematite). Mn<sup>2+</sup>-oxides may contribute to a light red tinge (Hu *et al.* 2012). This diversity represents geological changes in chemo-physical conditions during flint diagenesis.

The aureole-shaped dots around the inclusions, as described by Beuker (2014), can be explained as three-dimensional bioturbation trace fossils, also known as ichnofossils. These are the remains of burrows left by seabed inhabitants (Schnick 2025). Most habitat or feeding structures, which vary in diameter from sub-millimetric to centimetres, in the uppermost layers of the already soft but dimensionally stable seabed were passively refilled by resuspended sediment containing biodebris (e.g. disaggregated sponges and calcspheres), or by washed-in chalk lithoclasts (Knaust and Schnick 2024). Some ichnofossils are filled with faecal excretions or a chalky lining. Occasionally flint meals appear as non silicified chalky filled parts of burrows. Reburrowing occurred by different ichnotaxa. The burrows contrast with the red flint due to their white, grey, brown or light reddish fill. Trace fossils occur at varying frequencies throughout the Cretaceous period but are not specific to any particular time of the stratigraphic record.

The comparative statistical analysis of the four most important diagnostic features (Tab. 1) demonstrates that red Heligoland flint (redHF) and reddish iron-patinated blades from the late Palaeolithic site Offenseth-Aspern (redIPF) can be distinguished with a high reliability. Four microscopic fossil and diagenetic indicators were considered as most distinctive: dinoflagellate cysts, bryozoans, Liesegang pattern and manganese dendrites. Their frequencies differ strongly between the two lithotypes. Dinoflagellates occur in 90 % of redIPF but only in 1% of redHF; bryozoans are present in 94% of redIPF and in 15% of redHF; Liesegang pattern are rare in redIPF (1%) but characteristic in redHF (64%); and manganese dendrites are rare in redIPF (1%) but common in redHF (37%).

Chi-square tests applied to each feature (assuming n=100 per group) confirm that all four differences are highly significant (p<0.001). The null hypothesis of no distinction between the two groups is therefore rejected. A combined likelihood-ratio approach further indicates very strong overall evidence.

Power analyses show that already small sample sizes suffice to achieve robust discrimination: with n=20 specimens per group the test power exceeds 0.8, and with n=30 power surpasses 0.95. For individual classification, a naive Bayes model yields an overall assignment accuracy of 97.6% when equal priors are assumed. Sensitivity is higher for redIPF (99.1%) than for redHF (96.1%), reflecting the greater distinctiveness of dinoflagellate and bryozoan abundances. When realistic priors are introduced (e.g. redHF rarer in

Table 1: Percent distribution of the four most important diagnostic indicators.

	dinoflagellate cysts (%)	bryozoans (%)	liesegang pattern (%)	manganese dendrites (%)
red iron patinated flint	90	94	1	1
red Heligoland Flint	1	15	64	37

the sample), the expected classification accuracy further increases beyond 99%.

It is reasonable to suggest that some of the reddish blades from Offernseth-Aspern site may be made of red Heligoland flint. Proof cannot be obtained without destruction of the artefacts. Of the 50 investigated artefacts from the Offenseth-Aspern site, the original grey or grey-brown colour of the flint was recognizable in 14 of them, making it highly likely that they can be classified as Scandinavian flint. However, it should be noted that it is unclear how many cores were used to produce the blades at the Offenseth-Aspern site, or what role, if any, visible inclusions played in the selection of raw materials.

## Conclusions

Distinguishing between red Heligoland flint and red iron patinated Scandinavian flint is possible under the light microscope due to the presence of distinct microscopic characteristics, despite the ambiguity of their macroscopic colour appearance. The absence or presence of petrological (Liesegang pattern and Manganese dendrites) and micropaleontological features (dinoflagellate cysts and bryozoans) enables clear differentiation.

Supporting criteria for classification as red Heligoland flint are the more frequent occurrence of ichnofossils, calcispheres, planktonic and benthic foraminifera, blue

chalcedony void fill, and red dots on white inclusions compared to red iron patinated Scandinavian flint.

In summary, statistical evaluation of fossil and diagenetic features confirms that red Heligoland flint is a petrographically and paleontologically distinct variety. The high classification accuracy and extremely low error probabilities provide a quantitative basis for recognizing this material as a separate lithotype in archaeological and geological contexts.

It stands out as an open question whether distinct microscopic characteristics can also contribute to a differentiation between Heligoland grey spotted tabular flint and (unpatinated) speckled Scandinavian flint. This is of great archaeological interest because it seems from the archaeological record that significantly more Stone Age tools were produced from tabular Heligoland flint than from the ‘exotic’ red Heligoland flint (Beuker 2014).

## Acknowledgement

We would like to thank Lena and Jan Rickmer Ludwig, Bude 31, Helgoland, for their generous support with heligoland raw material, Hans Stühmer, Heligoland, for sharing his lifelong experience with the red Heligoland Flint, Mara Weber for providing the finds from Groß Offenseth-Aspern site and Antje Jürgens for her help and patience.

## References

- Aliyu, M. M. 2016. *The Origin and Properties of Flint in the Upper Cretaceous Chalk*. PhD thesis. Leeds, University of Leeds.
- Beuker, J. 2014. Die Flintarten von Helgoland und die Benutzung von Helgoländer Plattenflint. *Siedlungs- und Küstenforschung im südlichen Nordseegebiet* 37, 19–32.
- Brandl, M. 2014. Genesis, Provenance and Classification of Rocks within the Chert Group in Central Europe. *Archaeologia Austriaca* 97–98(2013–2014), 33–58.
- Brandl, M., Martinez, M. M., Hauzenberger, C., Filzmoser, P., Nymoen, P. and Mehler, N. A. 2018. Multi-technique analytical approach to sourcing Scandinavian flint: Provenance of ballast flint from shipwreck “Leirvigen 1”, Norway. *PLoS ONE* 13(8): e0200647. DOI: 10.1371/journal.pone.0200647.
- Cai, Y., Li, X., Hu, X., Chen, X. and Pan, Y. 2009. Paleoclimatic approach to the origin of the coloring of Turonian pelagic limestones from the Vispi Quarry section (Cretaceous, central Italy). *Cretaceous research* 30, 1205–1216.
- Diaz General, E.N. 2013. *The influence of fractures on the vulnerability to pollution of a carbonate aquifer: Monte Conero (Italy)*. Dottorato di ricerca. Bologna, University di Bologna.
- Fiers, G., Halbrucker, E., De Kock, T., Vandendriessche, H., Crombé, P. and Cnudde, V. 2021. Thermal Alteration of Flint: An Experimental Approach to investigate the Effect on Material Properties. *Lithic technology* 46(1), 27–44.
- Fries, J. E. and Veil, S. 2014. Fernkontakte späteiszeitlicher Jäger und Sammler in der norddeutschen Tiefebene-Ein Klingenkern aus rotem Helgoländer Flint von einem Oberflächenfundplatz am Dümmer bei Damme, Landkreis Diepholz. *Siedlungs- und Küstenforschung im südlichen Nordseegebiet* 37, 125–140.

- Högberg, A. and Olausson, D. 2007. *Scandinavian Flint – an Archaeological Perspective*. Aarhus, Aarhus University Press.
- Högberg, A., Hughes, R. E. and Olausson, D. 2014. Chemical analysis of red and black Heligoland flint - initial results and comparisons with flint from Scandinavia. *Siedlungs- und Küstenforschung im südlichen Nordseegebiet* 37, 59–66.
- Hu, X., Scott, R. W., Cai, W., Wang, Ch. and Melinte-Dobrinescu, M. C. 2012. Cretaceous oceanic red beds (CORBs): Different time scales and models of origin. *Earth-Science Reviews* 115, 217–248.
- Jurkowska, A. and Swierczewska-Gladysz, E. 2020. Evolution of Late Cretaceous Si cycling in the formation of siliceous nodules (flints and cherts). *Global and Planetary Change* 195, 103334. DOI: 10.1016/j.gloplacha.2020.103334
- Knaust, D. and Schnick, H. 2024. Trace fossils from the Maastrichtian chalk of the Isle of Rügen, north-east Germany. *Netherlands Journal of Geoscience* 103, e12.
- Krüger, F. J. 1980. Untersuchungen über die roten Flinte von Helgoland und eine Deutung möglicher Färbungsursachen. *Meyniana* 32, 105–112.
- Luedtke, B. 1992. *An Archeologist's guide to Chert and Flint*. Archaeological Research tools 7. Los Angeles, University of California.
- Madsen, H. B. and Stemmerik, L. 2010. Diagenesis of Flint and Porcellanite in the Maastrichtian Chalk at Stevns Klint, Denmark. *Journal of Sedimentary Research* 80, 578–588. DOI: 10.2110/jsr.2010.052
- Magni, S., Martin-Martin, J. D., Bons, P. D. and Gomez-Rvas, E. 2025. Stylolithes in Carbonate Rocks: Morphological variability according to the host rock texture. *Minerals* 15, 132.
- Mortimore, R. 2020. Flint in the late Cretaceous Chalk of NW Europe: links across the European platform. *Deposits* 2020. <https://depositsmag.com/2020/07/17/flints-in-the-late-cretaceous-chalk-of-nw-europe/> [accessed: 24-11-2025].
- Nabika, H., Itatani, M. and Lagzi, I. 2020. Pattern formation in precipitation reactions: The Liesegang Phenomenon. *Langmuir* 36, 481–497. DOI: 10.1021/acs.langmuir.9b03018
- Plath, J. 2024. Pioniere des Nordens - Der Fundplatz Offenau. *Heimatkundliches Jahrbuch für den Kreis Pinneberg. Beiträge zur Regionalgeschichte* 2024, 215–220.
- Scheinost, A. C. and Schwertmann, U. 1999. Color Identification of Iron Oxides and Hydroxysulfates: Use and Limitations. *Soil Science Society of America Journal* 63, 1463–1471.
- Schmid, F. and Spaeth, C. 1978. Zur Altersstellung des braunroten Feuersteins von Helgoland. *Neues Jahrbuch für Geologie und Paläontologie* 78, 427–429.
- Schmid, F. and Spaeth, C. 1981. Feuerstein-Typen der Oberkreide Helgolands, ihr stratigraphisches Auftreten und ihr Vergleich mit anderen Vorkommen in NW-Deutschland. *Staringia* 6(1), 35–38.
- Schmid, F. and Spaeth, C. 1991. Die Kreide der Nordseeinsel Helgoland. *Geologisches Jahrbuch Reihe A* 120, 97–103.
- Schnick, H. 2025. A tubular debrite preserved in a *Thlassinoides paradoxicus* burrow - evidence of bottom-current induced slope failure in the Maastrichtian chalk of Rügen (Baltic Sea). *Paläontologische Gesellschaft, Paläontologische Zeitschrift* 2025. DOI: 10.1007/s12542-025-00727-y
- Schönfeld, H.-J. and Mücke, T. 1991. Zur Foraminiferen-Stratigraphie der Schreibkreide von Helgoland. *Geologisches Jahrbuch Reihe A* 120, 117–126.
- Schwertmann, U. and Cornell, R. M. 2000. *Iron Oxides in the Laboratory - preparation and characterization*. Weinheim, Wiley-VCH.
- Spaeth, C. 1990. Zur Geologie der Insel Helgoland. *Die Küste* 49, 1–32.
- Stühmer, H. H. 1991. Die Helgoländer Kreideklippen bei Extrem-Niedrigwasser: Eine Dokumentation. *Geologisches Jahrbuch Reihe A* 120, 63–67.
- Terberger, T., Schneider, J. and Fries, J. E. 2020. The site of Edeweicht 82-East, district of Ammerland, and the role of Red Heligoland flint in the Late Glacial. *Prähistorische Zeitschrift* 95(1), 1–16. DOI: 10.1515/pz-2020-0006.
- von Grafenstein, U., Böhmer, P., Daut, G., von Mücke, T., Müller, W. and Prohaska, J. Z. 1991. Zur Geologie Helgolands: Unterwasser-Kartierung des Gebietes südwestlich der Insel. *Geologisches Jahrbuch Reihe A* 120, 19–35.
- Wood, C. J. and Schmid, F. 1991. Upper Cretaceous of Helgoland NW-Germany: Lithology, Palaeontology and Biostratigraphy. *Geologisches Jahrbuch Reihe A* 120, 37–61.
- Zhang, T., Liu, X., Ma, M., Lü, B., Mao, X., Chen, J., Liu, G. and Tang, Y. 2022. Origin of hematite in the Middle Cretaceous red chinks on the eastern coast of England. *Sedimentary Geology* 429, 106073. DOI: 10.1016/j.sedgeo.2021.106073

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# The colour of magic

## Exotic raw materials, prospecting, and the Late Palaeolithic of northern Europe

Felix Riede

### Abstract

Knappable stone transported over long distances and the rare occurrence of so-called ‘exotic’ raw materials have long been used to reconstruct Palaeolithic mobility, identity, and social networks. Their potential role as attractors in the landscape and as pull factors in the dispersal of Late Palaeolithic hunter-gatherers northwards at the end of the Pleistocene has received less attention, however. This contribution is inspired by Berit Eriksen’s wide-ranging work on raw material procurement, lithic technology, and consistently international, regionally comparative perspective. With reference to recent discoveries of rare and colourful raw materials (amber and azurite) in Late Palaeolithic contexts across Europe – and, more speculatively, with reference to entirely invisible raw materials such as salt and blubber – I here discuss the importance of ‘exotic’ raw materials in the social fabric of Late Palaeolithic foragers, and the potential role of prospecting for such raw materials as a dispersal driver. As novel discoveries and methods increasingly make these rare raw materials visible, a greater awareness of their importance may be called for.

*Keywords: Final Palaeolithic, amber, prospection, landscape learning*

### Introduction

Among the many topics that Berit Eriksen has touched upon in her long career is the provisioning and importance of so-called ‘exotic’ raw materials in the Magdalenian, Late Palaeolithic and Mesolithic of Europe (Eriksen 2002a). With characteristic focus on one of her regions of choice, Berit masterfully reviewed the evidence for long-distance transport of both knappable lithic and other rather more ‘exotic’ materials – chiefly fossilised and non-fossilised molluscs, jet, and amber – in southwestern Germany and northern Switzerland. Against the backdrop of her tabulations and with reference to foundational works by Binford (1977; 1979) and Morrow and Jeffries (1989), she argued that these raw materials were mostly procured in an embedded manner, *i.e.* as part of cyclical movements motivated first and foremost by seasonal shifts in resource availability. Supplementing this, the occasional ‘exotic’ object signals, she argued, long-distance trade or barter, testified most immediately by worked Baltic amber occurring in the Magdalenian layers at Moosbühl II and Champréveyres in Switzerland, and both Atlantic and Mediterranean molluscs in Early Mesolithic and Magdalenian layers across a handful of southwest German sites. Some of these mollusc shells were turned into ornaments (Rähle 1983; 1994), and thus were likely involved in the negotiation of social identities (*e.g.* Baker *et al.* 2024; Rigaud *et al.* 2022; Schwendler 2012). The function – social or otherwise – of the unmodified shells remains

opaque. Further drawing on lithic provenancing along major western European rivers (Floss 1994; 2000), Berit could paint a dynamic picture of variable Magdalenian procurement strategies and show how these contrasted to the somewhat smaller-world networks of the Early Mesolithic. Evidence for Late Palaeolithic raw material acquisition strategies was notably scarce at that time.

Over the last decades, a great deal of new evidence has emerged. Our knowledge of the circulation of molluscs has expanded (Álvarez-Fernández 2002; 2003; 2009), supporting the key role of major river valleys as conduits of travel and communication (Álvarez-Fernández 2001). At the same time, the evidence of amber use has increased substantially, notably so for the Late Palaeolithic. Here, sites such as Weitsche and Grabow – located near each other – in northern Germany provide evidence of both amber procurement and amber working (e.g. Di Maida 2013; Veil and Breest 2006; Veil *et al.* 2012), while the tentative re-dating of some southern Scandinavian pendants and animal figurines to the Late Palaeolithic would further expand this corpus and its geographic reach (Petersen 2021). Remarkably, novel zooarchaeological investigations aided by methodological innovations such as ZooMS have identified whale bone artefacts in an ever-increasing number of Magdalenian assemblages (Charpentier *et al.* 2022; McGrath *et al.* 2025), including ones far inland such as Andernach (Langley and Street 2013). These further attest to long-range mobility at this time and to the importance of not only considering inorganic proxies. Alongside the emergence of this new evidence, novel conceptual perspectives and methods for capturing the structural properties of the social connections reflected in these material proxies have become available (de Pablo *et al.* 2022). Drawing on an expanded version of Berit's original data, a formal network analysis enabled the quantification of the changing dynamics – and ruptures – in how these Late Pleistocene and Early Holocene communities were enmeshed (Riede 2014). In this analysis, it was not so much the paucity of evidence for longer-distance connectivity in the Late Palaeolithic but the specific structural connectivity properties that became both evident and significant in terms of the (limited) ability of some contemporaneous communities to weather environmental stressors (cf. Whallon 2006).

Here, I further add to the evidence of 'exotic' raw material procurement in the Late Palaeolithic by discussing fresh discoveries from a range of Late Palaeolithic sites. I present new evidence for the exploitation of an expanded range of 'exotic' raw materials that – in the spirit of Berit's commitment to regional comparison (e.g. Eriksen 1996) – also allow us to better link Late Pleistocene core regions such as southwestern Germany with its contemporaneous 'hinterland'. More specifically, I interrogate the role of rare goods including knappable stone as well as other materials as drivers of dispersal at that time. Embedded in the

overarching context of climatic and environmental change, which is providing the general affordances for dispersal, I suggest that "frontier scanning" (Hickey 1984, 18) for such rare resources – in other words: prospecting – may have played into the specific land use decisions made during the dispersal into new territories (see also Park 2023). I discuss emerging evidence for the active extraction of such materials with such sites or micro-regions becoming 'persistent places' (cf. Barton *et al.* 1995) in landscapes otherwise mostly devoid of people.

### **Frontier scanning and prospecting for resources in the Late Palaeolithic**

Within the context of the Late Palaeolithic, I here focus specifically on the *Federmesser-Gruppen*/Arch-Backed Point phenomenon, a northerly derivative of the Late Magdalenian generally dated to the Allerød chronozone/Greenland Interstadial 1<sub>d-a</sub> (Eriksen 2002b; Schwabedissen 1954; Sobkowiak-Tabaka 2017). The *Federmesser-Gruppen* have an expansive trans-Alpine spatial distribution from the Atlantic seaboard to Central Europe, and from the shores of Doggerland to the Alpine lowlands, albeit also with gaps (Schmidt *et al.* 2025). Settlement histories and intensities varied regionally. The *Federmesser-Gruppen* dispersal followed earlier and most likely unsuccessful pulses (Barton *et al.* 2003; Pedersen *et al.* 2023), with rapid movements northwards and eastwards that coincided with the warming that commenced after the Older Dryas. Such dispersal is attested to by radiocarbon dates straddling the transition from GI-1<sub>d</sub> and GI-1<sub>c</sub> (e.g. Riede *et al.* 2010; Veil *et al.* 2012). According to palaeogenomic analyses, this dispersal was associated with new populations with origins in south-eastern France (e.g. Posth *et al.* 2023).

The alacrity of this dispersal is commensurate with a rapid leap-frog dispersal rather than a slow infilling of the landscape. A key driver of a slow dispersal would be successive ecological change in which habitat types shift northwards along latitudinal gradients. *Federmesser-Gruppen* sites occur in a range of habitats, however, and a considerable breadth of biotic resources was exploited (Yaworsky *et al.* 2024). One example suggestive of how very specific resources may have pulled dispersing foragers across long distances at this time comes from the very northern tip of what today is Denmark and which in the Allerød would have been the very margins of the human world. The bulk of Allerød-age human settlement in southern Scandinavia is concentrated in the east where terrestrial and lacustrine resources likely were in focus (Mortensen *et al.* 2014). There is, however, also a cluster of sites far off this rather lush region in the desolate northwestern coastal margins facing the stormy North Sea (see Fischer *et al.*, 2013; Nilsson 1987). A recent analysis focusing on the occurrence and chronology of stranded whales in Late Pleistocene southern Scandinavia makes the argument that these were particularly frequent in the early

and middle parts of the Allerød where they also overlapped with the presence of terrestrial resources (Hussain *et al.* 2025). Stranded whales offer many valuable resources. These include edibles but also go beyond these. Parallel work on identifying whale remains in zooarchaeological assemblages in France and Germany alluded to above has identified whale bones that have been collected, curated and transported over considerable distances. Alongside these, people may have been collecting and transporting blubber, ambergris, as well as driftwood and – from these northern shores in particular – amber.

Amber, in turn, allows us to connect the margins of Late Pleistocene Europe to other sites, also beyond the spectacular but mostly undated animal figures (Petersen 2019; 2021). Amber occasionally occurs in Late Magdalenian and Late Palaeolithic sites from the British Isles to Eastern Europe (Bielińska-Majewska and Łydźba-Kopczyńska 2025; Burdukiewicz 2009). Most of these finds are of Baltic amber and some may have been collected along Europe's palaeo-shorelines. However, amber can also be sourced in riverbeds and moraines across Europe. This local occurrence of amber may, for instance, have led *Federmesser-Gruppen* folks to repeatedly visit the Weitsche/Grabow microregion. Here, previous and new field investigations have yielded clear evidence of amber-working in a region that otherwise does not stand out as more attractive than neighbouring ones (Fig. 1). The amber that occurred naturally in the region would have to be searched for using a surface or near-surface prospecting approach.

Shallow mining has recently been demonstrated to be within the behavioural repertoire of Late Palaeolithic foragers. At Orońsko, for instance, Osipowicz and colleagues (2019) have been able to demonstrate that the deep brown chocolate flint was mined in small shafts here already during the Allerød using bone picks. Chocolate flint has a wide distribution in Central Europe and its systematic procurement and circulation certainly dates back to the *Federmesser-Gruppen* (Sulgostowska 1997; Werra and Kerneder-Gubała 2021). Similarly, the characteristically red Heligoland flint achieved an initial occurrence peak during the Allerød (Terberger *et al.* 2020; see also Jürgens, this volume). Red hues are found in some variants of toolstone – also in the Late Palaeolithic of Europe (Hess 2019) – and are otherwise also relatively common in the Palaeolithic in the form of ochre. For Heligoland flint it was its specific and no doubt evocative origin from what must have been a lone mountain in the otherwise low-lying terrain of Doggerland at that time that made it valuable.

Besides the reds of Heligoland flint, ochre is known to have been mined in the Late Palaeolithic at significant places such as Rydno located, like Orońsko, in southern Poland. Recent microscopic analyses aimed at provenancing the flint and ochre materials found at Rydno and Orońsko link these together (Kerneder-Gubała *et al.* 2025) with materials

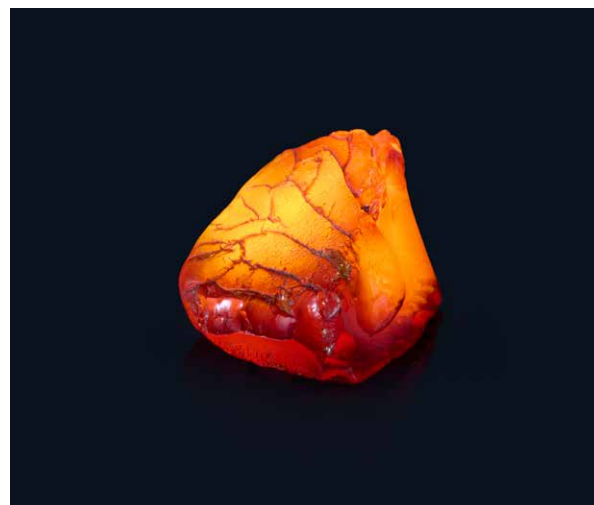


Figure 1: A newly discovered piece of amber-working waste (Length: 10 mm, width: 6 mm, thickness: 5 mm from renewed fieldwork at Grabow 15. Using UV-torches, microscopic amber debris was found across the entire site. Photo: J. Due/Felix Riede.

circulating between them. Ochre was also mined at Lovas in Hungary (Trájer 2022), and these sites together raise the question of how common such mining activities were given the regularity with which ochre is encountered in Late Palaeolithic sites.

Looking westward, one site that has yielded ochre is Mühlheim-Dietesheim, located on the River Main just east of Frankfurt. Excavated first in the late 1970s and early 1980s by Fruth (1979; 1994), the site belongs to the *Federmesser-Gruppen*. Renewed fieldwork at this site has confirmed the relative intactness of the find layer (Riede *et al.* 2024); a newly obtained radiocarbon date on charcoal found in the legacy collection yielded an Early Holocene date, while OSL dating and heavy minerals analysis strongly support a chronological placement in the early-to-middle Allerød. A latent tent structure may be evident in the spatial distribution of the lithics and larger stones used as tent canvas weights. Lithic raw materials link the assemblage west- and eastward to regions along the River Main (Rosenstein 1992) and Fruth (1979; 1994) had already noted the presence of ochre in the original excavation reports. Besides the occurrence of ochre, however, the Mühlheim-Dietesheim inventory has been hiding a much more remarkable find: Long exhibited in the local museum in Mühlheim, a roughly worked and vaguely bowl-shaped basalt artefact shows traces of blue colouring embedded in an encrustation that is patchily preserved on the artefacts upper side (Fig. 2). A detailed, multi-pronged analysis of these traces indicate that these blue specks are azurite, a bright blue copper derivative (Wisher *et al.* 2025).

Azurite does occur in the region, but true surface exposures are rare – more normally, this material needs

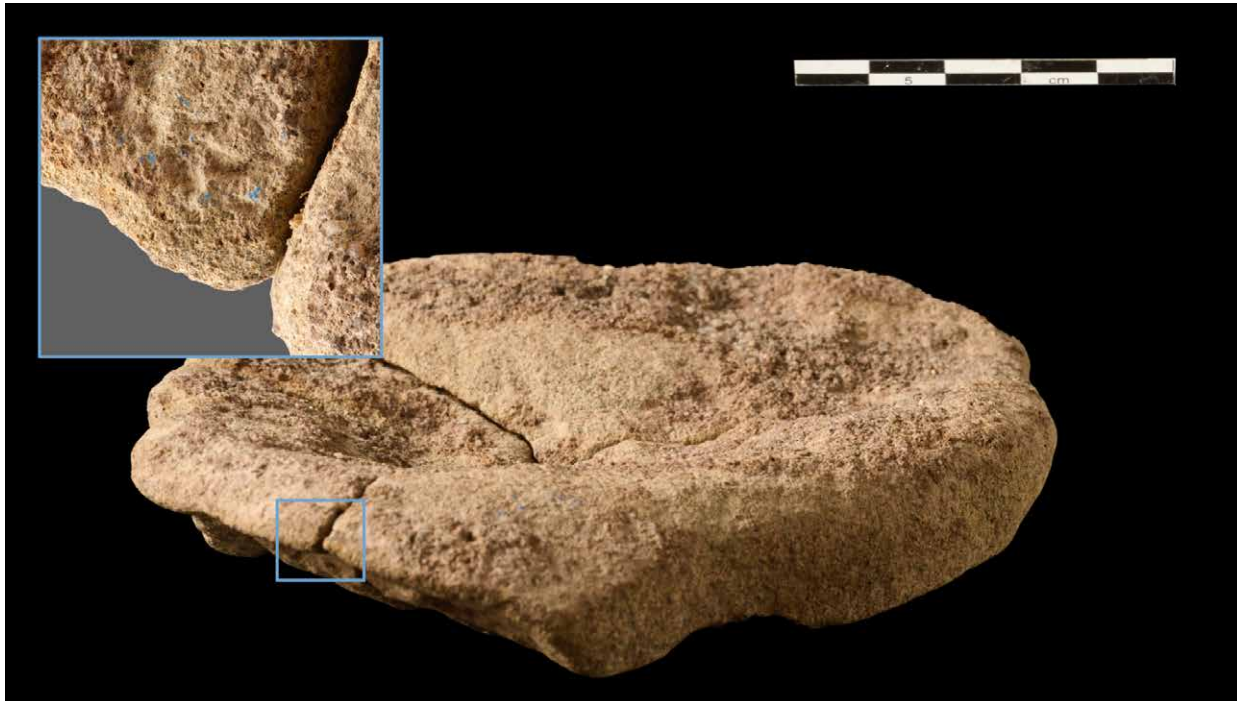


Figure 2: The basalt ‘palette’ from Mühlheim-Dietesheim. Blue azurite spots are macroscopically visible at multiple locations and microscopy reveals a much more widespread occurrence linked to the partially preserved crust. The inset shows the blue specks at just one location. Photo: J. Due/Felix Riede.

to be mined. There are currently no other examples of blue pigment use in the European Palaeolithic, so a firm assessment of why, how, and for which purpose these *Federmesser-Gruppen* folks processed azurite – and whether the Mühlheim-Dietesheim ‘palette’ is more than an idiosyncratic instance – remains difficult. It is worth noting, however, that azurite finds do occur in the Near Eastern Neolithic and later periods where they often come from women’s graves and where the azurite is thought to have been used for cosmetic purposes (e.g. Schotsmans *et al.* 2022). This finding does add yet another piece of evidence in favour of a more colourful Late Palaeolithic, and in favour of the notion that prospecting – the clearly motivated search for specific resources – played some role in structuring settlement patterns and land use at this time (Fig. 3).

A final raw material worth considering here as a specific attractor for Late Palaeolithic *Federmesser-Gruppen* is salt. Well-known as a major commodity in Europe’s later Prehistory (e.g. Sherlock 2021; Weller 2015), salt may already have played a role in food preservation techniques in the Mesolithic (Maritan *et al.* 2018), although evidence remains scarce. Natural salt sources may have been attractive for Pleistocene animals and humans alike; salt springs or licks are ecological hotspots in landscapes broadly comparable with those of the Late Pleistocene with increased abundances of the sorts of animals commonly targeted by *Federmesser-Gruppen* foragers (e.g. Ayotte *et al.*

2008; Brochez *et al.* 2020; Lavelle *et al.* 2014; Sedikhin 2021). Furthermore, humans, too, value salt as a culinary ingredient (e.g. Dudley *et al.* 2012). Two recently (re)investigated *Federmesser-Gruppen* sites are situated near known natural salt springs: Rothenkirchen in Hessen (Germany) and Dybvadbro near Kolding (Denmark). At Rothenkirchen, initially investigated by Fiedler (1976) and Hofbauer (1992), later tephrochronological investigations suggested an early/middle Allerød age of the site (Riede 2012). Notably, the central part of Germany north of the River Main, east of the River Rhine, and west of the Elbe/Saale catchment is poor in Late Palaeolithic sites (see Eriksen 1996; Kitagawa *et al.* 2025; Riede 2016). Given this overall sparsity, the site of Rothenkirchen may reflect special-purpose prospecting excursions targeting the salt source. Similarly, Dybvadbro is located near to the natural salt spring at Harte (Andersen and Ødum 1930; Brandorff and Hansen 1927). Following up on earlier rescue excavations, new work at the site carried out in 2023 yielded debitage, backed and tanged points as well as scrapers that fit snugly into the overall *Federmesser-Gruppen* lithic tool spectrum. OSL dating suggests an Allerød age for the assemblage. The possibility of acquiring salt may have been decisive for human presence here.

### Magical materials and where to find them

When Berit reflected on whether ‘exotic’ raw materials were obtained chiefly through embedded or special-

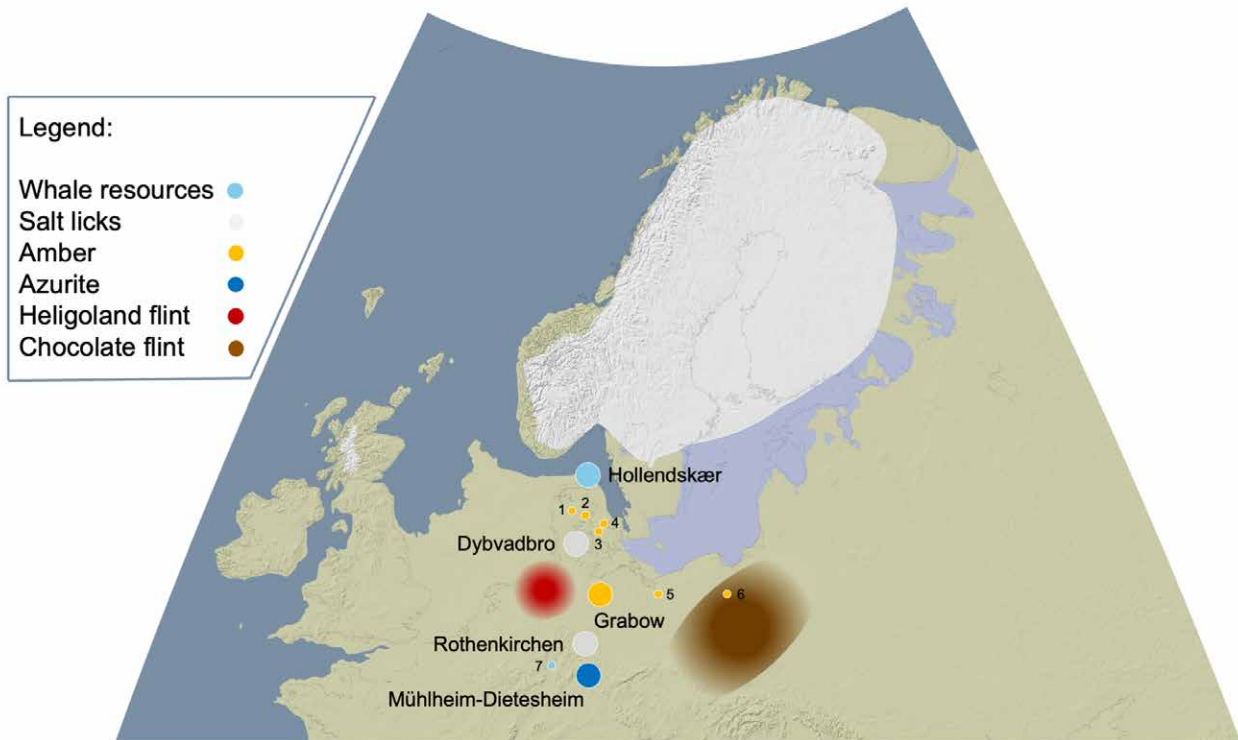


Figure 3: The approximate occurrence of differently coloured specific and otherwise rare raw materials in *Federmesser-Gruppen* contexts across Europe, plotted on the palaeogeographic reconstructions of Allerød-age Europe as compiled under Berit's auspices by the Zentrum für Baltische und Skandinavische Archäologie (ZBSA; see <https://zbsa.eu/allerod/>). The occurrence of Heligoland flint follows Terberger *et al.* (2020), the chocolate flint distribution is from Sulgostowska (1997), supplemented with data from Werra and Kernerder-Gubała (2021). The amber find distribution is from Petersen (2019; 2021) and Bielińska-Majewska and Łydźba-Kopczyńska (2025), azurite from Wisner *et al.* (2025), cetacean remains from Hussain *et al.* (2025) and Langley and Street (2013). The proximity to natural salt sources at Rothenkirchen is mentioned by Hofbauer (1992). The sites specifically mentioned in the present paper are marked with large dots. The remaining sites are: 1. Resen; 2. Tangkrogen; 3. Næsby Strand; 4. Egemark; 5. Dobigniew; 6. Brzoza; 7. Andernach.

purpose procurement in the Late Magdalenian and Early Mesolithic of Europe, she referenced selected ethnographic cases discussed by Binford (1977; 1979) and Morrow and Jeffries (1989). While iconic, the data presented in these studies are rather limited. These can be balanced with ethnographic observations on sex-specific long-distance mobility motivated by, among other aspects, the acquisition of materials (Cavalli-Sforza and Hewlett 1982; Garg *et al.* 2021). They can additionally be balanced with the known long-distance movements of dispersing Thule foragers who made lengthy journeys to explore new territories and also to acquire resources such as meteoric iron from a known source at Cape York (McCartney and Mack 1973; Park 2023). Among many Australian Aboriginal groups, colour in general was significant in negotiating social relations (Taçon 2008). As far back in time as the African Middle Stone Age, the colour of lithic raw material appears to have mattered (*e.g.* Bader *et al.* 2025).

Returning to prehistoric Europe, Berit herself did entertain the possibility that the heat treatment of lithic raw material in the Early Mesolithic of southern Germany was in

part motivated by the colour transformation rather than the improvement in workability these raw materials undergo in the process (Eriksen 2006). More recently, Hess (2019) and Nyland (2020) have independently suggested with reference to yet other ethnographic case studies that charismatic – magical even – materials were attractive due to innate properties such as colour, transparency, and lustre. In the high-elevation terrain of the Alps and Norway, the mining of translucent rock quartz – of ‘cloudstones’ (Nyland 2020) – is well documented and presents a clear example of raw materials that were acquired at significant procurement costs that stand in no relation to the purely functional affordances of this material (*e.g.* Cornelissen *et al.* 2022; Hess *et al.* 2021). Both Nyland and Hess further argue that the social value of a given material is not exclusively determined by its rarity nor by the difficulty of acquiring it. By this token, the sites discussed here have each provided direct or circumstantial evidence of raw material of unusual colour, feel, or origin. This distinctiveness, I argue, may have served as pull factors during the initial dispersal of the *Federmesser-Gruppen* through prospecting, and subsequently played a role in the

making of persistent places in the landscapes they inhabited through repeated habitation and, at times, even near-surface mining. In this framework, it is not the ‘exotic’ but in fact the specific local resources that are the most interesting; these determine the specific location of sites.

The use of extraordinary and colourful materials to negotiate social relations and emerging regional or transregional identities has not received a great deal of attention in the Palaeolithic in general, nor in the Late Palaeolithic of Europe in particular. Most surveys of ancient colour use promote the view that, in the Palaeolithic, red and black hues dominated (Rappenglück 2011; Watts 2015), and some even argue that concepts and words for colours beyond these hues did not exist prior to the Neolithic

(Warburton 2012). The procurement of ‘exotic’ materials is mostly seen as embedded in other activities and thereby relegated as largely epiphenomenal. The brief foray into the Late Palaeolithic of Europe undertaken here demonstrates that not only were salient materials with a wide range of colours and other unusual properties in circulation at this time but that these were acquired through targeted procurement, at times even acting as pull factors that promoted human presence in particular areas at or beyond the margins of contemporaneous settlement cores. As novel discoveries and methods increasingly make these rare raw materials visible, a greater awareness of their importance as a form of ‘vibrant matter’ (*sensu* Bennett 2010) may be called for.

## References

- Álvarez-Fernández, E. 2001. L’axe Rhin-Rhône au Paléolithique supérieur récent: l’exemple des mollusques utilisés comme objets de parure. *L’Anthropologie* 105(4), 547–564. DOI: 10.1016/S0003-5521(01)80052-2.
- Álvarez-Fernandez, E. 2002. Perforated *Homalopoma sanguineum* from Tito Bustillo (Asturias): Mobility of Magdalenian groups in northern Spain. *Antiquity* 76(293), 641–646.
- Álvarez-Fernandez, E. 2003. Die Reise der Schnecke *Columbella rustica* während des Mesolithikums und zu Beginn des Neolithikums in Europa. *Archäologisches Korrespondenzblatt* 33(2), 157–166.
- Álvarez-Fernandez, E. 2009. Magdalenian personal ornaments on the move: A review of the current evidence in Central Europe. *Zephyrus* 63, 45–59.
- Andersen, J. and Ødum, H. 1930. Om Forekomsten af saltførende Aflejringer i Danmarks Undergrund. *Danmarks Geologiske Undersøgelse II. Række* 52, 1–111. DOI: 10.34194/raekke2.v52.6840.
- Ayotte, J. B., Parker, K. L. and Gillingham, M. P. 2008. Use of Natural Licks by Four Species of Ungulates in Northern British Columbia. *Journal of Mammalogy* 89(4), 1041–1050. DOI: 10.1644/07-MAMM-A-345.1.
- Bader, G. D., Sommer, C., Linstädter, J., Masia, D. P., Blessing, M. A., Forrester, B. and MacDonald, B. L. 2025. Decoding hunter-gatherer-knowledge and selective choice of lithic raw materials during the Middle and Later Stone Age in Eswatini. *Journal of Archaeological Science* 180. DOI: 10.1016/j.jas.2025.106302.
- Baker, J., Rigaud, S., Pereira, D., Courtenay, L. A. and d’Errico, F. 2024. Evidence from personal ornaments suggest nine distinct cultural groups between 34,000 and 24,000 years ago in Europe. *Nature Human Behaviour* 8(3), 431–444. DOI: 10.1038/s41562-023-01803-6.
- Barton, R. N. E., Berridge, P. J., Walker, M. J. and Bevins, R. E. 1995. Persistent places in the Mesolithic Landscape: an example from the Black Mountain Uplands of South Wales. *Proceedings of the Prehistoric Society* 61, 81–116.
- Barton, R. N. E., Jacobi, R. M., Stapert, D. and Street, M. J. 2003. The Late-glacial reoccupation of the British Isles and the Creswellian. *Journal of Quaternary Science* 18(7), 631–643.
- Bennett, J. 2010. *Vibrant Matter: A Political Ecology of Things*. Durham, NC, Duke University Press. DOI: 10.2307/j.ctv111jh6w.
- Bielińska-Majewska, B. and Lydźba-Kopczyńska, B. 2025. Provenance study of amber discovered in the Toruń Basin on Late Palaeolithic site 50 in Brzoza (Poland). *Praehistorische Zeitschrift* [Preprint]. DOI: 10.1515/pz-2025-2009.
- Binford, L. R. 1977. Forty-seven trips: a case study in the character of archaeological formation processes. In: Wright, R.V.S. (ed.), *Stone Tools as Cultural Markers: Change, Evolution and Complexity*. Canberra, Humanities Press Inc., 24–36.
- Binford, L. R. 1979. Organization and Formation Processes: Looking at Curated Technologies. *Journal of Anthropological Research* 35(3), 255–273.
- Brandorff, J. O. and Hansen, S. 1927. Grundundersøgelser i Kolding. *Danmarks Geologiske Undersøgelse IV. Række* 2(2), 1–77. DOI: 10.34194/raekke4.v2.6976.
- Brochez, C. B., Rea, R. V., Crowley, S. M. and Hodder, D. P. 2020. Year-round patterns of mineral lick use by Moose (*Alces americanus*), deer, and Elk (*Cervus canadensis*) in north-central British Columbia. *The Canadian Field-Naturalist* 134(4), 361–374. DOI: 10.22621/cfn.v134i4.2485.
- Burdukiewicz, J. M. 2009. Further Research on Amber in Palaeolithic Archaeology. In: Burdukiewicz, J. M., Cyrek, K., Dyczek, P. and Szymczak, K. (eds.),

- Understanding the Past. Papers offered to Stefan K. Kozłowski*. Warsaw, University of Warsaw, 69–74.
- Cavalli-Sforza, L. L. and Hewlett, B. 1982. Exploration and mating range in African Pygmies. *Annals of Human Genetics* 46, 257–270.
- Charpentier, A., Rodrigues, A.S., Houmard, C., Lefebvre, A., McGrath, K., Speller, C., van Der Sluis, L., Zazzo, A. and Pétilion, J. M. 2022. What's in a whale bone? Combining new analytical methods, ecology and history to shed light on ancient human-whale interactions. *Quaternary Science Reviews* 284, 107470. DOI:10.1016/j.quascirev.2022.107470.
- Cornelissen, M., Auf der Maur, C. and Reitmaier, T. 2022. A Glacially Preserved Mesolithic Rock Crystal Extraction Site in the Swiss Alps. *Norwegian Archaeological Review* 55(1), 96–102. DOI:10.1080/00293652.2022.2052747.
- Di Maida, G. 2013. The potential of digital microscopic analysis of amber artefacts from Grabow 15. *Die Kunde N.F.* 64, 1–10.
- Dudley, R., Kaspari, M. and Yanoviak, S. P. 2012. Lust for Salt in the Western Amazon. *Biotropica* 44(1), 6–9.
- Eriksen, B. V. 1996. Regional Variation in Late Pleistocene Subsistence Strategies. Southern Scandinavian Reindeer Hunters in a European Context. In Larsson, L. (ed.), *The Earliest Settlement of Scandinavia and its relationship with neighbouring areas*. Acta Archaeologica Lundensia Series in 8° 24. Stockholm, Almqvist & Wicksell, 7–22.
- Eriksen, B. V. 2002a. Fossil mollusks and exotic raw materials in late glacial and early postglacial find contexts – a complement to lithic studies. In: Fisher, L.E. and Eriksen, B.V. (eds.), *Lithic raw material economies in late Glacial and early Postglacial Europe*. Oxford, Archaeopress, 27–52.
- Eriksen, B. V. 2002b. Reconsidering the geochronological framework of Lateglacial hunter-gatherer colonization of southern Scandinavia. In: Eriksen, B.V. and Bratlund, B. (eds.), *Recent studies in the Final Palaeolithic of the European plain*. Højbjerg, Jutland Archaeological Society, 25–42.
- Eriksen, B. V. 2006. Colourful Lithics - The “Chaîne Opératoire” of Heat Treated Chert Artefact in the Early Mesolithic of Southwest Germany. In: Kind, C.-J. (ed.), *After the Ice Age. Settlements, subsistence and social development in the Mesolithic of Central Europe*. Stuttgart, Konrad Theiss Verlag, 147–154.
- Fiedler, L. 1976. Ein endpaläolithischer Fundplatz bei Rothenkirchen, Kreis Fulda. *Archäologisches Korrespondenzblatt* 6, 267–269.
- Fischer, A., Clemmensen, L. B., Danahue, R., Heinemeier, J., Lykke-Andersen, H., Lysdahl, P., Mortensen, M. F. and Olsen, J. 2013. Late Palaeolithic Nørre Lyngby—a northern outpost close to the west coast of Europe: Nørre Lyngby in spätpaläolithischer Zeit—ein nördlicher Außenposten nahe der Westküste Europas. *Quartär* 60, 137–162.
- Floss, H. 1994. *Rohmaterialversorgung im Paläolithikum des Mittelrheingebietes*. Monographien des Römisch-Germanischen Zentralmuseums 21. Bonn, Dr. Rudolf Habelt.
- Floss, H. 2000. Le couloir Rhin-Saône-Rhône: axe de communication au Tardiglaciaire?. In: *Les derniers chasseurs-cueilleurs d l'Europe occidentale: Actes du colloque international de Besançon 1998*. Besançon, Presses Universitaires Franc-Comtoises, 313–321.
- Fruth, H.-J. 1979. Ein spätpaläolithischer Fundplatz bei Mühlheim-Dietesheim, Kreis Offenbach. *Archäologisches Korrespondenzblatt* 9, 261–266.
- Fruth, H.-J. 1994. Der spätpaläolithische Fundplatz Mühlheim-Dietesheim, Kreis Offenbach. *Fundberichte aus Hessen* 22/23(1982–83), 1–67.
- Garg, K., Padilla-Iglesias, C., Restrepo Ochoa, N. and Knight, V. B. 2021. Hunter-gatherer foraging networks promote information transmission. *Royal Society Open Science* 8(12). DOI:10.1098/rsos.211324.
- Hess, T. 2019. *Das Helga-Abri im Achtal. Lithische Technologie und Rohmaterialversorgung der spätmagdalénienzeitlichen und frühmesolithischen Gruppen*. Tübingen, Kerns Verlag.
- Hess, T., Turck, R., de Vries, G. and Della Casa, P. 2021. A Prehistoric Rock Crystal Procurement Site at Fiescheralp (Valais, Switzerland). *Lithic Technology* 46(3), 209–220. DOI:10.1080/01977261.2021.1899626.
- Hickey, C. G. 1984. An Examination of Processes of Cultural Change among Nineteenth Century Copper Inuit. *Études/Inuit/Studies* 8(1), 13–35.
- Hofbauer, H. 1992. Ein spätpaläolithischer Fundplatz bei Rothenkirchen, Kreis Fulda (Hessen). *Archäologisches Korrespondenzblatt* 22, 329–340.
- Hussain, S. T., Hellerøe, S. F., Dalager, H. N., Nielsen, E. S., Vinter, M. and Riede, F. 2025. Was the Late Glacial human occupation of northernmost Europe facilitated by whales? New data and perspectives on lithic technology and the paleoecology of the Vendsyssel area, Northern Jutland, Denmark. *The Journal of Island and Coastal Archaeology* 20(2), 317–345. DOI:10.1080/15564894.2023.2277727.
- Kerner-Gubała, K., Kościuk-Załupka, J., Gurba, D. and Śloniewski, M. 2025. Social networks around the Orońsko flint mining area (Central-Southern Poland) during the Late Palaeolithic: The first results of the SEM-EDS analysis of flints and pigments. *Archeologické rozhledy* 77(1), 63–87. DOI:10.35686/AR.2025.261.
- Kitagawa, K., Burger-Völlmecke, D., Brown, S., Olsen, J. and Riede, F. 2025. Paleolithic occupations in the Lahn Valley of Central Germany: New dating and

- ZooMS results from Wildscheuer, Wildweiberlei, and Wildhaus. *Journal of Archaeological Science: Reports* 61. DOI:10.1016/j.jasrep.2024.104951.
- Langley, M. C. and Street, M. 2013. Long range inland-coastal networks during the Late Magdalenian: Evidence for individual acquisition of marine resources at Andernach-Martinsberg, German Central Rhineland. *Journal of Human Evolution* 64(5), 457–465. DOI:10.1016/j.jhevol.2013.01.015.
- Lavelle, M. J., Phillips, G. E., Fischer, J. W., Burke, P. W., Seward, N. W., Stahl, R. S., Nichols, T. A., Wunder, B. A. and VerCauteren, K. C. 2014. Mineral licks: motivational factors for visitation and accompanying disease risk at communal use sites of elk and deer. *Environmental Geochemistry and Health* 36(6), 1049–1061. DOI:10.1007/s10653-014-9600-0.
- Maritan, L., Iacumin, P., Zerboni, A., Venturelli, G., Dal Sasso, G., Linseele, V., Talamo, S., Salvatori, S. and Usai, D. 2018. Fish and salt: The successful recipe of White Nile Mesolithic hunter-gatherer-fishers. *Journal of Archaeological Science* 92, 48–62. DOI:10.1016/j.jas.2018.02.008.
- McCartney, A. P. and Mack, D. J. 1973. Iron Utilization by Thule Eskimos of Central Canada. *American Antiquity* 38(3), 328–339. DOI:10.2307/279720.
- McGrath, K., van der Sluis, L. G., Lefebvre, A., Charpentier, A., Rodrigues, A. S., Álvarez-Fernández, E., Baleux, F., Berganza, E., Chauvière, F. X., Dachary, M. and Duarte Matías, E. 2025. Late Paleolithic whale bone tools reveal human and whale ecology in the Bay of Biscay. *Nature Communications* 16(1). DOI:10.1038/s41467-025-59486-8.
- Morrow, C. A. and Jeffries, R. W. 1989. Trade or embedded procurement?: a test case from southern Illinois. In Torrence, R. (ed.), *Time, Energy, and Stone Tools*. Cambridge, Cambridge University Press, 27–33.
- Mortensen, M. F., Henriksen, P. S. and Bennike, O. 2014. Living on the good soil: relationships between soils, vegetation and human settlement during the late Allerød period in Denmark. *Vegetation History and Archaeobotany* 23(3), 195–205. DOI:10.1007/s00334-014-0433-7.
- Nilsson, T. 1987. Senglacial bosättning i Vendsyssel. *Kuml* 1987, 47–75. DOI:10.7146/kuml.v35i35.110467.
- Nyland, A. J. 2020. In Search of Cloudstones? The Contribution of Charismatic Rocks Towards an Understanding of Mesolithic and Neolithic Communities in the Montane Regions of South Norway. *Proceedings of the Prehistoric Society* 86, 43–64. DOI:10.1017/ppr.2020.4.
- Osipowicz, G., Kerneder-Gubała, K., Bosiak, M., Makowiecki, D. and Orłowska, J. 2019. The oldest osseous mining tools in Europe? New discoveries from the chocolate flint mine in Orońsko, site 2 (southern Poland). *Quaternary International* 512, 82–98. DOI:10.1016/j.quaint.2019.02.005.
- de Pablo, J. F.-L., Romano, V., Derex, M., Gjesfjeld, E., Gravel-Miguel, C., Hamilton, M. J., Migliano, A. B., Riede, F. and Lozano, S. 2022. Understanding hunter-gatherer cultural evolution needs network thinking. *Trends in Ecology & Evolution* 37(8), 632–636. DOI:10.1016/j.tree.2022.04.007.
- Park, R. W. 2023. The Thule Migration: A Culture in a Hurry? *Open Archaeology* 9(1), 20220326. DOI:10.1515/opar-2022-0326.
- Pedersen, J. B., Assmann, J. J., Normand, S., Karger, D. N. and Riede, F. 2023. Climate Niche Modeling Reveals the Fate of Pioneering Late Pleistocene Populations in Northern Europe. *Current Anthropology* 64(5), 599–608. DOI:10.1086/726700.
- Petersen, P. V. 2019. Amber, animal figures and protective art in Scandinavia. *Die Kunde N.F.* 70, 145–164.
- Petersen, P. V. 2021. Zigzag lines and other protective patterns in Palaeolithic and Mesolithic art. *Quaternary International* 573, 66–74. DOI:10.1016/j.quaint.2019.09.029.
- Posth, C., Yu, H., Ghalichi, A., Rougier, H., Crevecoeur, I., Huang, Y., Ringbauer, H., Rohrlach, A. B., Nägele, K., Villalba-Mouco, V., Radzeviciute, R., Ferraz, T., Stoessel, A., Tukhbatova, R., Drucker, D. G., Lari, M., Modi, A., Vai, S., Saupe, T., Scheib, C. L., Catalano, G., Pagani, L., Talamo, S., Fewlass, H., Klaric, L., Morala, A., Rué, M., Madelaine, S., Crépin, L., Caverne, J.-B., Bocaeye, E., Ricci, S., Boschini, F., Bayle, P., Maureille, B., Le Brun-Ricalens, F., Bordes, J.-G., Oxilia, G., Bortolini, E., Bignon-Lau, O., Debout, G., Orliac, M., Zazzo, A., Sparacello, V., Starnini, E., Sineo, L., van der Plicht, J., Pecqueur, L., Merceron, G., Garcia, G., Leuvrey, J.-M., Bay Garcia, C., Gómez-Olivencia, A., Połtowicz-Bobak, M., Bobak, D., Le Luyet, M., Storm, P., Hoffmann, C., Kabaciński, J., Filimonova, T., Shnaider, S., Berezina, N., González-Rabanal, B., González Morales, M. R., Marín-Arroyo, A. B., López, B., Alonso-Llamazares, C., Ronchitelli, A., Polet, C., Jadin, I., Cauwe, N., Soler, J., Coromina, N., Rufí, I., Cottiaux, R., Clark, G., Straus, L. G., Julien, M.-A., Renhart, S., Talaa, D., Benazzi, S., Romandini, M., Amkreutz, L., Bocherens, H., Wißing, C., Villotte, S., Fernández-López de Pablo, J., Gómez-Puche, M., Esquembre-Bebia, M. A., Bodu, P., Smits, L., Souffi, B., Jankauskas, R., Kozakaitė, J., Cupillard, C., Benthien, H., Wehrberger, K., Schmitz, R. W., Feine, S. C., Schüler, T., Thevenet, C., Grigorescu, D., Lüth, F., Kotula, A., Piezonka, H., Schopper, F., Svoboda, J., Sázalová, S., Chizhevsky, A., Khokhlov, A., Conard, N. J., Valentin, F., Harvati, K., Semal, P., Jungklaus, B., Suvorov, A., Schulting, R., Moiseyev, V., Mannermaa, K., Buzhilova, A., Terberger, T., Caramelli, D., Altena, E., Haak, W. and Krause, J. 2023. Palaeogenomics of

- Upper Palaeolithic to Neolithic European Hunter-Gatherers. *Nature* 615, no. 7950, 117–26.
- Rähle, W. 1983. Schmuck aus Molluskenschalen von der Magdalénien-Station Petersfels bei Engen (Hegau). In: Albrecht, G., Berke, H. and Poplin, F. (eds.), *Naturwissenschaftliche Untersuchungen an Magdalénien-Inventaren vom Petersfels, Grabungen 1974–1976*. Tübingen, Verlag Archaeologica Venatoria, 154–158.
- Rähle, W. 1994. Neue Funde jungpaläolithischen Schalenschmuckes vom Hohlen Fels bei Schelklingen, Alb-Donau-Kreis, und vom Petersfels bei Engen, Kreis Konstanz. *Fundberichte aus Baden-Württemberg* 19(1), 95–98. DOI: 10.11588/fbbw.1994.1.48270.
- Rappenglück, M. 2011. The Palaeolithic Colour Palette and Charm of Hues: Pigments in Earlier Prehistory (800 ka–10 ka BP). In: *Colours in Culture and Science. 200 Years Goethe's Colour Theory. Proceedings of the Interdisciplinary Symposium in Hamburg, Oct. 12–15, 2010*. Nuncius Hamburgensis 22. Hamburg, tredition GmbH, 44–65.
- Riede, F., Weber, M. J., Grimm, S. B. and Fahlke, J. M. 2010. Neue Daten für alte Grabungen. Ein Beitrag zur spätglazialen Archäologie und Faunengeschichte Norddeutschlands. *Archäologisches Korrespondenzblatt* 40(3), 297–316.
- Riede, F. 2012. Tephrochronologische Nachuntersuchungen am endpaläolithischen Fundplatz Rothenkirchen, Kreis Fulda. Führte der Ausbruch des Laacher See-Vulkans (10966 v. Chr.) zu einer anhaltenden Siedlungslücke in Hessen? *Jahrbuch des nassauischen Vereins für Naturkunde* 133, 47–68.
- Riede, F. 2014. Eruptions and ruptures – a social network perspective on vulnerability and impact of the Laacher See eruption (c. 13,000 BP) on Late Glacial hunter-gatherers in northern Europe. *Archaeological Review from Cambridge* 29(1), 67–102.
- Riede, F. 2016. Changes in mid- and far-field human landscape use following the Laacher See eruption (c. 13,000 BP). *Quaternary International* 394, 37–50. DOI: 10.1016/j.quaint.2014.07.008.
- Riede, F., Pedersen, J. B., Birndorfer, T. and Steffens, P. 2024. Geoarchäologisch motivierte Grabung am spätpaläolithischen Fundplatz Mühlheim-Dietesheim. *hessenArchäologie* 2023, 65–69.
- Rigaud, S., O'hara, J., Charles, L., Man-Estier, E. and Paillet, P. 2022. The management of symbolic raw materials in the Late Upper Paleolithic of South-Western France: a shell ornaments perspective. DOI: 10.31235/osf.io/z7pqq.
- Rosenstein, A. 1992. Spätpaläolithische Funde am Unteren Main. *Archäologische Informationen* 15(1/2), 172–176. DOI: 10.11588/ai.1992.1&2.19811.
- Schmidt, I., Gehlen, B., Winkler, K., Arrizabalaga, A., Arts, N., Bicho, N., Crombé, P., Eriksen, B. V., Grimm, S. B., Kapustka, K. and Langlais, M. 2025. Large scale and regional demographic responses to climatic changes in Europe during the Final Palaeolithic. *PLoS ONE* 20(4). DOI: 10.1371/journal.pone.0310942.
- Schotsmans, E. M. J., Busacca, G., Lin, S. C., Vasić, M., Lingle, A. M., Veropoulidou, R., Mazzucato, C., Tibbetts, B., Haddow, S. D., Somel, M. and Toksoy-Köksal, F. 2022. New insights on commemoration of the dead through mortuary and architectural use of pigments at Neolithic Çatalhöyük, Turkey. *Scientific Reports* 12(1). DOI: 10.1038/s41598-022-07284-3.
- Schwabedissen, H. 1954. *Die Federmessergruppen des nordwesteuropäischen Flachlandes. Zur Ausbreitung des Spät-Magdalénien*. Neumünster, Wachholtz Verlag.
- Schwendler, R. H. 2012. Diversity in social organization across Magdalenian Western Europe ca. 17–12,000 BP. *Quaternary International* 272–273(0), 333–353. DOI: 10.1016/j.quaint.2012.03.054.
- Sedikhin, N. V. 2021. The salt licking activity of the European Moose (*Alces alces* Linnaeus, 1758) in the Leningrad region of Russia: temporal and behavioral aspects. *Russian Journal of Theriology* 20(2), 158–172. DOI: 10.15298/rusjtheriol.20.2.05.
- Sherlock, S. J. 2021. Early Neolithic salt production at Street House, Loftus, north-east England. *Antiquity* 95(381), 648–669. DOI: 10.15184/aqy.2021.25.
- Sobkowiak-Tabaka, I. 2017. *Rozwój społeczności Federmesser na Nizinie Środkowoeuropejskiej*. Poznań, Instytut Archeologii i Etnologii Polskiej Akademii Nauk.
- Sulgostowska, Z. 1997. The Phenomenon of Chocolate Flint Distribution on the North European Plain During the Final Palaeolithic. In: R. Schild and Z. Sulgostowska (eds.), *Man and Flint*. Warsaw, Polish Academy of Sciences, 313–318.
- Taçon, P. S. C. 2008. Rainbow Colour and Power among the Waanyi of Northwest Queensland. *Cambridge Archaeological Journal* 18(2), 163–176. DOI: 10.1017/S0959774308000231.
- Terberger, T., Schneider, J. and Fries, J. E. 2020. The site of Edeweicht 82-East, district of Ammerland, and the role of Red Heligoland flint in the Late Glacial. *Praehistorische Zeitschrift* 95(1), 1–16. DOI: 10.1515/pz-2020-0006.
- Trájer, A. J. 2022. Placing of the second oldest red ochre mine in mainland Europe, Lovas, Hungary, to human, paleoenvironmental and paleobiogeographic context. *Quaternary Science Reviews* 292, 107670. DOI: 10.1016/j.quascirev.2022.107670.
- Veil, S., Breest, K., Grootes, P., Nadeau, M. J. and Hüls, M. 2012. A 14 000-year-old amber elk and the origins of northern European art. *Antiquity* 86(333), 660–673.
- Veil, S. and Breest, K. 2006. Origins of Mesolithic Art? A Recently Discovered Pendant and Other Objects of

- Amber from the Federmesser Site Weitsche, County of Lüchow-Dannenberg (Lower Saxony, Germany). In: Kind, C.-J. (ed.), *After the Ice Age. Settlements, subsistence and social development in the Mesolithic of Central Europe*. Stuttgart, Konrad Theiss Verlag, 285–296.
- Warburton, D. A. 2012. Colourful Meaning: Terminology, abstraction and the Near Eastern Bronze Age. In: Johannsen, N. N., Jessen, M. D. and Jensen, H. J. (eds.), *Excavating the Mind: Cross-sections through culture, cognition and materiality*. Århus, Aarhus University Press, 183–208.
- Watts, I. 2015. Early color symbolism. In: Elliot, A. J., Franklin, A. and Fairchild M. D. (eds.), *Handbook of Color Psychology*. Cambridge Handbooks in Psychology. Cambridge, Cambridge University Press, 319–339. DOI: 10.1017/CBO9781107337930.016.
- Weller, O. 2015. First salt making in Europe: an overview from Neolithic times. *Documenta Praehistorica* 42, 185–196. DOI: 10.4312/dp.42.12
- Werra, D. H. and Kerneder-Gubała, K. 2021. “Chocolate” flint mining from Final Palaeolithic up to Early Iron Age - a review. In: Bostyn, F., Giligny, F. and Topping, P. (eds.), *From Mine to User: Production and Procurement Systems of Siliceous Rocks in the European Neolithic and Bronze Age*. Proceedings of the XVIII UISPP World Congress (4-9 June 2018, Paris, France) Volume 10 Session XXXIII-1&2. Oxford, Archaeopress, 42–56. DOI: 10.2307/jj.15136049.9
- Whallon, R. 2006. Social networks and information: Non-“utilitarian” mobility among hunter-gatherers. *Journal of Anthropological Archaeology* 25(2), 259–270.
- Wisher, I., Birch, T., Andreasen, R., Canosa, E., Norrehed, S., Reguer, S., Lemasson, Q., Oras, E., Johanson, K., Kinnaird, T., Birndorfer, T. 2025. The earliest evidence of blue pigment use in Europe. *Antiquity*, 1–16. DOI: 10.15184/aqy.2025.10184
- Yaworsky, P. M., Hussain, S. T. and Riede, F. 2024. The effects of climate and population on human land use patterns in Europe from 22ka to 9ka ago. *Quaternary Science Reviews* 344, 108956. DOI: 10.1016/j.quascirev.2024.108956

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# 'Lyngby axes' from Ahrensburg (Schleswig-Holstein, Germany)

Supplementary material

Éva David

## Abstract

This paper supplements previous publications on the 'Lyngby axes' to enhance our understanding of these artefacts in the context of the emergence of heavy-duty activities involving osseous tools in the Stone Age. The specimens analysed in this paper were the only ones recovered from the storage room where the Stellmoor faunal collection is available at the Schleswig-Holstein State Museum in Schloss Gottorf. Excavated from the upper layer of the Ahrensburgian culture site during the Second World War, the 'Lyngby axes' are of significant importance, as they provide evidence of a specific crafting activity in northern Germany at the final Late Glacial (first half of the 9<sup>th</sup>-11<sup>th</sup> millennia cal BCE). Surface analysis indicates that various morphologies of reindeer antler were selected for their genuine, naturally broken first brow or bez tine remaining perpendicular to the perch. Regardless of aspect or dimensions, or whether made of sub-fossil or fresh antler, these improvised tools were used, once basically reduced to a 'reverse L-shape', as a single tool type *in situ* for split-based tasks.

*Keywords: Late Glacial, reindeer, antler, tool, technology*

## Introduction

The 'Lyngby axes' are tools made from reindeer antler that were first discovered in Nørre Lyngby 7, Jutland, Denmark (Müller 1897). These tools appear to have first been utilised during the Laacher See event of 10.972 cal BCE (Baales *et al.* 2002), and certainly during the consecutive cold GS-1 episode from 10750 to 9620 cal BCE (Weber *et al.* 2011). A recent taphonomic analysis revealed that, of the ten specimens dated by radiocarbon, only those made from fresh, slaughtered reindeer materials are likely to be contemporary with this last stage of the Late Glacial period (David and Eriksen 2021).

The 'Lyngby axes' are believed to have originated in the Upper Palaeolithic (Klima 1987; Morosan 1934). These antler tools are enigmatic, primarily due to the fact that they were mostly found in c. 46 scattered locations across northern Europe (for distribution map, see Girininkas *et al.* 2016), from England to the East Baltic regions (Ballin and Saville 2003; Childe 1942; 1949; Clark 1936; Cook and Jacobi 1994; Fuglestedt 2007; Larsson 1996; Louwe Kooijmans 1974; Mathiassen 1948; Mithen *et al.* 2015; Müller 1901; Petersen and Johansen 1991). When found in a secure context, the 'Lyngby axes' are considered to

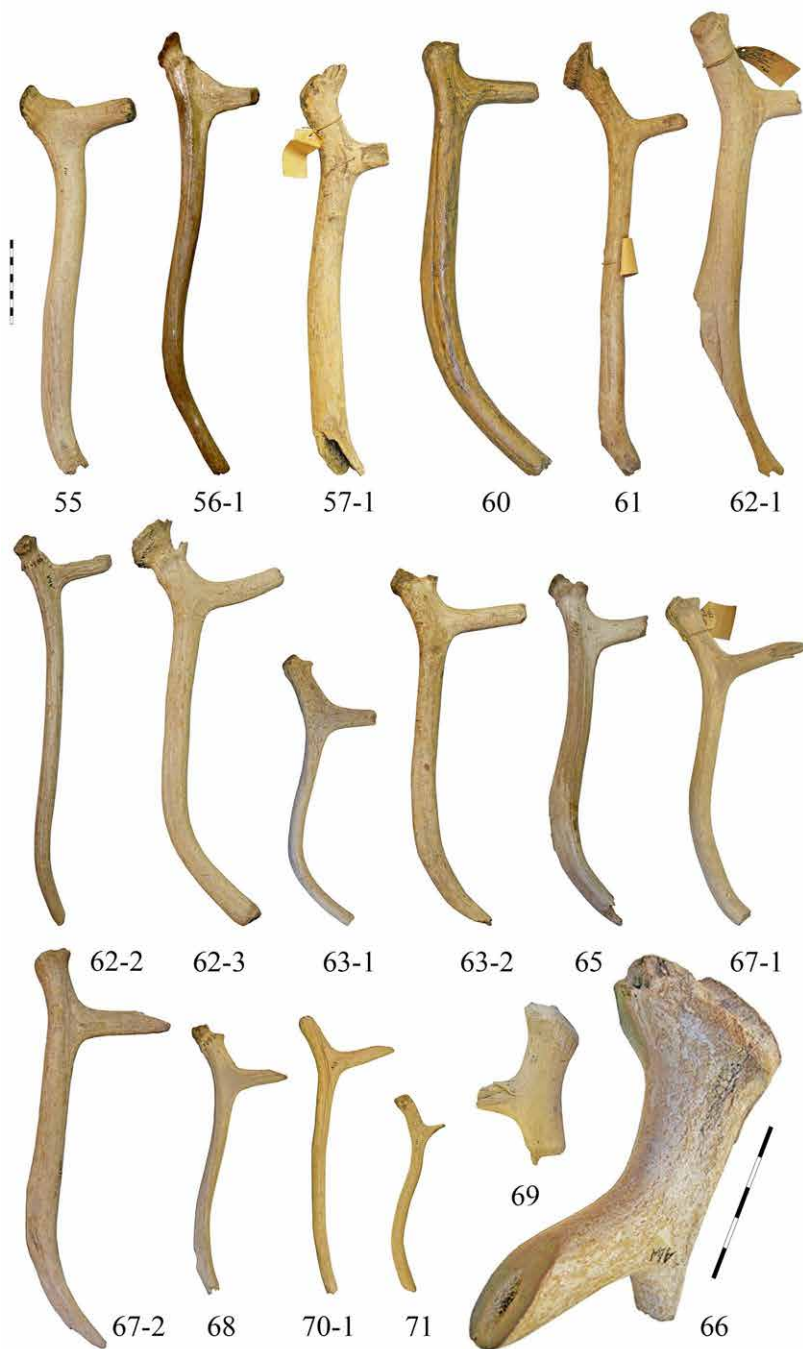


Figure 1: The 18 'Lyngby axes' found in the Stellmoor faunal collection (Schleswig-Holstein, Germany). Scale in cm.

represent a single tool type, associated with the upper layer of the Stellmoor site in Germany (Rust 1943), and are thus emblematic of the Ahrensburgian culture of the Younger Dryas chronozone (Baales 1996). However, as this archaeological culture is not thought to be found in the eastern Baltic, where similar 'Lyngby axes' have been recognized as antler stray finds (Philippsen *et al.* 2019; Zagorska *et al.* 2019), it is unclear whether the eponymous cultural material would actually reflect a distinct human group (Riede and Edinborough 2012). Furthermore, one

of the Danish 'Lyngby axes' dates to the 9<sup>th</sup> millennium cal BCE (Stensager 2004), which predates the Ahrensburgian occupation of the site by at least 500 years (Fischer and Tauber 1986). Nevertheless, these antler tools provide evidence of human occupation in northern Europe during the final Late Glacial period.

The artefact type was first identified as Late Glacial cultural remain following its discovery in Late Glacial sediment deposits, where cuts were made for geological transects to establish stratigraphic sequencing between

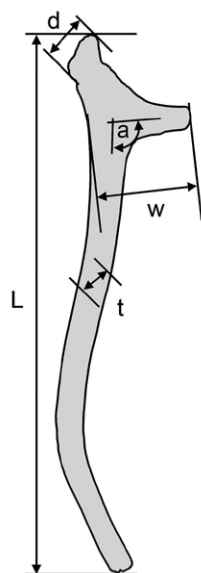


Figure 2: List of ‘Lyngby axes’, with their measurements in centimetres and angle. The labels correspond to the numbering of the plates where the pieces are illustrated in the original publication (Rust 1943).

Label	State	Length (L)	Width (W)	Thickness (t)	Angle (a)	Diametre (d)
55	L	48	12,1	3	91°	3,2
56-1	R #	51	11,2	2,9	89°	4
57-1	L	48	7	3,2	97°	4
60	L	49	11	3,2	90°	3
61	L #	50	11	3,2	94°	5,2
62-1	L #	55	11	3,2	92°	4
62-2	L #	49	13	1,9	89°	3
62-3	R #	50	13,6	2	104°	5,2
63-1	L	32	9,3	1,3	92°	2
63-2	R #	44	13	2	94°	3
65 *	R #	40	10	1,9	96°	3
66	R	recut	10	3,5	89°	4,8
67-1	L	40	12	1,9	106°	3
67-2	R	46	14,3	2,4	96°	3
68	L #	32	8,2	1,6	102°	2,6
69	L	recut	10	4	100°	4
70-1		32	11	1,5	92°	2,6
71		24	4,4	4,2	101°	2

\* (modern?) engraved # unshed stag antler

the Pleistocene and Holocene epochs (Jessen and Nordmann 1915). The introduction of the tool type can be associated with changes that occurred in the glacial landscape, most notably the replacement of dwarf birch by downy birch (Mortensen *et al.* 2011). The tool is made of a pruned-off reindeer antler (Fig. 1).

As the broken brow or bez tine is perpendicular to the perch and comes in various shapes, Alfred Rust – who excavated the eponymous Ahrensburg organic-based (gyttja) stratigraphic layer at the Stellmoor site located near the town of Ahrensburg in Schleswig-Holstein (northern Germany) – suggested that these artefacts were used as hoes of various types (Rust 1943). These were found in large numbers (around 50 artefacts) alongside other cultural remains that are significant to the knowledge of Late Glacial hunting economy (Baales 1999), as well as amongst numerous reindeer carcasses bearing impact marks (Bratlund 1996). The presence of wooden foreshafts and arrows used for bow hunting suggests that people had knowledge of the steep topography, which was possibly crossed by reindeer herds (Price *et al.* 2017). Therefore, the classical functional hypothesis proposes that Late Glacial hunters used ‘Lyngby axes’ as weapons or maces with which to slaughter reindeer during their migration (Bokelmann 1991; Schwantes 1952). Although the antler tool is often found to be empty of a spongy core, the damaged edge has led some scholars to suggest that a flint blade was fixed into the perceived socket of the tine in order to use the antler as a club (Clausen 2004). Other suggestions have been put forward, but the arguments remain debatable because they depend largely on the finding contexts and/or the only traces observed on the artefact (Goslar *et al.* 2006; Rašková Zelinková 2010). Therefore, this paper describes changes in reindeer antler volume as relevant to human activity and explores the implications of these changes as a common pattern in the

substantial Ahrensburgian corpus of Stellmoor. The aim is not to prioritise one functional hypothesis over another, but rather to establish whether the artefact can be defined as a tool and, if so, to determine if it represents the earliest example of heavy-duty activities involving osseous tools in the Stone Age.

### Characteristics of the ‘Lyngby axes’

Despite the time constraints of the two-day study period in 2009, analysis of the Stellmoor material revealed 18 pieces of worked reindeer antler amongst the available faunal remains at the Schleswig-Holstein State Museum’s storage facilities at Schloss Gottorf. These are all specimens of ‘Lyngby axes’ found in the Ahrensburg cultural layer. Their analysis involved documenting the artefacts using macrophotography and optical observations with manual binocular magnification glasses offering between 10-times and 20-times zoom. The terminology, morphometrics and taphonomy nomenclature are those used by David and Eriksen (2021).

### General aspects

With the exception of no. 66 and 69, all of the ‘Lyngby axes’ are mostly intact. These two numbers have been reworked in the past to extract blank products (David 2004, 22). The artefacts are otherwise of a basic, ‘reverse L-shape’ in morphology. The longest part represents the straightest of the perch, once detached from the palmate end in a transverse cut or break at the level of the posterior tine. On average, the artefacts are 43.0 cm long and 2.6 cm thick. This also corresponds to the thickness of the antler perch in its natural state, as evidenced by the faunal material of the site used for comparative reference. The size of the module has apparently not been a determining factor in their use, as both tiny and large calibres have been employed (Fig. 2).

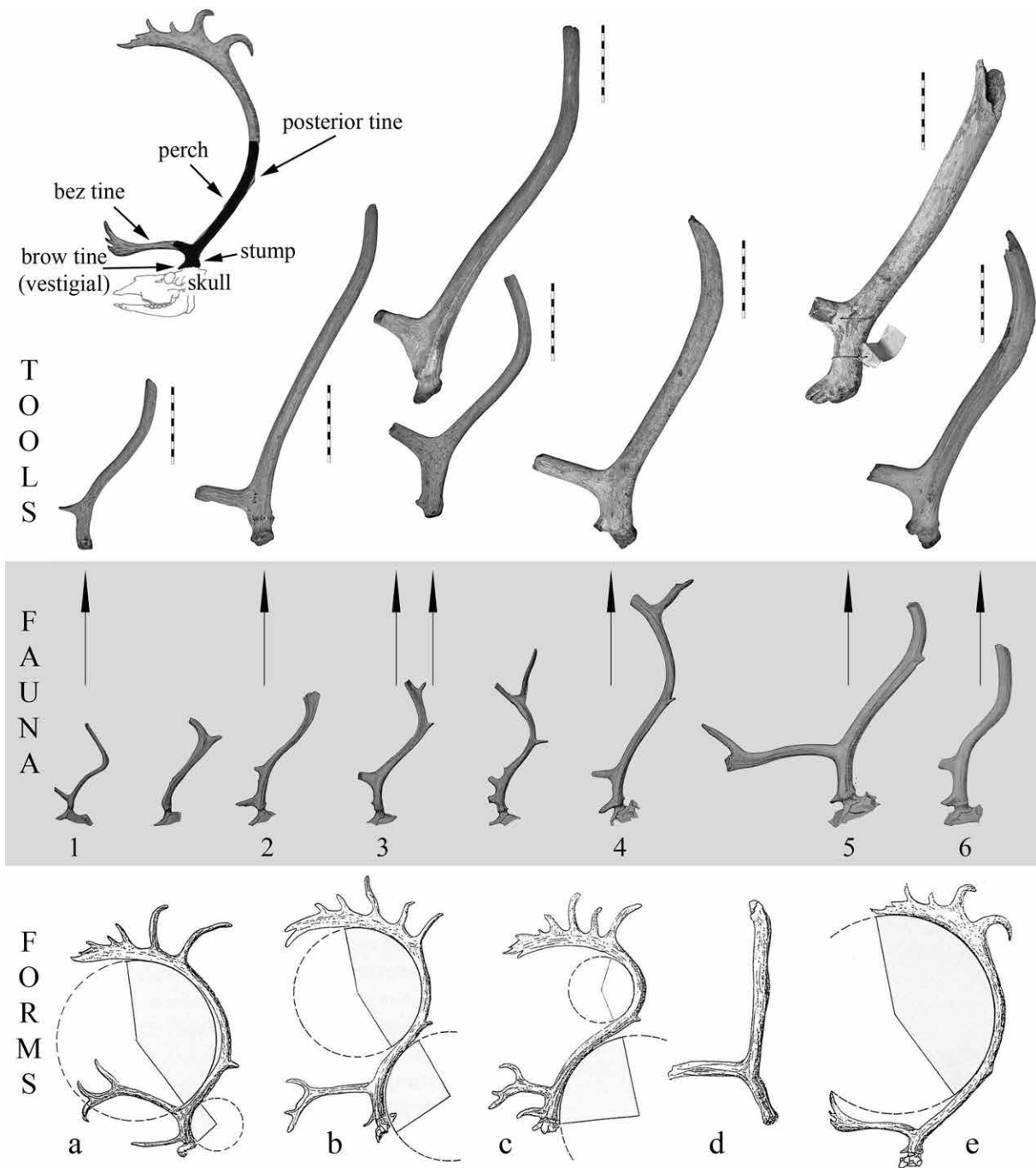


Figure 3: Schematic location of the 'Lyngby axe' (black) on the reindeer antler. Thin or large antler material (1 to 6) have been used by Ahrensburgian hunters, regardless of whether shed or unshed, as a complete specimen relevant to the Late Glacial records (after Rust 1943, 119), in either circular ('a' to 'c' and 'e') or in sword-like shapes ('d'). Scales: 10 cm.

On average, the brow or bez tine, which contains the most prominent active part, measures 10.6 cm in length. This tine shows damage patterns at its extremity and forms an angle with the perch ranging from 89° to 106°. Thus, the average angle of the active end is

close to 90°, which probably explains why only the basal tine is retained: the brow tine (see no. 60 and 62-2) or the bez tine if the brow tine is vestigial (see no. 57-1, 63-1 and 67-1). Whether the artefact resembles an adze or an axe depends on how the working edge is oriented:

perpendicular or parallel to the shaft (perch). However, this working edge cannot be accurately measured as it is often quite damaged, blunt or broken. The only exceptions are no. 66, where the (only real) bevel plane forms a 45° angle with the bezel tine, and the truncated ones, which range from 27° to 30° as discarded material (nos. 62-1, 63-1, 65, 68, 70-1 and 71).

The other protruding end of the 'Lyngby axe' corresponds to the stump, with an average maximum diameter around 3.4 cm, increasing to 3.7 cm if made of unshed antler. The latter case concerns nearly half of the sample for which the skull cap was reduced into a medallion (David and Eriksen 2021). Comparing the faunal remains with the reindeer antler used to make the tools would help to identify the origin of the pieces, which may have come for this half from the loose material perhaps of low-migrating reindeer herds locally. As reindeer herds crossed or maybe grazed nearby, the materials had to be gathered or, in any case, extracted on site before technical activities could be planned. A precise scenario regarding the economic organisation of the hunters from these shed and unshed antler pieces requires an in-depth comparative study of 'Lyngby axes' according to the age, sex and killing season of the hunted animals of the Ahrensburgian archaeological layer (see Fontana and Chauvière 2023).

### Anatomy-related morphological aspects

All 'Lyngby axes' are antler tools obtained from the reindeer species *Rangifer tarandus*. The right and left parts of the antler from adult animals were both used indiscriminately, but no pairing was found. Currently, the artefacts appear to reflect the diversity of the reindeer populations, as is generally seen in the Late Glacial fauna (Weinstock 2000). This is evident in their shape, size, and sex: a few items are indeed antler materials from females, as the adult morphology of the antler is quite smaller in size (Fig. 1, nos. 63-1, 68, 70-1 and 71). The tools' general appearance corresponds to the natural antler morphologies also found on the site, meaning they are either large or reduced in size, and comprise various calibres of natural forms. This suggests the use of a specific hunting practice, whereby a proportion (not a part) of the reindeer population was tracked (see Grønnow *et al.* 1983). For example, the 'Lyngby axe' no. 57-1, which was possibly produced from module no. 5, a faunal remain record of the site, resembles the 'b' Late Glacial model (Fig. 3). Given the position of the bezel tine and the circle it forms together with the perch, the different morphologies of the shed and unshed materials used to make the tools suggest that distinct reindeer populations were involved in the production of 'Lyngby axes'. Therefore, it is possible that the site acted as a natural trap for reindeer herds during their migrations, due to its steep topographical relief locally.

### Taphonomy-related surface aspects

The outer surface of the artefacts is currently orange- to grey-brown in colour, with a loss of organic matter and demineralisation of the hard tissues. The bone and broken edges have degraded uniformly in a porous material. In this respect, the 'Lyngby axes' are consistent with each other and the rest of the original faunal collection, regardless of whether the corpus represents one or multiple human occupations. With the exception of those restored with wax (Fig. 4, no. 60), the antler desquamated equally at the surface. Thus, only the deepest marks are reminiscent of the agent or factor that caused the change to the tools' outer appearance. Nevertheless, it has been possible to determine the purpose of the antler artefacts at the level of the assemblage, since identifiable anatomical areas exhibit similar patterns.

Although the broken or incised surfaces are visibly comparable to each other regardless of the artefact, some of them are much darker in colour. If the colour of a pattern changes at a certain depth around the entire antler ring in cross section, without any other modifications, it suggests that decayed or subfossil antler material was used (David and Eriksen 2021). Otherwise, the entire surface of the artefact exhibits the same range of colours and external aspects, regardless of whether the edges are damaged or worn. This suggests that all marks or scars on the bone are contemporary as an inherent part of the material's diagenesis. The change suggests that Ahrensburgian hunters also used older remains (Fig. 4, B, nos. 57-1, 62-2 and 65), perhaps as a substitute for antler material possibly found *in situ* in ancient deposits. Note that the site also provides an earlier chrono-cultural horizon, the Hamburgian, which is distinct stratigraphically and characterised by numerous antler pieces (Rust 1943). Therefore, it is conceivable that the initial buried material may have been more or less accessible during the Ahrensburgian occupation. Comparing the surface aspects of the antler remains from both cultural horizons would help to address this issue. It would also ensure that certain artefacts actually did originate from gathered shed antler rather than from pieces extracted from a previous anthropogenic deposit. Perhaps the poorly fused anatomical lines of the antler bases made them easy to grasp from the merging carcasses on the osseous floor (see the stump aspect of no. 60). Please note that the steep topography is predominantly north-facing, enabling the long-term preservation of anthropogenic deposits within the ice.

The modern alterations appear, in contrast, as clear white marks on the desquamated anatomy, suggesting that the material was damaged during recent relocation (Fig. 4, D, no. 62-1), not to mention the yellow paper that has been glued on a piece (Fig. 4, B, no. 56-1) and the handwritten labels in black ink (Fig. 4, E, no. 69).

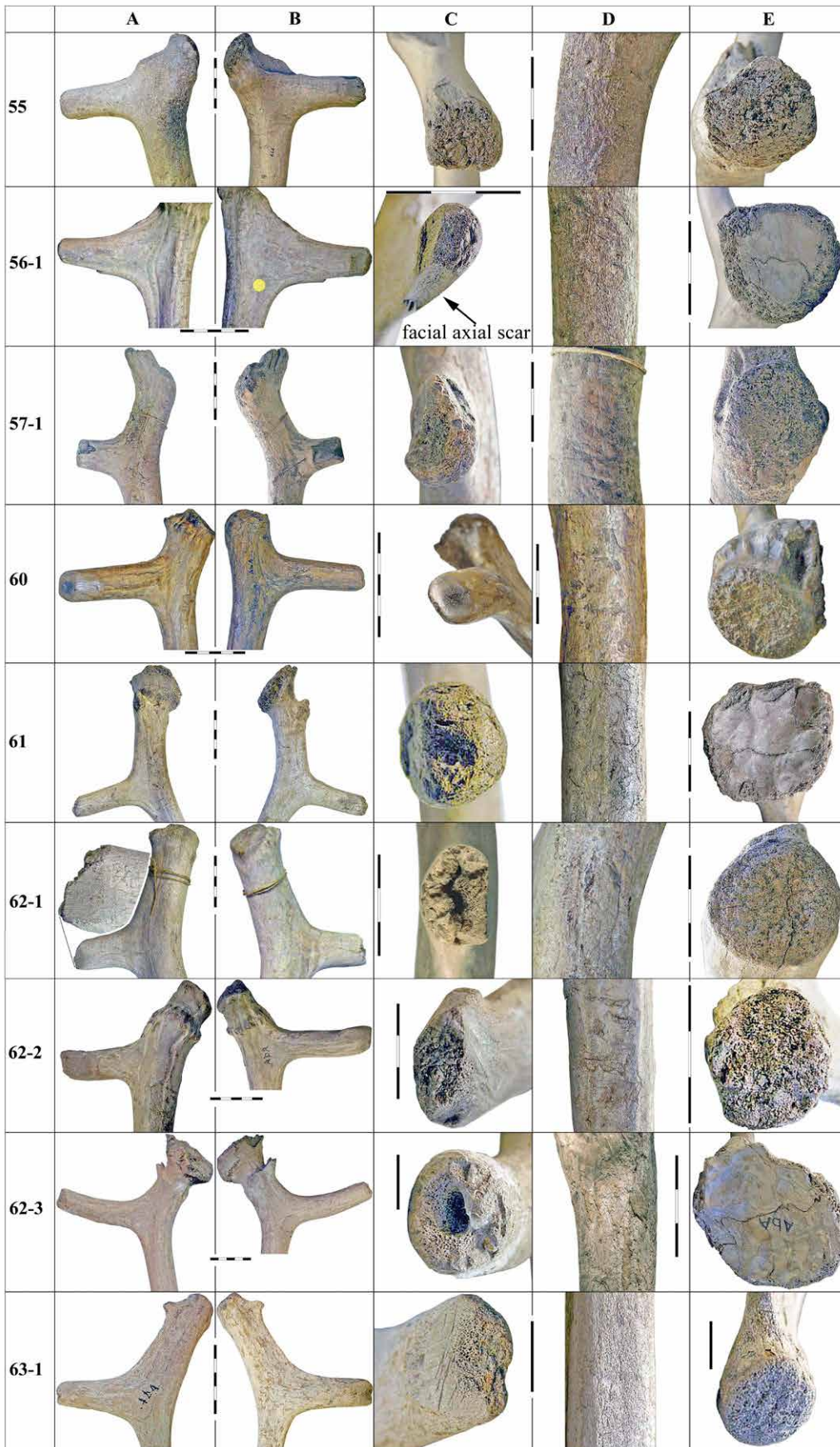


Figure 4: Details of the Lyngby type. A – Upper face; B – Lower face; C – Edge side; D – Back side; E – Upper shed or unshed end. Scale-subdivisions: 1 cm.

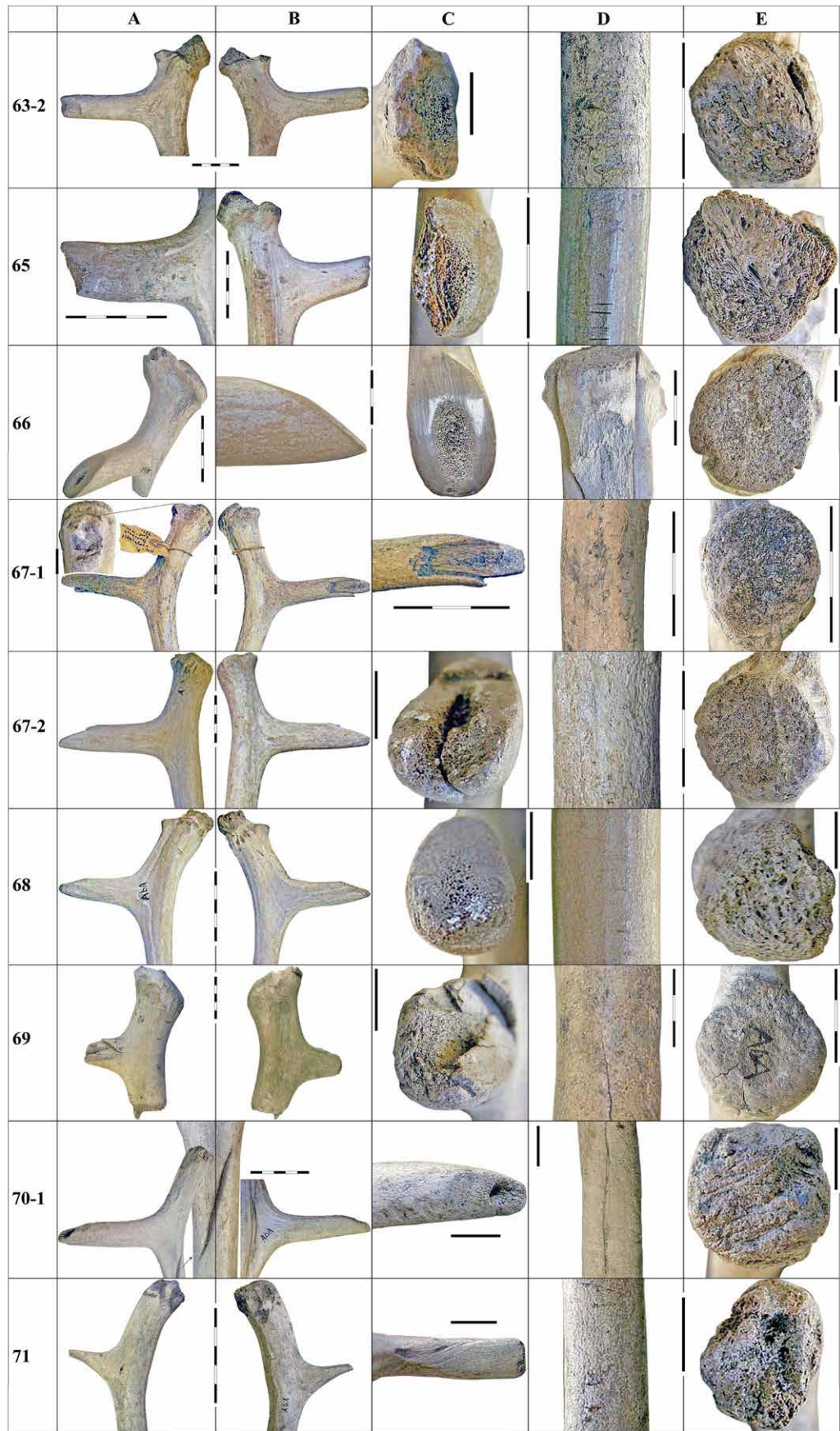


Figure 4 continued.

## Typology-related technical aspects

All artefacts display six patterns based on the consistent aspects of their surface (regularities):

1. a damaged appearance, or the removal of all or part of the vestigial or first tine;
2. a blunt appearance at the tip of the bez or remaining basal tine;
3. a series of isolated transverse impact marks along the concave front side of the antler;
4. a transverse cut or broken end of the shaft (perch);
5. a plane of randomly distributed transverse impact marks on the back side;
6. a medallion-shaped bone cap or a stump with crushed and/or hatched tissues.

The other aspects (irregularities) are revealed by the truncation of the bez tine (Fig. 4, C, nos. 60, 62-1, 62-2, 63-1, 63-2, 65, 66 and 71). Late Glacial antler shapes are known to have yielded a significant number of specimens with natural broken basal tine (Bouchud 1966). Although it is difficult to distinguish between natural breaks resulting from animal activity and breakage due to use, the presence of overlapping facial-axial scars on similarly blunted edges suggests that all specimens have reached the final stage of exhaustion. Sometimes these scars have been regularised (Fig. 4, C, no. 65), but they usually continue to transform into a blunt appearance until the truncation becomes too altered (Fig. 4, C, nos. 55 to 57-1). During use, facial-axial scars have accidentally damaged the prominent active end, whether it initially corresponded to a natural broken or sharpened bez tine (Fig. 4, C, nos. 63-2, 67-2, 68 and 69). The scars either damaged its side (Fig. 4, C, no. 55), its face (Fig. 4, C, no. 61) or both (Fig. 4, C, no. 56-1), and even in an oblique way (Fig. 4, C, nos. 57-1 and 69). The scars developed as single removals at a right angle, extending to the point where the bone broke upon impact (Fig. 4, B, no. 55). This suggests that the lithic product came into contact with the cortex, and that the antler tool could be handled in any way once it had been reduced to a reverse 'L' shape, with the prominent tine applied perpendicular to the lithic edge.

As scars caused by use often occur alongside regular patterns that indicate the degree of wear to the edges, it is assumed that all artefacts present are of the same tool type. Given that various antler morphologies have been used to make antler tools, it is not surprising that the artefacts exhibit significant variability within this category. The prominent edge and the back side, and to a certain extent the medallion, were all active parts that could be used to varying degrees of intensity, depending on how the antler was hand held during use.

## Functionality-related volumetric change

The intention in transforming the anatomical volume was not so much to create a bevelled end as to regularise the shape of the antler tine at its extremity. The active part was implemented with the primary aspect of the antler tine in mind. This is either a broken beak tine that was used as it was (Fig. 4, C, no. 67-1), or a truncation that occurred while the antler was being used as a tool, as evidenced by the oblique plane in zigzag shape of the broken end. Alternatively, it could have been deliberately modified for use. In this case, the bez tine was thinned by scraping along its length (Fig. 4, A, no. 62-1, C, nos. 62-2 and 63-1 except the overlapping incisions). There is no difference in the surface marks on pieces with perpendicular or parallel working edges (Figure 4, C, nos. 62-1, 62-2 compared with 66 and 71). To a certain extent, the medallion has also taken on a blunt shape along its edges (Fig. 4, E, nos. 55 and 63-2), which was not caused by it becoming round due to past gnawing by dogs that may have accompanied the hunters (Fig. 4, E, nos. 61 and 62-3). The intention was not to shape the skull cap in the form of a particular medallion (no. 56-1), but rather to minimise the remaining protruding edge of the skull in order to maximise the percussion tool's effectiveness (Figure 4, E, nos. 63-2 and 65).

The edges of the tools became blunted from hammering the burr or pedicle part and the prominent extremity. The best-preserved pieces also show evidence of percussion-driven splitting, with a chipped appearance to the smooth cutting edge (Fig. 4, C, no. 66), and the overlapping straight zigzag plane resulting from transverse flexion caused by lateral compression due to the lever effect (Fig. 4, C, nos. 62-1 and 62-3). The association of patterns shared by all artefacts, particularly the blunt prominent edge and random transverse impact marks, is displayed in opposite but parallel planes. This suggests that the front and back edges of the tool were used in the same axial motion, regardless of the initial form or dimensions of the active part of the tine (Fig. 5, top). Thus, the antler shaft probably acted as a handle when the tool was used as a wedge and/or a hammer for split-based percussion tasks. This contradicts the aforementioned assumption that it was used as a mace for slaughter. Anyway, antler is a relatively flexible material if not propelled, making it unsuitable for striking blows to animal heads (David *et al.* 2016).

The antler surface was struck with force and eventually worked using large, sharp lithic artefacts. This resulted in crushed tissue (Fig. 4, C, nos. 55, 61, 69) displaying together with hatched (Fig. 4, E, no. 70-1) or isolated impact marks (Fig. 4, C, no. 69) of varying intensity and random distribution on the front (stump/skull) and/or back side of the tool (Fig. 4, D, nos. 55 to 62-2, 63-2 and 68). Given the need for experimentation at this stage of the analysis, it is difficult to determine the exact functioning process. During the use, damage to the antler caused by wear and

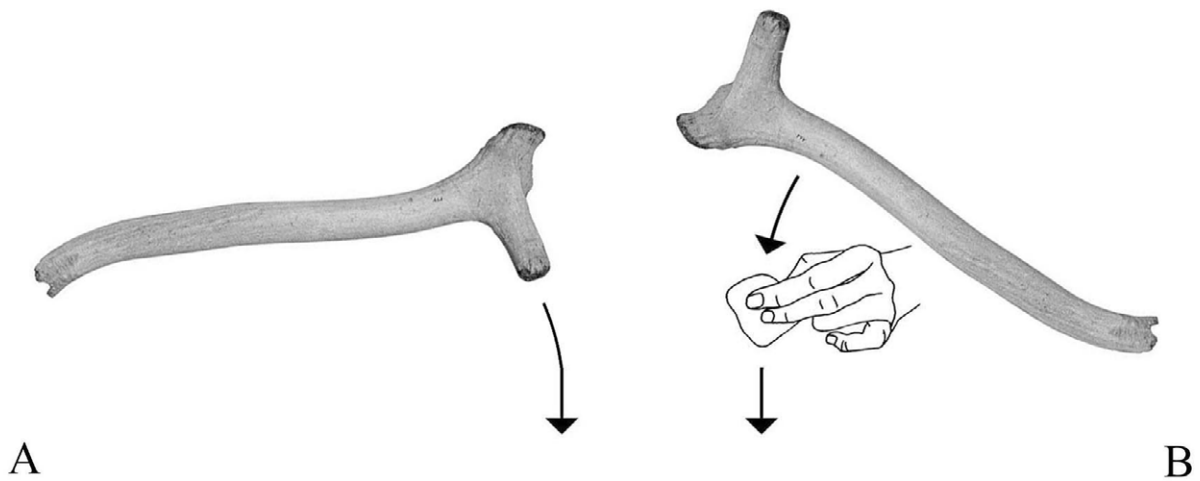


Figure 5: The various aspects of the most prominent active end of the Lyngby type (top pictures, nos. 69, 63-1 and 66) can theoretically be explained by the different ways in which the antler tool was used for a single split-based task (bottom). Acting as a wedge, the tool was inserted by percussion, making use of the natural shaft's prominent edge (A). When acting as a hammer, either the back or the upper medallion would have made contact with the lithic product, possibly to split wooden material by indirect percussion (B).

breakage seems to have co-occurred, but perhaps not simultaneously (David 2024). It is conceivable that the final change in the prominent active part could be seen as the reindeer antler being turned to the striking position that was previously conducted with its back. Therefore, the use of stone products in conjunction with splitting appears to be complementary (Fig. 5, bottom). In theory, the interest in using an antler shaped like a reversed L in percussive actions lies in the possibility of using one side (the beak) after the other (the back) for that the wooden fibres would first detach and then split by inserting the wedge.

## Results

The hunters used a variety of antler basal morphologies as improvised tools. These were partly sourced from fresh reindeer carcasses at the killing site. Others were sourced from antler pieces that were either brought to the

activity area or perhaps found in older material deposits at the killing site. These were all discovered as remains of expedient tools left *in situ*. The specimens discussed in the paper show modifications that have transformed the initial volume of the antler matrix in similar ways. The anatomical element was reduced into a single basic 'reverse L-shape' for specific crafting activities involving split-based tasks, for which the use of lithic products as intermediate pieces was required. Whether natural or truncated in an oblique plane, the break in the bez tine was acting as a wedge. The repeated percussion during the splitting process resulted in the blunt edge of the antler's prominent edge and antler basal part, as well as in the hatched aspect of the back side and upper medallion coming into contact with the lithic products. The bez tine's edge was sharpened either perpendicular or parallel to the main shaft. Depending on this, the antler tool was applied lengthwise or crosswise to

the material being worked. The Lyngby type would concern a technology dedicated to producing straight organic shapes, such as wooden shafts and foreshafts, similar to those unearthed during excavations at the site. At most, one of these arrow shafts is dated to the end of the Younger Dryas chronozone, as is the Ahrensburgian occupation of the Stellmoor site (Meadows *et al.* 2018). In this way, the antler tools were not used as axes or adzes, but rather as hammer wedges for wood-working. Several tools would have been used in a repeated procedure involving ‘two-times action’ per piece: first, the lithic product (or another Lyngby tool) struck the antler wedge (using its back for the lithic product and its stump/medallion for the Lyngby tool); then the wedge was turned so that its beak-shaped edge could be inserted to split the material being worked by (direct or indirect) percussion. Experimental tests with bone tools show that similar ‘reverse L-shapes’ can efficiently split two-year-old pine trunks lengthwise (David *et al.* 2006). By contrast, the Lyngby type does not display the same level of smoothness associated with side friction (except no. 66), which is often observed in lengthwise-split wood-based materials. But this may be caused by the aforementioned taphonomy of the artefacts.

## Discussion

It appears that Lyngby axes were used as a wedge hammer for splitting tasks, requiring percussion. Therefore, it is reasonable to draw a parallel with the earliest heavy-duty osseous tools used in prehistory (David 2025). The Ahrensburgian specimens vary considerably due to the variety of reindeer antler calibres used to craft them, which have different origins in terms of provenance and species. In contrast, Postglacial heavy-duty tools tend to exhibit consistent sizes, regardless of their location on the red deer antler. The difference may be due to the logistical mobility of the last Late Glacial groups (Naudinot and Jacquier 2014). This would have prevented them from investing in tools that could easily be damaged when used with lithics. At that time, the site of Stellmoor may have served as both a killing area and a possible refuge ecozone, where eventually diverse populations of hunted reindeer were locally transformed into defined hunting equipment made from available organic materials, in particular antler and wood. This suggests commendable foresight in relation to material constraints and established practices, encouraging widespread group

participation in production and subsistence activities while minimising the effort required for tool production. Overall, Lyngby axes exemplify the Ahrensburgian logistic approach of carrying out a variety of technical tasks in an integrated way, that include planning within a plotted location rich in organic sources, which is traversed or seasonally occupied by reindeer herds.

The potential for substantial crafting of heavy-duty tools was also limited by the cyclical nature of antler growth of the migratory species, coupled with drastic changes to the habitat of large game animals at the end of the Ice Age (Drucker *et al.* 2022). Trees living in subfreezing environments for extended periods are prone to brittle fracture (Ai *et al.* 2024). The excellent preservation of organic materials over centuries would have been aided by a permanent ice cover over the anthropogenic deposits in the steep topography. This explains why the shed antlers display smooth, facial-axial scars resulting from its use, as if the antler pieces were still fresh. Under these conditions, producing arrow shafts and foreshafts would have required adapting percussion-based splitting techniques, using pruned-off antler shafts rather than wooden clubs for percussive actions. If the task was heavy-duty, there was therefore no need for the antler tool to be designed specifically for that purpose. Heavy-duty osseous tools properly emerged later, with the introduction of hafting systems crafted precisely to hold various types of wedges, with antler forms adapted to fit wooden shafts. Aside from hunting equipment, the concept of creating tools for specific tasks rather than planning to use the readily available osseous matrix on the spot emerged in Northern Europe during the Postglacial, as part of a more residential approach to mobility during the Maglemosian.

## Acknowledgements

I would like to thank Berit Valentin Eriksen for giving me the opportunity to work on the ‘Lyngby axes’ under ideal conditions, and for arranging my accommodation at the Schloss Gottorf Museum. Berit’s occasional involvement in the photographic documentation of the project was valuable in helping to streamline its execution. It has been a pleasure to share ideas. It is therefore my pleasure to offer her this paper as a formal expression of my gratitude. I would also like to thank the three reviewers of the paper for their positive and constructive feedback.

## References

- Ai, M., Gao, S., Song, X. and Feng, M. 2024. Evaluation of the effects of temperature and cooling rate on the freezing of water in wood using dielectric spectroscopy. *Wood Science and Technology* 58, 589–608.
- Baales, M. 1996. *Umwelt und Jagdökonomie der Ahrensburger Rentierjäger im Mittelgebirge*. Mainz, Römisch-Germanisches Zentralmuseum, Forschungsinstitut für Vor- und Frühgeschichte.
- Baales, M. 1999. Economy and seasonality in the Ahrensburgian. In: Kozłowski, S.k. and Gurba, J. (eds.), *Tanged Points Cultures in Europe: Read at the International Archaeological Symposium: Lublin, September, 13-16, 1993*. Lublin, Wydawnictwo Uniwersytetu Marii Curie-Skłodowskiej, 64–75.
- Baales, M., Jöris, O., Street, M., Bittmann, F., Weninger, B. and Wiethold, J. 2002. Impact of the Late Glacial Eruption of the Laacher See Volcano, Central Rhineland, Germany. *Quaternary Research* 58, 273–288.
- Ballin, T. B. and Saville, A. 2003. An Ahrensburgian-type tanged point from Shieldaig, Wester Ross, Scotland, and its implications. *Oxford Journal of Archaeology* 22(2), 115–131.
- Bokelmann, K. 1991. Some new thoughts on old data on humans and reindeer in the Ahrensburgian Tunnel Valley in Schleswig-Holstein, Germany, In: Barton, N., Roberts, A. J. and Roe, D.A. (eds.), *The Late Glacial in north-west Europe: Human adaptation and environmental change at the end of the Pleistocene*. London, CBA Research Report Council for British Archaeology, 72–81.
- Bouchud, J. 1966. *Essai sur le renne et la climatologie du Paléolithique moyen et supérieur*. Périgueux, Imprimerie Magne.
- Bratlund, B. 1996. Hunting strategies in the Late Glacial of northern Europe: A survey of the faunal evidence. *Journal of World Prehistory* 10, 1–48.
- Childe, V. G. 1942. The antiquity and function of antler axes and adzes. *Antiquity* 16(63), 258–264.
- Childe, V. G. 1949. *L'aube de la civilisation européenne*. Paris, Payot.
- Clark, J. G. D. 1936. *The Mesolithic settlement of northern Europe. A study of the food-gathering peoples of northern Europe during the early post-Glacial period*. Cambridge, Cambridge University Press.
- Clausen, I. 2004. The reindeer antler axe of the Alleröd period from Klappholz LA 63, Kreis Schleswig-Flensburg/Germany. Is it a relic of the Federmesser, Bromme or Ahrensburg culture? In: Terberger, T. and Eriksen, B. V. (eds), *Hunters in a changing world - Environment and Archaeology of the Pleistocene - Holocene Transition (ca. 11000 – 9000 B.C.) in Northern Central Europe*. Internationale Archäologie Arbeitsgemeinschaft Kongress 5. Rahden/Westf., Verlag Marie Leidorf, 141–164.
- Cook, J. and Jacobi, R. 1994. A Reindeer antler or 'Lynghby' axe from Northamptonshire and its context in the British Late Glacial. *Proceedings of the Prehistoric Society* 60, 75–84.
- David, É. 2004. *Technologie osseuse des derniers chasseurs préhistoriques en Europe du Nord (X<sup>e</sup>-VIII<sup>e</sup> millénaires avant J.-C.)*. Le Maglemosien et les technocomplexes du Mésolithique. Dissertation. Paris, Monique Mergoil. <https://www.yumpu.com/fr/document/view/17411530/technologie-osseuse-des-derniers-chasseurs-prehistoriques-en-53> [accessed: 11-11-2025]
- David, É. 2024. On the polysemic nature of traces and co-occurring patterns in anthropized material – contribution of a “retoucher” with a flaked bone aspect from Roc-en-Pail (France). *Sprawozdania Archeologiczne* 76(1), 139–158.
- David, É. 2025. Bone tool technology. In: Nilsson Stutz, L., Peyroteo Stjerna, R. and Törv, M. (eds.), *The Oxford Handbook of Mesolithic Europe*. Oxford, University Press, 783–797.
- David, É., Casseyas, C., Van Der Slot, P. and Léotard J.-M. 2016. A symbolic use of antler in growth, to face neolithization. In: Selena Vitezović (ed.), *Close to the bone: current studies in bone technologies*. Belgrade, Institute of Archaeology, 112–120.
- David, É. and Eriksen, B. V. 2021. Antler tool's biography shortens time frame of Lynghby-Axes to the last stage of the Late Glacial. In: Gaudzinski-Windheuser, S. and Jöris, O. (eds.), *The Beef behind all Possible Pasts. The Tandem-Festschrift in Honour of Elaine Turner and Martin Street*. Monographien des Römisch-Germanischen Zentralmuseums 157. Mainz, Verlag des Römisch-Germanischen Zentralmuseums, 639–656.
- David, É. Seppä, J., Pelegrin, J., Hansen, L. and Gustavson, L. 2006. *The bone tools of 10.000 years ago. Maglemosian “Bone Adze”: The 2005 experiments (Denmark): Addendum*. A Lejre experimental Centre project (n°15/6). DVD. <https://shs.hal.science/halshs-03927835> [accessed 11-11-2025]
- Drucker, D. G., Bridault, A. and Boethius, A. 2022. Post-glacial human subsistence and settlement patterns: insights from bones. *Archaeological and Anthropological Sciences* 14(7), e10.1007.
- Fischer, A. and Tauber, H. 1986. New 14C-datings of the late Palaeolithic cultures from northwestern Europe. *Journal of Danish Archaeology* 5, 7–13.
- Fontana, L. and Chauvière, F.-X. 2023. The nomadism cycle of recent palaeolithic societies from reindeer antler economy. In: David, É. and Hrnčiarik, E. (eds.), *Contact, circulation, exchange. Proceedings of the*

- Modified Bone & Shell UISPP Commission Conference (2-3 March 2017, University of Trnava)*. Industrie de l'os préhistorique XV. Oxford, Archaeopress, 33–51.
- Fuglestedt, I. 2007. The Ahrensburgian Galta 3 site in SW Norway. *Acta Archaeologica* 78(2), 87–110.
- Girininkas, A., Rimkus, T., Slah, G., Daugnora, L., Stančikaitė, M. and Zabiela, G. 2016. Lyngby type artefacts of Lithuania in the context of the Stone Age in Europe: Multidisciplinary study. *Arheologija un Etnogrāfija* 29, 13–30.
- Goslar, T., Kabaciński, J., Makowiecki, D., Prinke, D. and Winiarska-Kabacinska, M. 2006. Datowanie radiowęglowe zabytków z Kolekcji Epoki Kamienia Muzeum Archeologicznego w Poznaniu. *Fontes Archeologici posnanienses* 42, 5–25.
- Grønnow, B., Meldgaard, M. and Nielsen, J.B. 1983. *Aasivissuit – the great summer camp. Archaeological, ethnographical and zoo-archaeological studies of a caribou-hunting site in west Greenland*. Meddelelser om Grønland: Man and Society 5. Copenhagen, Kommissionen for videnskabelige undersøgelser i Grønland.
- Jessen, A. and Nordmann V. 1915. *Ferskvandslagene ved Nørre Lyngby*. Danmarks Geologiske Undersøgelse II(29). Kjøbenhavn, C. A. Reitzel.
- Klima, B. 1987. Paläolithische Geweihindustrie aus Pavlov. *Památky Archeologické* 76, 289–370.
- Larsson, L. 1996. The colonization of south Sweden during deglaciation. In: Larsson, L. (ed.), *The earliest settlement of Scandinavia and its relationship with neighbouring areas*. Acta archaeologica Lundensia. Series in 8° 24. Stockholm, Almqvist & Wiksell International, 141–155.
- Louwe Kooijmans, L. 1974. *The Rhine Meuse delta, four studies on its prehistoric occupation and Holocene geology*. Analecta Prehistorica Leidensia 7. Leiden, E.J. Brill.
- Mathiassen, T. 1948. *Danske Oldsager I*. København, Gyldendal.
- Meadows, J., Heron, C., Hüls, M., Philippsen, B. and Weber, M.-J. 2018. Dating the lost arrow shafts from Stellmoor (Schleswig-Holstein, Germany). *Quartär* 65, 105–114.
- Mortensen, M. F., Birks, H. H., Christensen, C., Holm, J., Noe-Nygaard, N., Odgaard, B. V., Olsen, J. and Rasmussen, K. L. 2011. Lateglacial vegetation development in Denmark - New evidence based on macrofossils and pollen from Slotseng, a small-scale site in southern Jutland. *Quaternary Science Reviews* 30, 2534–2550.
- Müller, S. 1897. Nye Stenalders Former. *Aarbøger for Nordisk Oldkyndighed og Historie* 1896, 301–419.
- Müller, S. 1901. Nouveaux types d'objets de l'Âge de la pierre. *Mémoires de la Société Royale des Antiquaires du Nord nouvelle série*/1896–1901, 85–165.
- Mithen, S., Wicks, K., Pirie, A., Riede, F., Lane, C., Banerjea, R., Cullen, V., Gittins, M. and Pankhurst, N. 2015. A Lateglacial archaeological site in the far north-west of Europe at Rubha Port an t-Seilich, isle of Islay, western Scotland: Ahrensburgian-style artefacts, absolute dating and geoarchaeology. *Journal of Quaternary Science* 30(5), 396–416.
- Morosan, N. N. 1934. La station paléolithique de la grotte de Stâncu Ripiceni. *Dacia* V–VI/1934–1935, 1–22.
- Naudinot, N. and Jacquier, J. 2014. Socio-economic organization of Final Palaeolithic societies: new perspectives from an aggregation site in western France. *Journal of Anthropological Archaeology* 35, 177–189.
- Petersen, P. V. and Johansen, L. 1991. Sølbjerg I—An Ahrensburgian Site on a Reindeer Migration Route through Eastern Denmark. *Journal of Danish Archaeology* 10(1), 20–37.
- Philippsen, B., Ivanovaitė, L., Makhotka, K., Sauer, F., Riede, F. and Olsen, J. 2019. Eight new Late Pleistocene/Early Holocene AMS dates from the southeastern Baltic. *Radiocarbon* 61(2), 615–627.
- Price, T. D., Meiggs, D., Weber, M.-J. and Pike-Tay, A. 2017. The migration of Late Pleistocene reindeer: Isotopic evidence from northern Europe. *Archaeological and Anthropological Sciences* 9, 371–394.
- Rašková Zelinková, M. 2010. Reconstructing the “chaîne opératoire” of skin processing in Pavlovian bone artifacts from Dolní Věstonice I, Czech Republic. In: Legrand-Pineau, A., Sidéra, I., Buc, N., David, É. and Scheinsohn, V. (eds.), *Ancient and modern bone. Artefacts from America to Russia*. BAR International Series 2136. Oxford, BAR Publishing, 191–200.
- Riede, F. and Edinborough, K. 2012. Bayesian radiocarbon models for the cultural transition during the Allerød in southern Scandinavia. *Journal of Archaeological Science* 39, 744–756.
- Rust, A. 1943. *Die Alt- und Mittelsteinzeitlichen Funde von Stellmoor*. Neumünster, Wachholtz.
- Schwantes, G. 1952. Wann endete das Paläolithikum? *Zeitschrift für Morphologie und Anthropologie* 44(1–2), 237–244.
- Stensager, A. O. 2004. Nyt lys på gammelt fund. *Vendsyssel Nu og Da* 2004, 38–43.
- Weber, M.-J., Grimm, S. B. and Baales, M. 2011. Between warm and cold: impact of the Younger Dryas on human behaviour in Central Europe. *Quaternary International* 242(2), 277–301.
- Weinstock, J. 2000. *Late Pleistocene reindeer populations in Middle and Western Europe. An osteometrical study of Rangifer tarandus*. BioArchaeologica 3, Tübingen, Mo Vince Verlag.
- Zagorska, I., Eriksen, B. V., Meadows, J. and Zelčs, V. 2019. Late Palaeolithic settlement of Latvia confirmed by

radiocarbon dating of bone and antler artefacts. In: Eriksen, B. V., Rensink, E. and Harris, S. (eds.), *The Final Palaeolithic of Northern Eurasia. Proceedings of the Amersfoort, Schleswig and Burgos UISPP Commission Meetings*. Schriften des Museums für Archäologie Schloss Gottorf 13. Kiel, Ludwig, 343–362.

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# Active and passive seismic measurements for mapping and investigating kettle holes

An example from Tyrsted (Jutland, Denmark)

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and Wolfgang Rabbel

## Abstract

Reconstructing landscapes in formerly glaciated regions is essential for understanding Late Palaeolithic hunter-gatherer mobility and environmental adaptation in Southern Scandinavia. At Tyrsted (Denmark), a multidisciplinary geoarchaeological investigation was undertaken between 2017–2018 to characterise a buried kettle hole associated with nearby finds from the Bromme technocomplex. Ground Penetrating Radar (GPR) and Electromagnetic Induction (EMI) provided only a partial view of the kettle hole's morphology, limited to shallow depths ( $\leq 2$  m), while seismic measurements with shear waves (SH-waves) extended the depth imaging down to 5 m but lacked full detail of internal heterogeneity. Therefore, we tested Rayleigh wave dispersion analysis combined with Full Waveform Inversion (FWI) applied to SH-wave records to more accurately detect small glacial depressions and better resolve their depth and internal structure in relation to Late Palaeolithic occupation, while also comparing these new results with previous geophysical data. The results reveal a bowl-shaped depression down to 5 m deep, filled with low-velocity gyttja and peat ( $< 100$  m/s), consistent with a melt-out kettle hole formed by decaying dead ice. Compared with previous geophysical data, seismic methods achieved greater depth resolution and identified internal velocity contrasts (30–200 m/s), indicating fluctuating conditions during the Allerød–Younger Dryas transition. These findings highlight the complementary role of passive seismics and advanced inversion techniques in extending the depth of investigation for glacial bodies and improving interpretation of the post-glacial environmental dynamics. Geoarchaeologically, the refined morphology of the kettle hole suggests that the pond at Tyrsted extended further than previously reconstructed.

**Keywords:** *Bromme, kettle hole, Rayleigh wave dispersion, Full Wave Inversion, Geoarchaeology*

## Introduction

Understanding the spatial and environmental contexts of Late Palaeolithic human occupation remains a key challenge in prehistoric archaeology, particularly in formerly glaciated landscapes where sedimentation and post-glacial processes often obscure evidence of past activity. Kettle holes, palaeo-lakes, and other glacially induced depressions frequently serve as focal points for archaeological research due to their potential to preserve organic-rich sediments and traces of prehistoric human-environmental interaction (Clausen 2010; Lanoë *et al.* 2022; Wild *et al.* 2020). These features, though often silted and integrated into modern farmland, provide valuable windows into past human-environmental interactions.

Recent geoenvironmental research has increasingly emphasized the importance of reconstructing Late Pleistocene landscapes to better understand patterns of human settlement and mobility among hunter-gatherer groups. Two case studies - the kettle hole at Tyrsted in Denmark (Corradini *et al.* 2020), which forms the primary focus of this chapter, and Lieth Moor in Northern Germany (Detjens *et al.* 2024), a comparable Late Palaeolithic site that will be discussed later in the Discussion section - illustrate a shared methodological and theoretical approach to this challenge. Both studies combine non-invasive geophysical techniques (including Ground Penetrating Radar (GPR) and Electromagnetic Induction (EMI)) with sedimentological and archaeological data to identify palaeo-landscape features, particularly small waterbodies such as palaeo-ponds and kettle holes. By reconstructing the morphology, extent, and stratigraphy of these former wetlands, the studies aimed to locate and interpret Late Palaeolithic occupation layers, refine chronologies, and improve our understanding of the interaction between humans and rapidly changing postglacial environments. At Tyrsted, an extensive archaeological survey was carried out in 2016 ahead of planned construction work, leading to the discovery of a small kettle hole (at the so-called site 10; Fig. 1) with exceptional preservation of organic material (Eriksen *et al.* 2017). A rescue excavation in early 2017, conducted under harsh winter conditions, revealed numerous Late Palaeolithic artefacts attributed to the Bromme technocomplex (c. 13000–12500 cal BP), including flint tools, a tanged point, and worked reindeer antlers. The gyttja and peat layers also contained well-preserved fish remains and botanical macrofossils such as birch and poplar branches, twigs, and even beaver-gnawed wood. Although some finds were relocated during the excavation and thus not recorded *in situ*, the kettle hole serves as a rare natural archive of Late Glacial and Early Holocene sediments, offering valuable insights into post-glacial environments. It provides a unique opportunity to reconstruct the ecological and cultural landscape of early human occupation in Southern Scandinavia. Tyrsted thus provides an important case study for understanding how Late Glacial hunter-gatherers interacted with the landscape.

A further integrated geophysical survey was conducted to investigate the internal structure and spatial extent of another suspected kettle hole (at the so-called site 8; Fig. 1). GPR provided high-resolution imaging of the near-surface down to ~2 m depth, revealing internal layering consistent with stratigraphic units such as decomposed peat, gyttja, and clay-rich deposits. A bowl-shaped reflector around 1.5 m depth corresponds to the transition between grey-clay/sandy deposits and grey-green gyttja, which marks the transition between local Allerød - Younger Dryas lithozones and thus the (tentatively dated) timeframe of the Bromme technocomplex. Electromagnetic Induction data showed a low-resistivity anomaly aligned with the kettle hole location, extending laterally with increasing depth, likely due to high water content and fine-grained sediment. While EMI offered useful horizontal mapping capabilities, it lacked vertical resolution and depth penetration. SH-wave seismic measurements delivered the most complete structural information, identifying a distinct low-velocity zone (<100 m/s) down to ~5 m depth, clearly outlining the steep-sided shape of the kettle hole. Seismic reflectors allowed correlation with stratigraphic transitions, including the critical Allerød-Younger Dryas interface.

Based on these results, we decided to further investigate the site using passive seismic methods and advanced processing to more accurately map the full extent and morphology of the kettle hole. The main objectives of this study are: (1) to evaluate the potential of ambient seismic noise analysis for identifying small buried glacial depressions; (2) to compare the results with previous GPR, EMI, and active seismic data; and (3) to refine the morphological model of the Tyrsted kettle hole in relation to Late Palaeolithic occupation. After an overview of previous work in Tyrsted, we present the new results, which have been derived from the analysis of ambient seismic noise with respect to the dispersion of Rayleigh waves, and from Full Waveform Inversion (FWI) analyses of actively performed shear wave measurements. These methods provide a more detailed image of the extension and morphology of the investigated kettle hole, providing the baseline for future studies of similar features and their role in reconstructing prehistoric human occupation patterns.

## Methods

### Ground penetration radar (GPR) and Electromagnetic induction (EMI) at Tyrsted

To investigate the kettle hole extent, radar measurements were conducted at site 8 (Fig. 1) using a GSSI GPR unit with a 200 MHz antenna (for more detailed information about processing see Corradini *et al.* 2020). The method relies on the emission of electromagnetic pulses, with reflections caused by dielectric permittivity contrasts. Depth of penetration and resolution are influenced by soil conductivity, antenna

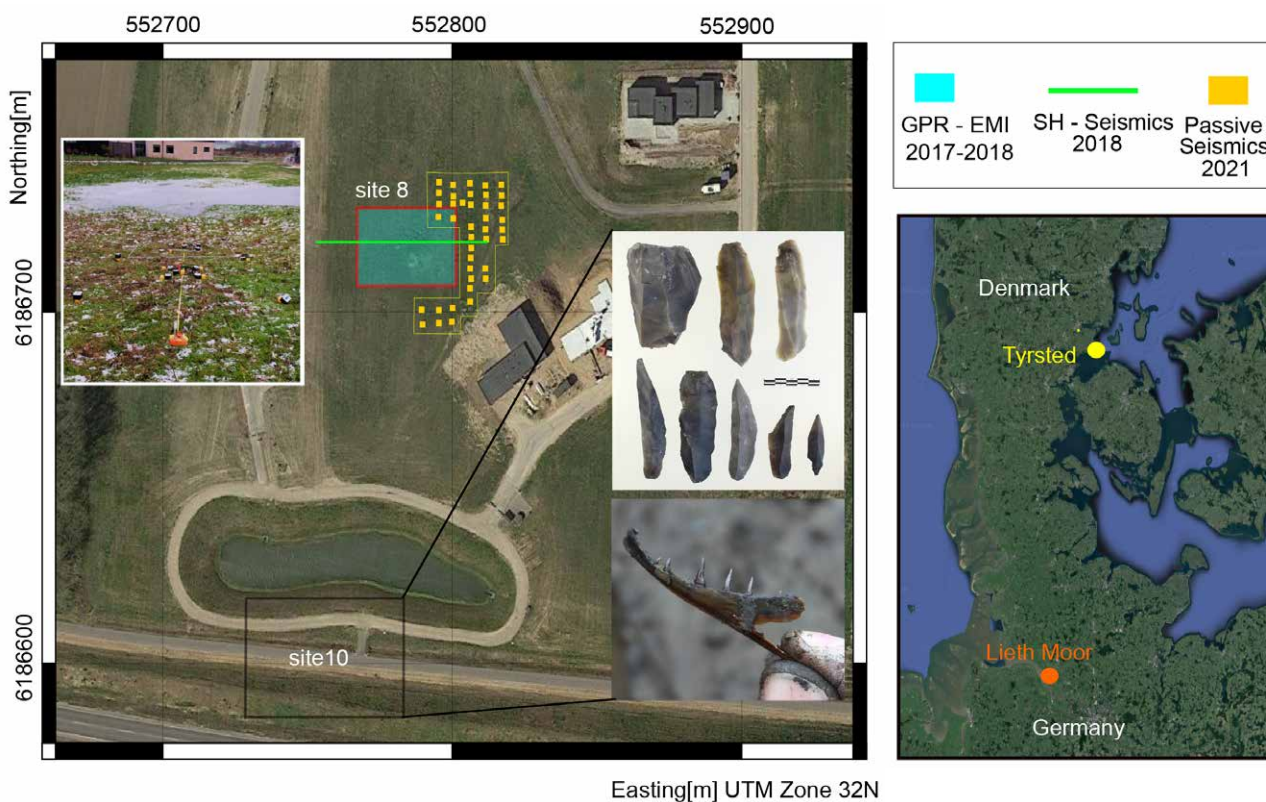


Figure 1: Location of the sites of interest in Tyrsted and geophysical measurements carried out at site 8 in 2017–2018 and the passive seismics measurements performed in 2021. Excavated kettle hole and archaeological finds at site 10; Top: Late Palaeolithic flint artefacts found during the excavation. Photo © Horsens Museum; Bottom: One c. 14000 year old jaw of pike (*Esox lucius* sp.). Photo: © Morten Fischer Mortensen.

frequency, and wave attenuation due to energy absorption. High water content and clay-rich sediments reduce signal penetration and resolution. Lower antenna frequencies allow deeper investigation but at the cost of resolution, which is typically a quarter of the wavelength.

Electromagnetic induction measurements at site 8 were carried out using a CMD Mini-Explorer (GF Instruments) in both vertical coplanar and horizontal coplanar configurations (Fig. 1). Data were collected along east–west oriented profiles spaced 1 m apart, with a sampling frequency of 10 Hz (for more detailed information about processing see Corradini *et al.* 2020).

### Dispersion analysis of Rayleigh waves from ambient seismic noise

Seismic depth sounding using ambient noise recordings is a passive geophysical method that analyses natural or anthropogenic ground vibrations to investigate subsurface structures. By recording ambient seismic noise with arrays of geophones and analysing the dispersion of surface waves, particularly Rayleigh waves, this technique allows for the estimation of shear-wave velocity profiles with depth, without the need for active seismic sources (*e.g.* Thorwart and Rabbel 2023). Ambient seismic noise is dominated by surface waves. At higher frequencies (>5 Hz), the sources are

primarily anthropogenic, such as traffic and construction activity, whereas lower-frequency noise (0.05–1 Hz) is mainly of natural origin, such as ocean waves or wind (Bonnetfoy-Claudet *et al.* 2006). Surface waves have frequency-dependent penetration depths, so local subsurface properties can be inferred by determining their frequency-dependent phase velocities (dispersion).

To analyse Rayleigh wave dispersion, we used mini-arrays at 36 locations, using two different configurations. Each array recorded for 15 minutes. Only the vertical component of the geophones was used to isolate Rayleigh wave signals. The data were filtered and divided into overlapping time windows. For each window, slowness and propagation direction were estimated using beamforming, along with a coherence value indicating the quality of the estimation. The 20 data points with the highest coherence were averaged to derive the phase velocity of the Rayleigh wave. Rayleigh wave dispersion curves were derived in the 3.5–50 Hz range, then smoothed and interpolated across all arrays. These results were used to create maps showing the spatial distribution of the propagation velocity of Rayleigh waves for a set of selected oscillation frequencies. The numerical value of the Rayleigh wave velocity can be regarded as a measure of average soil stiffness down to a certain maximum depth, which is

determined by the selected frequency. In our case values between 100 and 250 m/s are found representing the range of values from soft fine-grained soil enriched in organic material to rather sandy non-organic soils.

### Full waveform inversion (FWI) of shear wave seismograms

Full waveform inversion (FWI) was applied to a surface wave dominated data set recorded along a linear profile measured in 2018 (green line in Fig. 1). Shear waves were excited using a horizontal sledgehammer source and measured with equidistantly distributed horizontal component geophones (Corradini *et al.* 2020). With FWI, the recorded seismograms are inverted to subsurface models of the seismic shear wave velocity  $v_s$  and density  $\rho$ . For this task, wave propagation in the subsurface is modelled numerically with the Finite Differences Method. The inversion aims to minimize the difference between modelled and field data iteratively. Simultaneously, the models of the seismic parameters are improved. The final models can be interpreted regarding relevant material properties *e.g.* shear stiffness, porosity, and compaction.

Elastic 2D FWI was performed in the time-domain with the software DENISE-SH (Köhn *et al.* 2012; Zolchow *et al.* 2025a). We used a Cartesian grid with discretization of 0.05 m as well as a sequential lowpass filter inversion workflow (L-strategy) with 80 Hz maximal corner frequency and an alternating offset window (Köhn *et al.* 2019; Zolchow *et al.* 2025b). The required initial velocity model was based on the available first arrival travel time tomography (FATT) of refracted shear waves (Corradini *et al.* 2020), whereas the density is derived with an empirical relation (Ulugergerli and Uyanik 2007). Visco-elastic effects including attenuation and dispersion are considered via a constant seismic quality factor  $Q_s=10$  (Kurzmann *et al.* 2013), which was optimized through performing forward modelling test runs.

The results are presented in the form of depth sections showing the distribution of shear wave propagation velocities found underneath the profile line, along which the measurements were carried out. Again, low wave velocities stand for soft fine-grained organically enriched sediments, high velocities for the stiffer sandy soils (Corradini *et al.* 2020).

## Results

### Rayleigh wave velocity maps based on seismic noise analysis

The velocity distribution maps (Fig. 2) for two selected frequencies (4 Hz and 12 Hz) reveal a pronounced, elongated zone of low velocity (<100 m/s, shown in blue), clearly contrasting with the surrounding high-velocity zones (>250 m/s, shown in red). This low-velocity zone becomes

spatially narrower at lower frequencies, indicating a lens-shaped body that is broader near the surface. These patterns correlate with the interpretations from the dispersion curves. Given that lower-frequency surface waves penetrate deeper than higher-frequency ones, the frequency-dependent size of the low-velocity area suggests a depth-limited soft sediment body. This geophysical signature aligns with the presence of a kettle hole, previously identified in the study area and known to be infilled with soft, organic-rich sediments such as peat and clayey silt (Corradini *et al.* 2020). These materials exhibit significantly lower seismic velocities (<100 m/s) compared to the surrounding consolidated substrate (>250 m/s). From the phase velocities and the Rayleigh wave depth approximation (depth  $\approx 0.4 \times$  wavelength), the infill is estimated to reach a depth of approximately 5 meters at 4 Hz, consistent with previous SH-wave seismic surveys by Corradini *et al.* (2020), despite slight spatial offsets between the survey lines. Fig. 2 also shows that locally in the centre of the supposed depression, depth can reach even 6 m, and the feature seems to consist of two bodies, the northeastern-most appears to be small and adjacent to the bigger one.

### Full waveform inversion of shear wave records

In the inverted shear wave velocity models (Fig. 3), the kettle hole ( $v_s < 80$  m/s, blue to violet hues in Fig. 3) exhibits a significant contrast to the underlying consolidated substrate ( $v_s > 150$  m/s, green to red in Fig. 3). Due to higher velocity contrasts than in the results of travel time tomography (FATT) (Fig. 8b; Corradini *et al.* 2020, reported also in Fig. 3, top), the shape of the boundary layer is more clearly visible in the FWI. Additionally, the FWI reveals internal stratigraphic structures within the kettle hole including a local positive velocity anomaly (up to 200 m/s). In the section between 5–25 m along the profile, the FWI reveals strong horizontal layering with multiple seismic boundary layers (black, yellow, blue lines). Particularly striking is a narrow high velocity layer in the first 1.5 m below surface (see white arrow in Fig. 3, bottom) overlying a deeper low velocity zone. Regarding the overall stratigraphic structure, the FWI velocity model correlates well with the results of the reflection seismic processing by Corradini *et al.* (2020).

Based on the results of FWI, the shear wave velocity within the kettle hole is significantly lower ( $v_s = 30\text{--}50$  m/s) than indicated by the results of FATT ( $v_s = 50\text{--}80$  m/s). These especially low seismic velocities indicate a very high content of soft, organic-rich material within the kettle hole. We also observe lateral velocity variations within the kettle hole, suggesting inhomogeneities in the composition of the organic to sandy-clay gyttja sediment which varies slightly in vertical and horizontal direction. Furthermore, a lens-shaped area of increased velocity (white arrow in Fig. 3) may correspond to a local zone with significantly less organic content.

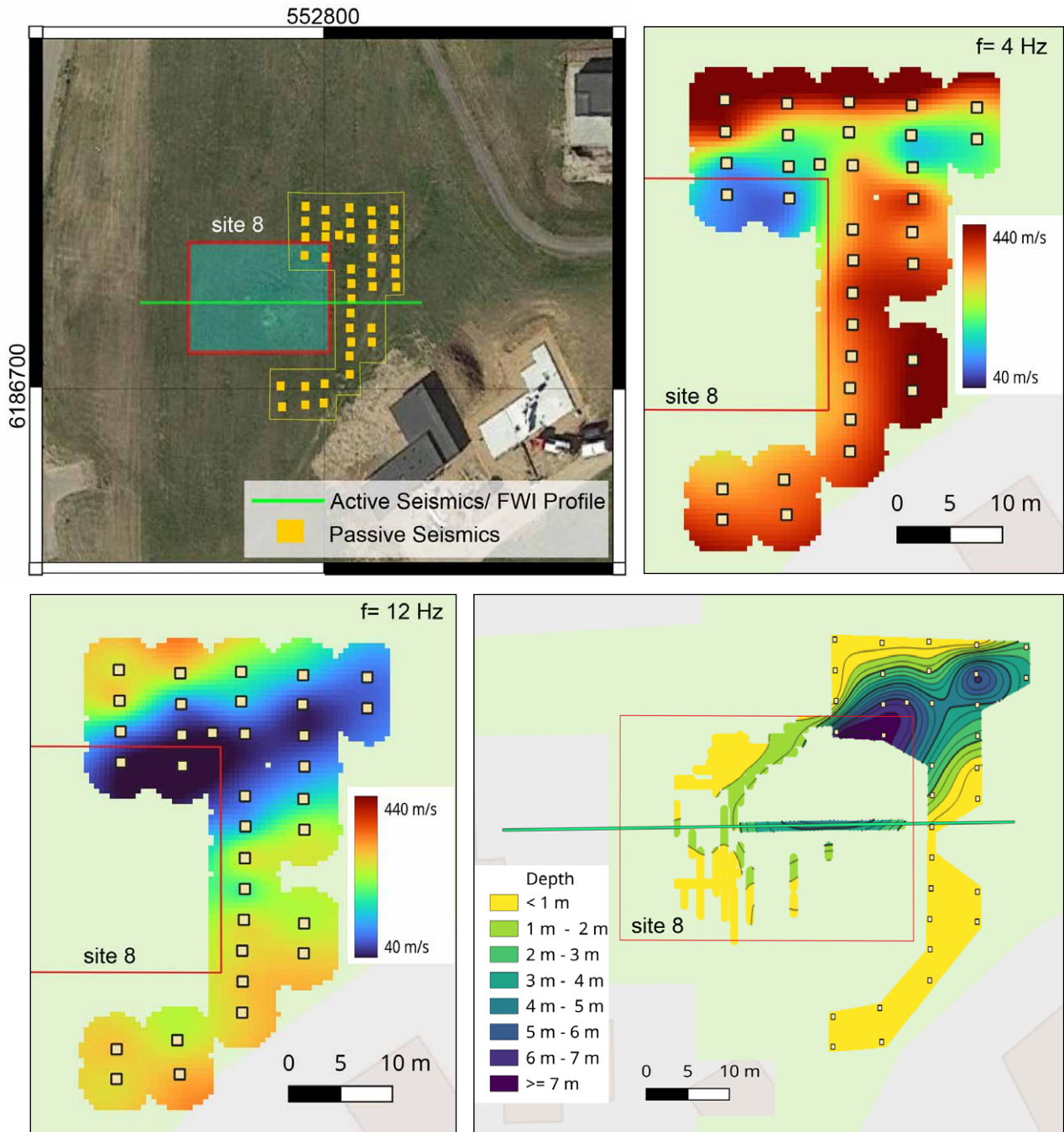


Figure 2: Overview of the measurements at Tyrsted (top left); velocity distribution for 4 Hz frequency (top right) and velocity distribution for 12 Hz (bottom left). Bottom right: depth estimation of the kettle hole.

### Multimethod comparison

Ground-penetrating radar (GPR) surveys conducted at site 8 revealed subsurface stratification down to ~2 m depth, though the interpretation was limited by high water content and gyttja-rich sediments that attenuated the radar signal. Key profiles (GPR12 and GPR18 in Fig. 6 of Corradini *et al.* 2020) identified a shallow reflector at ~0.5 m, interpreted as the topsoil interface, and a rounded reflector at ~1.5 m, likely

representing the transition from the grey-green gyttja, which shows an increasing minerogenic trend, to the overlying grey sandy-clay deposits. From an archaeological point of view, this transition is especially relevant as it marks the transition from the Late Allerød towards the Younger Dryas and thus the timeframe of the Bromme technocomplex in Southern Scandinavia. Reflections below 1 m became less distinct, and no clear signal was detected below 2 m.

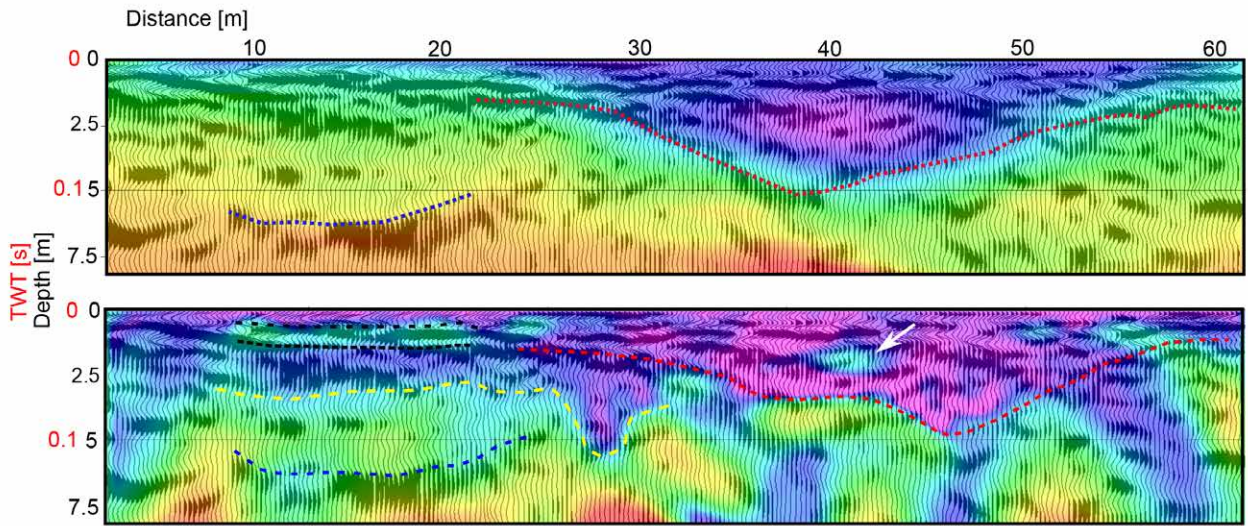


Figure 3: Comparison of seismic FATT (top) and FWI (bottom) with migrated seismic reflection profiles. A red dotted line indicates the bottom of the kettle hole. Dotted lines (black, yellow, blue) denote further strong seismic boundary layers. A white arrow indicates a high velocity anomaly within the kettle hole.

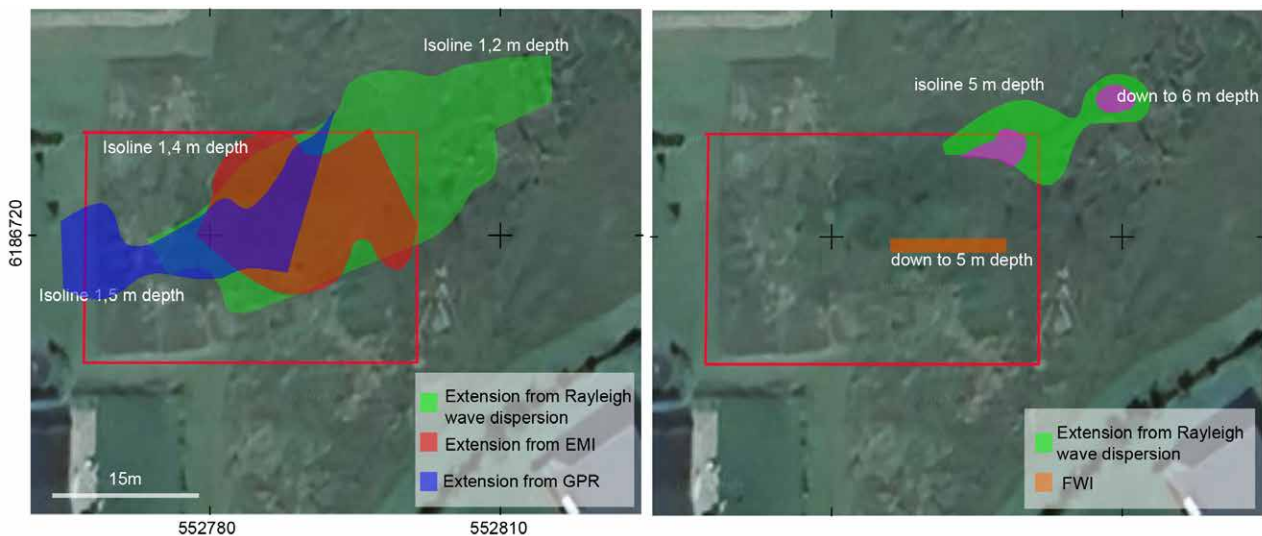
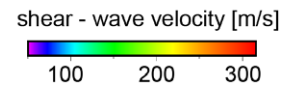


Figure 4: Comparison of depth contour lines derived from different geophysical methods used to characterize the Tyrsted kettle hole: GPR, EMI, Rayleigh wave dispersion analysis from ambient seismic noise and FWI. The contours illustrate the extent and estimate the depth of the depression, highlighting how Rayleigh wave analysis provides greater vertical penetration compared to GPR and EMI (top right).

Electromagnetic induction (EMI) surveys provided additional insight into lateral conductivity variations. Inverted EMI data revealed a high-resistivity surface layer ( $\sim 85 \Omega\text{m}$ ) overlying layers with decreasing resistivity ( $\sim 30 \Omega\text{m}$ ) (Corradini *et al.* 2020, Fig. 7). A pronounced low-resistivity anomaly is observed, corresponding to the inferred kettle hole location. Horizontal resistivity slices show that shallow low-resistivity zones expand laterally with depth down to  $\sim 1.5$  m, the maximum lateral extent of the kettle hole as also indicated by seismic data. In

order to comprehend the shape and extension of the kettle hole we merged the contour maps created from the measurements presented above with new seismic processing results, as presented in Fig. 4. The reflector delineating the surface morphology of the kettle hole was visible at depths of approximately 1.5–1.8 m in the GPR record. The interpolation of the GPR data suggests a depression that deepens towards the northeastern part of the area, reaching a depth of about 1.6 m (blue area in Fig. 4). To characterize the spatial extent of the kettle hole,

we compared the GPR-based contour map and the extent of increased values in the EMI conductivity slice at ~1.5 m depth (red area in Fig. 4).

In summary, the comparison of results from Rayleigh wave dispersion suggest that the kettle hole may extend further towards the northeast, where also a smaller subsidiary pond appears to have existed. Previously, this could only be hypothesized based on the GPR and EMI data alone, considering the shallower extension of the feature. However, seismic measurements revealed the depth of the kettle hole to be around 5 meters, precisely in the northeastern corner of site 8 with a smaller pond with depth between 5–6 m.

## Discussion

The integrated geophysical results presented in this study allow a more comprehensive reconstruction of the kettle hole at Tyrsted (site 8) than previously possible (Corradini *et al.* 2020), and provide new insights into both its geological formation and archaeological significance, as they help identifying sedimentary transitions and palaeo-environmental conditions that frame the Late Palaeolithic occupation. The passive and active seismic data reveal a sharply defined, bowl-shaped depression reaching depths of up to 5 m, filled with low-velocity, fine-grained sediments indicative of organic-rich gyttja and peat. This morphology and sediment composition are consistent with a melt-out kettle hole, formed by the melting of buried dead ice blocks during the Late Glacial period. Alternating high- and low-velocity zones correspond to transitions between different types of gyttja, reworked mineral layers, and peat reflecting phases of open-water sedimentation followed by an initial terrestrialization of the banks, including the formation of peat. Environmental shifts throughout the Late Glacial, *e.g.* at the Allerød–Younger Dryas transition, are reflected in lithological changes within the kettle hole and are detectable by the presented geophysical methods.

The improved depth penetration achieved by both the ambient noise analysis and the FWI now reveals the full vertical extent of the kettle hole, which had remained only partially resolved in the earlier EMI and GPR surveys. While EMI and GPR effectively captured the upper 1–2 m of the structure, their performance was constrained by signal attenuation in the water-saturated gyttja layers and by the dominance of conductivity contrasts. In contrast, seismic methods respond primarily to mechanical properties of the subsurface, allowing a distinction between soft, organic-rich infill and sandy substrate that cannot be reliably inferred from EMI data. Thus, the value of the passive seismic approach lies not merely in time efficiency, but in its ability to penetrate deeper and discriminate materials

based on stiffness and compaction, key parameters for reconstructing depositional and postglacial processes.

Compared to the earlier SH-wave tomography published by Corradini *et al.* (2020), the Full Waveform Inversion (FWI) provides a clearer and higher-resolution image of the internal stratigraphy. Both datasets identify a low-velocity depression, but the new inversion delineates more subtle internal inhomogeneities within the infill. These small-scale velocity variations (30–200 m/s) likely represent lateral differences in compaction, moisture, and organic content, suggesting heterogeneous accumulation processes rather than a single, uniform sedimentation phase. Thus, FWI is capable of imaging shifts in sedimentary properties reflecting shifting climatic circumstances throughout the Late Glacial towards the Holocene.

When we compare the case study at Tyrsted with previous results from the Lieth Moor study, a central commonality lies in their innovative use of geophysical methods to investigate palaeo-landscape features associated with Late Palaeolithic occupation. While GPR and EMI were employed at both sites to delineate the extent and internal stratigraphy of palaeo-wetlands, the Tyrsted case further utilized SH-wave seismic and refraction methods, which successfully imaged deeper sedimentary structures and revealed the targeted Late Allerød/Younger Dryas sedimentary transition. These promising seismic results suggest a methodological pathway that could be extended to other Late Palaeolithic sites such as Lieth Moor or the Ahrensburg Tunnel Valley – a key Late Glacial landscape known for its numerous Ahrensburgian sites and thus archaeologically highly relevant – particularly for investigating areas where GPR penetration is limited due to clay-rich or water-saturated sediments. Conversely, the systematic integration of EMI and legacy borehole data at Lieth Moor provides a model for combining conductivity mapping with palaeo-environmental interpretation, which could be applied in future surveys at Tyrsted or other kettle hole sites. Taken together, these studies demonstrate the value of a multi-method geophysical approach, where results from one case study can inform and refine strategies in another, ultimately enhancing our capacity to detect and contextualize ephemeral Late Glacial human activities across Northern Europe.

Methodologically, this study demonstrates that combining passive seismic noise analysis with high-resolution FWI offers a robust, non-invasive approach for characterising buried glacial features for archaeological research. Limitations remain, particularly regarding the influence of ambient noise directionality on array data and the sensitivity of inversion results to initial velocity models. However, this can be mitigated through the integration of borehole validation and sediment coring.

## Conclusions

This study highlights the potential of ambient seismic noise analysis for the detection and characterisation of small depressions in complex superimposed glacial landscapes that are of high archaeological relevance.

Regarding the main objectives of this study, we came to the following conclusions:

1. The results demonstrate that ambient-noise-based seismic measurements can successfully image the subsurface geometry of kettle holes with high reliability. The Rayleigh wave dispersion maps clearly outlined a low-velocity anomaly corresponding to the depression infill, while the frequency-dependent velocity variations provided depth-sensitive information on the vertical extent of the feature.
2. The comparison shows that seismic methods extend the depth of investigation from 1–2 m (GPR/ EMI) to approximately 5–6 m, providing a complete image of the kettle hole. The Full Waveform Inversion (FWI) reveals strong agreement with earlier reflection seismics but also highlights additional internal inhomogeneities within the infill.
3. The integrated seismic interpretation indicates that the depression extends further northeast than previously recognised, suggesting a larger pond at Tyrsted. The refined morphology therefore supports the view that hydrologically dynamic zones like Tyrsted played a central role in structuring human occupation, mobility, and resource exploitation in Southern Scandinavia during the Late Pleistocene.

To conclude, this study demonstrates that passive seismic noise measurements using flexible mini-array configurations can effectively image subsurface features such as buried kettle holes. The technique is not only adaptable and time-efficient but also particularly well-suited for archaeo-geophysical investigations, where rapid, non-invasive site assessments are essential. Advancements in seismic imaging, such as FWI, promise to further enhance resolution and understanding of subsurface features critical for interpreting human-environmental interactions during the Late Pleistocene. Furthermore, the method exerts minimal impact on the investigated area and is therefore particularly well-suited for sites subject to stringent environmental and cultural heritage protection regulations, such as *e.g.* the Ahrensburg Tunnel Valley. Overall, the Tyrsted case study demonstrates how non-destructive seismic imaging can substantially support the reconstruction of former environmental conditions, even at a very local scale. By resolving both the genesis and evolution of glacial depressions, they provide a more nuanced understanding of postglacial landscape development and its role in shaping human-environmental interactions at the end of the Pleistocene.

## Acknowledgements

We thank Horsens Museum for supporting the fieldwork and allowing the opening of a small trench to ground-truth the geophysical measurements. We are grateful to Sascha Krüger for assistance with fieldwork and pollen analysis of the sediments, and to Morten Fischer Mortensen for the sedimentary description of the test trench.

## References

- Bonnefoy-Claudet, S., Cotton, F. and Bard, P.-Y. 2006. The nature of noise wavefield and its applications for site effects studies, *Earth-Science Reviews* 79(3–4), 205–227. DOI:10.1016/j.earscirev.2006.07.004
- Clausen, I. 2010. Auf den Spuren von Alfred Rust und seinen Rentierjägern: Aktuelle Untersuchungen am Stellmoorhügel bei Ahrensburg, Kreis Stormarn, *Archäologische Nachrichten aus Schleswig-Holstein*, 15–19.
- Corradini, E., Eriksen, B. V., Mortensen, M. F., Nielsen, M. K., Thorwart, M., Krüger, S., Wilken, D., Pickartz, N., Panning, D. and Rabbel, W. 2020. Investigating lake sediments and peat deposits with geophysical methods - A case study from a kettle hole at the Late Palaeolithic site of Tyrsted, Denmark, *Quaternary International* 558(3), 89–106. DOI:10.1016/j.quaint.2020.08.008
- Detjens, S., Grimm, S. B., Oflaz, A., Wilken, D., Wunderlich, T., Rabbel, W. and Eriksen, B. V. 2024. We Came for the Lake—Late Pleistocene Landscape Reconstruction in Lieth Moor, District Pinneberg, Germany, *Geosciences* 14(2), 30. DOI:10.3390/geosciences14020030
- Eriksen, B. V., Krüger, S. and Wild, M. 2017. Tyrsted – a Late Palaeolithic Christmas gift, *ZBSA Jahresbericht 2017*, 78–79.
- Köhn, D., Nil, D. de, Kurzmann, A., Przebindowska, A. and Bohlen, T. 2012. On the influence of model parametrization in elastic full waveform tomography, *Geophysical Journal International* 191(1), 325–345. DOI:10.1111/j.1365-246X.2012.05633.x
- Kurzmann, A., Przebindowska, A., Köhn, D. and Bohlen, T. 2013. Acoustic full waveform tomography in the presence of attenuation: A sensitivity analysis, *Geophysical Journal International* 195(2), 985–1000. DOI:10.1093/gji/ggt305
- Lanoë, F. B., Zedeño, M. N., Jansson, A. M., Holliday, V. T. and Reuther, J. D. 2022. Glacial kettles as archives of early human settlement along the Northern Rocky Mountain Front, *Quaternary Research* 105, 135–150. DOI:10.1017/qua.2021.40
- Thorwart, M. and Rabbel, W. 2023. Passive seismic depth sounding by statistical array analysis. In: Wunderlich, T., Hadler, H. and Blankenfeldt, R. (eds.), *Advances in On- and Offshore Archaeological Prospection*. Kiel: Kiel University Publishing, 387–90.
- Ulugergerli, E. U. and Uyanik, O. 2007. Statistical Correlations Between Seismic Wave Velocities and SPT Blow Counts and the Relative Density of Soils, *Journal of Testing and Evaluation* 35(2), 187–191. DOI:10.1520/JTE100159
- Wild, M., Mortensen, M. F., Andreassen, N. H., Borup, P., Casati, C., Eriksen, B.V., Frost, L., Gregersen, K. M., Henriksen, M. B., Kanstrup, M., Olsen, J., Pedersen, K. B., Pedersen Peter V., Ramskov, C., Sørensen, L., Sørensen, M. and Wählin, S. 2020. Palaeolithic bone and antler artefacts from Lateglacial and Early Holocene Denmark: technology and dating, *Quartär* 67, 105–180. DOI:10.7485/qu.2020.67.88925
- Zolchow, M., Köhn, D., Wilken, D. and Rabbel, W. 2025a. Seismic survey of the Danevirke: Determining the multiple construction phases of a medieval fortification system through full waveform inversion (FWD), *Journal of Applied Geophysics*, 241(1), 105796. DOI:10.1016/j.jappgeo.2025.105796
- Zolchow, M., Köhn, D., Pickartz, N., Thorwart, M., Serbanescu, A., Erkul, E., Wilken, D., Dreibrodt, S., Hofmann, R., Müller, J., Lazar, C. and Rabbel, W. 2025b. Structure of the Multiphase Chalcolithic Tell Chiselet-Grădișteea Fundeanca (Romania) From SH-Wave Full-Waveform Inversion, Borehole Geophysics and Coring, *Archaeological Prospection* 10(3), 89. DOI:10.1002/arp.2002

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# Green shadows beneath the waves

A speculative vegetation survey of  
Doggerland during the GS-1

Sascha Krüger and Benjamin R. Gearey

## Abstract

This study synthesizes climatic, geomorphological, and palaeobotanical data to construct a speculative vegetation survey of Doggerland during the second half of Greenland Stadial 1 (GS-1, 12050–11650 cal BP). Utilizing pollen records from surrounding regions, the survey extrapolates hypothetical vegetation zones across the North Sea Basin. Results suggest that Doggerland comprised zones of diverse vegetation rather than a homogeneous tundra. Five large-scale biomes and one ecotone are proposed: (1) meagre grasslands west of Jutland, (2) extensive central wetlands with possible thermokarst features, (3) an East-West directed treeline-ecotone between Britain, the Netherlands and northern Germany, (4) dynamic wetlands in the Southern Bight and English Channel, (5) highly erosive environments with open grounds and scattered grass-covered areas on the Dogger Hills and Ling Bank, and (6) a hypothesized SW-NE heathland belt in eastern Doggerland dominated by crowberry. This study highlights Doggerland as a transitional European landscape, linking birch-pine woodlands in Germany with an oceanic tundra in Britain. The findings underscore the need for future sediment core analyses to refine vegetation reconstructions and enhance understanding of human-environment interactions in this now-submerged region.

*Keywords: Doggerland, Late Glacial vegetation, palaeobotany, Greenland Stadial 1 (GS-1)*

## Introduction

For more than 100 years there have been investigations on the natural environment of the once vast lands in the North Sea Basin that today lie beneath the waves – Doggerland (Coles 1998). Benefitting from large amounts of coring data from oil and gas companies (Fitch *et al.* 2005; 2007; Gaffney 2007; Gaffney and Fitch 2022a), but likewise from the application of targeted hydroacoustic measurements (Andresen *et al.* 2024; Hepp *et al.* 2017; 2019; Prins and Andresen 2019) our understanding of the landscape of Doggerland has significantly increased over the past 25 years.

Yet, these advances in exploring former landscapes strongly contrast with the state of knowledge on past vegetation cover – inseparable elements of landscapes. Over the past 25 years, there are only a few investigations of botanical macrofossils and pollen that are predominantly located close to the present-day shoreline (Bennike *et al.* 2023; Gearey *et al.* 2017; Krüger *et al.* 2017; Wolters *et al.* 2010). These studies demonstrate vegetation compositions similar to those of the areas surrounding the North Sea Basin. There, on dry

land, a variety of projects have produced a number of well dated vegetation records that, in addition to the near-coast records, can be utilized to hypothetically survey the flora of Doggerland of the Weichselian Late Glacial.

Equal to the surrounding land masses, the vegetation in the North Sea Basin was dependent on edaphic, climatic, plant-migratory and highly localised factors and certainly cannot be regarded as a uniform plant cover.

To better comprehend the likely diversity of the vegetation across Doggerland, this contribution compiles a brief overview on (i) climate and information on permafrost and wind systems, (ii) the distribution of large-scale water bodies, river courses and cover sands, as well as (iii) palynological and macro-botanical data. The synthesis aims at defining hypothetical biomes and ecotones across Doggerland.

Due to multiple severe environmental overturns in the course of the Late Pleistocene–Early Holocene it would be impossible to provide a complete diachronic overview. Therefore, this contribution focuses on a specific time slice of the Weichselian Late Glacial – the second half of the GS-1 (Bakke *et al.* 2009; Björck *et al.* 1998).

This time period between around 12050 and 11650 cal BP is also archaeologically of interest. Finds associated with contemporary hunter-gatherer groups of the Ahrensburgian technocomplex in *e.g.* one of the most important Late Glacial sites in Northern Europe (Ahrensburg Tunnel Valley) have predominantly been dated to the later phase of the GS-1 (Grimm *et al.* 2021).

The aim of this contribution is to provide a broad summary and overview of identifiable variations in the palaeoenvironment across a wide spatial area, based primarily on palynological records. This is done in the form of a map in order to formulate testable hypotheses and to stimulate future research. At the same time, it aims to show how diverse the vegetation of Doggerland was during a selected time interval of only 400 years and how heterogeneous the landscapes and flora consequently must have been on a diachronic scale.

## Backbones of the survey

### Temporal and spatial frame

Terminologies of the Late Glacial inherit a strong potential for misinterpretation (de Klerk 2004; Krüger 2020). In order to avoid these, the event stratigraphy is utilized (Björck *et al.* 1998). Therein, the youngest recorded *Greenland stadial* (GS) is the GS-1 which is generally associated with the Loch Lomond stadial (Lowe *et al.* 2019), the Younger Dryas, or the Dryas 3 (Krüger 2020).

The GS-1 (12896 ± 4 b2k–11703 ± 4 b2k, Rasmussen *et al.* 2006; 2014) can climatically be separated into two phases, with the Vedde Ash (12040 ± 35 cal BP, Bronk Ramsey *et al.* 2015) as a suitable chronological divide (Bakke *et al.* 2009; Krüger and Bogaard 2020). These 400 years

between the Vedde ash and the accepted onset of the Early Holocene form a rough climatic entity that is also reflected in the vegetation records around the North Sea Basin (Behre 1966; Krüger *et al.* 2020; Simmonds *et al.* 2021; Usinger 1975). These later 400 years of the GS-1 are the focal point of this contribution.

Geographically, the term Doggerland is difficult to define due to the high dynamics resulting from the shifting coastline as a consequence of sea level rise and eustatic balancing. It is not possible to determine the exact position of the coastlines for a specific time frame, such as the 400 years envisaged here. However, for this survey the coastline according to the EPHA maps (map *Dryas III*, vers. 1.1.0) are used (<https://zbsa.eu/en/european-prehistoric-and-historic-atlas/>), whereby Patton *et al.* (2017), Brooks *et al.* (2011) and Harff *et al.* (2017) provided essential information to draw the coastline of Doggerland.

Even if the extent of Doggerland is described as all the area flooded by the North Sea today (Coles 1998), there will not have been a noticeable transition between the present northern European plain and the former land in the North Sea Basin. For a better overview and differentiation of assumed biomes, the area of *Doggerland* is extended to the Netherlands, northern Germany, and Denmark (Fig. 1).

### Climatic framework

The climate of the GS-1 is generally considered as a sudden climatic cooling. This sudden cooling is accepted to be linked to an abrupt slowdown of the Atlantic Meridional Overturning Circulation (AMOC) in response to meltwater discharges from North American ice sheets (Schenk *et al.* 2018). With a sea ice boundary around 53°N (Ruddiman and McIntyre 1981), the northern coast of Doggerland (approximately 56°N) would have been frozen between late fall and early summer (Björck 2021).

The climate of the later phase of the GS-1, between 12050 and 11650 cal BP, was controlled by highly dynamic sea ice cover in the North Atlantic. This high dynamic resulted in increasing oceanicity and milder conditions across Doggerland compared to the first half of the GS-1 (Bakke *et al.* 2009; Palmer *et al.* 2012). The geographical divide between a more oceanic, wetter climate (in the western part of Europe and across Doggerland) and a continental, drier climate (in the East and South) (Prochnow *et al.* 2024), has been proven on the basis of isotopes and pollen data. The divide is argued to correspond to a line approximately at the height of the maximum Weichselian glaciation in northern Germany (Usinger 2004).

From the beginning of GS-1, strong westerly winds moved south, following the southward shifting sea ice boundary (Baldini *et al.* 2018; Brauer *et al.* 2008; Dreibrödter *et al.* 2020; Ruddiman and McIntyre 1981). However, these winds gradually weakened in the second half of the GS-1 (Bakke *et al.* 2009).

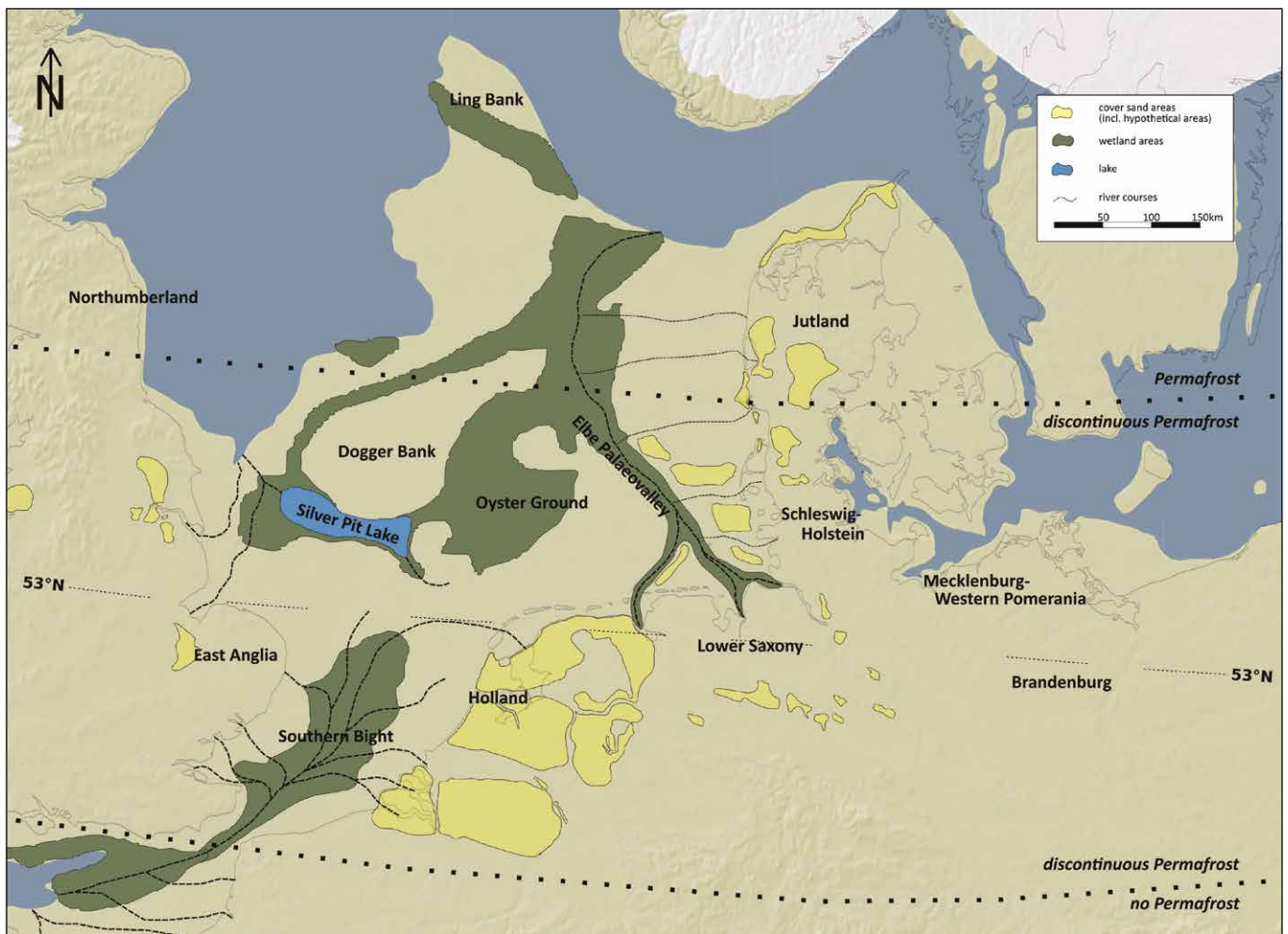


Figure 1: Assumed topography of Doggerland during the GS-1 as described in the text, including selected geographical designations.

The cold winters and only short summer episodes during the GS-1 resulted in the formation of permafrost across northern central Europe (Isarin 1997). Approximated permafrost zone boundaries – highly relevant for plant growth and root depth (Theuerkauf and Joosten 2012) – are given in Fig. 1.

### Main geomorphological characteristics of Doggerland

The general landscape and geomorphology, but also the occurrence of different substrates (which are decisive for the vegetation distribution) are characterised by four main factors:

1. The superimposed glacial series of the last two glaciations (Saalian and Weichselian).
2. The very dynamic courses and confluence of large and medium-sized European rivers.
3. The climatic conditions already outlined above (especially permafrost and wind).
4. The climate related formation of cover sands during the Weichselian Late Glacial.

The overall landscape of Doggerland during the GS-1 was most likely rather flat and characterised by gentle, abraded moraine ridges. The geomorphology thus resembled today's western Jutland and north-west Germany, or the gently undulating hill-covered landscapes of Holderness, east England (Chapman and Lillie 2004).

The sandur plains from the Saalian glaciation in today's English Channel were shaped by an enormous freshwater system fed by rivers such as Rhine, Thames, Meuse, Maas, Somme, or Seine (Mills 2022). The confluence of the Rhine and Thames with numerous minor tributaries in the area between the present-day districts of East Anglia (UK) and South and North Holland (NL) – *i.e.* the south and south-west of Doggerland – possibly led to the formation of extensive wetland areas between here and the English Channel area (Danukalova *et al.* 2017; Mills 2022).

The strong variation in water levels between the seasons due to the many tributaries caused the landscape (and vegetation) in this wetland area to be considerably energetic and dynamic. In later summer and autumn, many (sandy) areas in riverbeds were exposed due to lower water levels, providing potential for strong erosion by the westerlies. This, in addition to open land surface that lacked significant

vegetation cover, fed enormous cover sand formations, which were deposited predominantly across the present-day Netherlands (Antoine *et al.* 2003). The same processes also affected north-west Germany and Denmark (Kolstrup 2007; Kolstrup and Jørgensen 1981). The main redeposition of sand occurred during the GS-1 (probably the first half) and shows a clear decreasing intensity gradient from West to East (Woldstedt 1954).

The centre of Doggerland is characterised by the Dogger Bank rising above the plains. The Dogger Bank is a rather complex stratigraphic framework (Cotterill *et al.* 2012), which was widely visible as a ridge in the landscape during the GS-1. The ridge had a steeper southern slope and a gentle down-slope towards the north (Emery *et al.* 2019). To the south-west of the Dogger Bank, the Outer Silverpit lake was present during the GS-1 (Gaffney and Fitch 2022b).

The character of the wide area immediately south-south-east of the Dogger Bank is disputed. It is postulated by Hjelstuen *et al.* (2018) or Emery *et al.* (2019) that this area was shaped by a proglacial lake. It drained around 18700 cal BP (Hjelstuen *et al.* 2018) and consequently left behind a low-lying, very wide and flat area during the Weichselian Late Glacial. This region, known as Oyster Ground, would probably have been affected by the sea level rise due to the rise in groundwater levels and became a wetland around the GS-1 (Hoebe *et al.* 2024).

Gaffney and Fitch (2022b) opposed the assumption of a large lake with modelling of large-scale data, which shows a complicated network of river systems in the Oyster Ground area. Nevertheless, both assumptions demonstrate that a large area south of the Dogger Bank was an extensive wetland, although the precise character of this environment remains unclear. This is also confirmed by the work of Hepp *et al.* (2019), which revealed a distribution of extensive wetlands to the west of the Elbe Palaeovalley.

The east of Doggerland was dominated by the Elbe Urstromtal/Elbe Palaeovalley (EPV). The palaeo-Ems, palaeo-Elbe and palaeo-Weser connected north of the island of Juist and Norderney at about the level of Heligoland (Abegunrin *et al.* 2023; Hepp *et al.* 2017). From here, they formed the colossal EPV drainage system, draining vast coastal lowlands (Hepp *et al.* 2019). The EPV stretched northwards with an average width of around 30 km in an arc between Heligoland, western Jutland and the eastern tip of the Dogger Bank before reaching the Norwegian Trench.

Similar to the effects at the confluence of the Thames, Rhine, *etc.*, it can be assumed that seasonally varying water levels, highly dynamic watercourses together with westerly winds led to the deposition of aeolian sands to the east of the EPV. Hypothetically, a partly interrupted sand belt would thus stretch from the present-day Netherlands through the North Sea Basin past Heligoland to Jutland. Yet, this remains to be investigated, and the cover sands

in the North Sea Basin east of the EPV are hypothetically drawn (Fig. 1).

Although the location of the coastline of Doggerland is unclear, some characteristics can be assumed. For most of the year, the coastline was frozen, even in the second half of the GS-1 (Bjerck 2021). In the ice-free months, the coast was characterised by a strong tidal range over a very flat relief.

Whether basal peat formation occurred in the coastal hinterland is questionable. Moorlogs (Reid 1913) – big lumps of peat, broken out of the basal peat layers – would confirm basal peat formation like in many places across the North Sea Basin (Clark 1936). Yet, there are no moorlogs documented in the area. Nevertheless, the assumed coastline of the later GS-1 lies in the zone of continuous permafrost (Isarin 1997), and therefore the formation of peat is considered very unlikely.

It is apparent that Doggerland never formed a homogeneous 'land bridge' between Denmark and England. It was an area dominated by diverse and highly dynamic watercourses and wetlands. The watershed (Mills 2022) is situated between the wetlands of the Oyster Ground and the confluence of the Rhine and Thames. Following Mills (2022), this corridor probably formed the actual 'land bridge' between the later British Islands and the European mainland.

## Vegetation around the North Sea Basin

To date, there have only been a limited number of studies on Late Glacial and Early Holocene vegetation from the North Sea Basin. In the first half of the 20<sup>th</sup> century, numerous peat lumps/moorlogs were analysed, which showed a strong similarity to terrestrial Early Holocene spectra in their reconstructed vegetation composition (Erdtman 1925; Godwin and Godwin 1933; Reid 1913; Vermeer-Louman 1934; Whitehead 1920; Whitehead and Goodchild 1912). Later analyses of drill cores likewise unearthed Holocene sediments and peats (Behre and Menke 1969; Menke 1996; Wolters *et al.* 2010).

Palaeobotanical studies on Late Glacial sediments from the North Sea Basin have only been carried out in the last decades (Bennike *et al.* 2023; Brown *et al.* 2018; Gearey *et al.* 2017; Krüger *et al.* 2017). It is therefore essential to base a vegetation survey of Doggerland on pollen records from the present-day surrounding mainland.

In a compilation of terrestrial records (Tab. 1) different archives of various sizes, quality, preservation, resolution of analysis and dating accuracy are compared to each other. A synthesis is nonetheless relevant, because (i) the temporal range under consideration covers 400 years, so the values of the second half of the GS-1 can be averaged. Further, (ii) assumptions based on palynology can be validated by macro-botanical evidence, but most importantly, (iii) only general trends are compared.

For the overview map (Fig. 2) – based on records shown in Tab. 1 – pollen data are presented in simplified charts.

Bar sizes are averaged values of the second half of the GS-1 and are based on the taxa percentage calculated on total terrestrial pollen. Grasses and herbs are summarised in the yellow bar. The proportion of sedges (Cyperaceae) is given in blue. The black bar represents *Pinus* (pine) pollen values. The white bar represents *Betula* (birch). In only a few records a distinction was made between a *Betula pubescens*-type (downy birch) and *B. nana*-type (dwarf birch) pollen. Where this was the case, a green bar was added for *B. nana* values. The grey bar indicates *Salix* (willow) values.

The overview of pollen charts in Fig. 2 shows that zones can be recognised which are predominantly defined by climate related boundaries (permafrost, oceanity and precipitation) and edaphic boundaries (clay soils, well-drained soils, cover sands) (Theuerkauf and Joosten 2009; Mortensen *et al.* 2014a).

### Biomes and ecotones across and around Doggerland – a survey

Based on the compilation (Fig. 2), various gradients can be recognised across the North European Plain as far as Scotland, which can also be extrapolated into the North Sea Basin. Overall, there are two clear patterns across the study area that appear to be most closely coupled to temperature and humidity.

**North-south gradient:** The tree line corresponded approximately to the same latitude across the study area, based on pollen and macrofossils (see below; in the west between the northern Midlands and the southern part of northern England; in the east across Schleswig-Holstein and south of the Danish islands). Thus, it is plausible to interpolate the treeline-ecotone across central Doggerland. However, this treeline-ecotone (the transitional zone between woodland and tundra/grassland) must have had a very different character from east to west.

**East-west gradient:** A humidity gradient that is manifested in the change of tree species from *Pinus* in the east through *Betula* to *Salix* and many Cyperaceae (sedges) in the west. While the pines in north-eastern Germany reach tree size, the contemporary willow species in the British Isles are presumably rather shrubby representatives of their species (Vyle and Degenhardt 1967).

A more detailed view at individual regions of the North European Plain emphasizes these gradients. Commencing with Brandenburg and southern Mecklenburg-Western Pomerania in the south-east of the study area, a pine forest or pine-birch forest with varying degrees of openness can be assumed during the second half of the GS-1 (Jahns 2001; Kobe *et al.* 2019; Wolters 2002). Theuerkauf and Joosten (2012) were able to prove that 53° N correlates to a growth limit controlled by permafrost. Further north, open birch-pine and birch woodlands are represented, which are strongly linked to edaphic factors. Usinger (2004) refers

to this vegetation type as park tundra (open tundra with scattered trees or groups of trees at favourable sites).

Western Mecklenburg, Schleswig-Holstein and the Danish islands represent the treeline ecotone on a north-south trajectory. The northernmost evidence of *Betula pubescens* macrofossils is located at the level of the Flensburg Fjord (Krüger 2024). This northernmost evidence correlates to the permafrost boundary described by Isarin (1997). Low-growing tree birches were present in the region around Hamburg, with *Betula nana* increasingly dominating towards the north and the Danish islands, where dwarf birches dominated the tundra.

In Jutland and northern Denmark – north of the permafrost boundary – the dominance of grasses, along with *Artemisia* (mugworts), *Rumex* (sorrel) and other herbs but also *Salix* (probably *S. herbacea*, dwarf willow, and *S. polaris*, polar willow; Bennike *et al.* 2023), indicates wide open areas of meagre grassland. This grassland-biome can probably be extrapolated westwards to the EPV. It is also possible that areas of open grounds are to be expected due to the permafrost. A connection to erosion is also to be seen in record DOG2/site 31 with high pine values. These can certainly be explained by reworking or selection by differential preservation (Krüger *et al.* 2017).

In Lower Saxony (sites 24 and 25), the birch-pine stands formed during the GI-1 significantly thinned out and in some cases *Pinus* completely vanished. *Betula pubescens* is less represented than *Betula nana*. The occurrence of *Empetrum* (crowberry) is typical (Merkt and Müller 1999). Towards the North Sea, there were only a few scattered birch trees, but an abundance of *Empetrum* and partly *Calluna* (heather), which probably spread on the cover sands (Behre 1966; van der Hammen 1951).

The Netherlands were characterized by cover sands. Pines were growing on these well-drained sandy soils and were extensively displaced by fires from the end of GI-1a, providing space for heathy species, including many Ericaceae and *Empetrum* (Casparie and van Zeist 1960; Hoek and Bohncke 2002; van der Hammen 1951). The proportion of *B. nana* in the birch pollen cannot be clarified. However, it is likely that *B. nana* was dispersed on till deposits in northern parts of the Netherlands, similar to large parts of north-west Germany.

The strong occurrence of *Empetrum* and other heathland elements in the second half of the GS-1 along today's North Sea coast is considered to be related to the cover sands. The hypothesis of the sand belt across the German Bight from the Netherlands to Jutland would imply that Doggerland must have been a heath and dune landscape in this part and, thus, a type of crowberry-heath-belt stretched from SW to NE across the North European Plain.

Pollen records from northern Belgium and south-east England consistently show a high proportion of grasses and herbs (*Rumex*) and especially Cyperaceae. *Salix* consistently

<b>Nr.</b>	<b>record</b>	<b>reference</b>
1	Nørre Lyngby	Iversen 1942
2	Lendum	Mortensen unpubl.
3	Bølling Sø	Krüger and Damrath 2019
4	Tyrsted	Krüger and Mortensen unpubl.
5	Fuglebakkevej	Degerbøl and Krog 1959
6	Pårup	Krüger unpubl.
7	Torreberga	Björck <i>et al.</i> 1997
8	Slotseng	Mortensen <i>et al.</i> 2011
9	Vandvænget	Mortensen unpubl.
10	Krogsbølle	Mortensen unpubl.
11	Hasselø	Mortensen <i>et al.</i> 2014b
12	Blixmoor	Usinger and Wolf 1982
13	Vallensgård mose	Usinger 1978
14	Glowe	Lampe <i>et al.</i> 2016
15	Endinger Bruch (Hoher Birkengraben)	De Klerk 2002
16	Kubitzbergmoor	Usinger and Wolf 1982
17	Liether Moor/ Esinger Moor	Usinger 1981
18	Nahe palaeolake	Krüger <i>et al.</i> 2020
19	Stellmoor	Usinger unpubl.
20	Löddigsee	Jahns 2007
21	Unter-Ückersee	Jahns 2001
22	Rehwiese	Neugebauer <i>et al.</i> 2012
23	Döberitzer Heide – Schwanengrabenrinne	Wolters 2002
24	Hämelsee	Merk and Müller 1999
25	Westerhauderfehn	Behre 1966
26	Milheeze	Bos <i>et al.</i> 2006
27	De Borchert	Hoek and Bohncke 2002
28	Hijkermeer	van der Hammen 1949; Hoek and Bohncke 2002
29	Waskemeer	Casparie and van Zeist 1960
30	DOG 1	Krüger <i>et al.</i> 2017
31	DOG 2	Krüger <i>et al.</i> 2017
32	Moerbeke	Verbruggen 1979
33	Snellegem	Verbruggen 1979
34	Holywell Coombe	Preece and Bridgland 1999
35	Langshot Bog	Simmonds <i>et al.</i> 2021
36	Sea Mere	Hunt and Birks 1982
37	Hockham Mere	Bennett 1983
38	The Bog, Roos	Beckett 1981
39	Routh Quarry	Gearey 2008
40	Gransmoor	Walker <i>et al.</i> 1993
41	Tadcaster	Bartley 1962
42	Lake Flixton: Profile D	Simmons <i>et al.</i> 2022
43	The Flasks 69 (Nosterfield)	Innes <i>et al.</i> 2009
44	Pepper Arden Bottoms	Innes <i>et al.</i> 2024
45	Thorpe Bulmer	Bartley <i>et al.</i> 1976
46	Beanrig Moss – C	Webb and Moore 1982
47	Lundin Tower	Whittington <i>et al.</i> 1996
48	Picketillum	Whittington <i>et al.</i> 1991
49	Morrone Birkwoods	Huntley 1994
50	Abernethy Forest	Birks and Mathewes 1978

Table 1: pollen records and references used to compile Fig. 2.

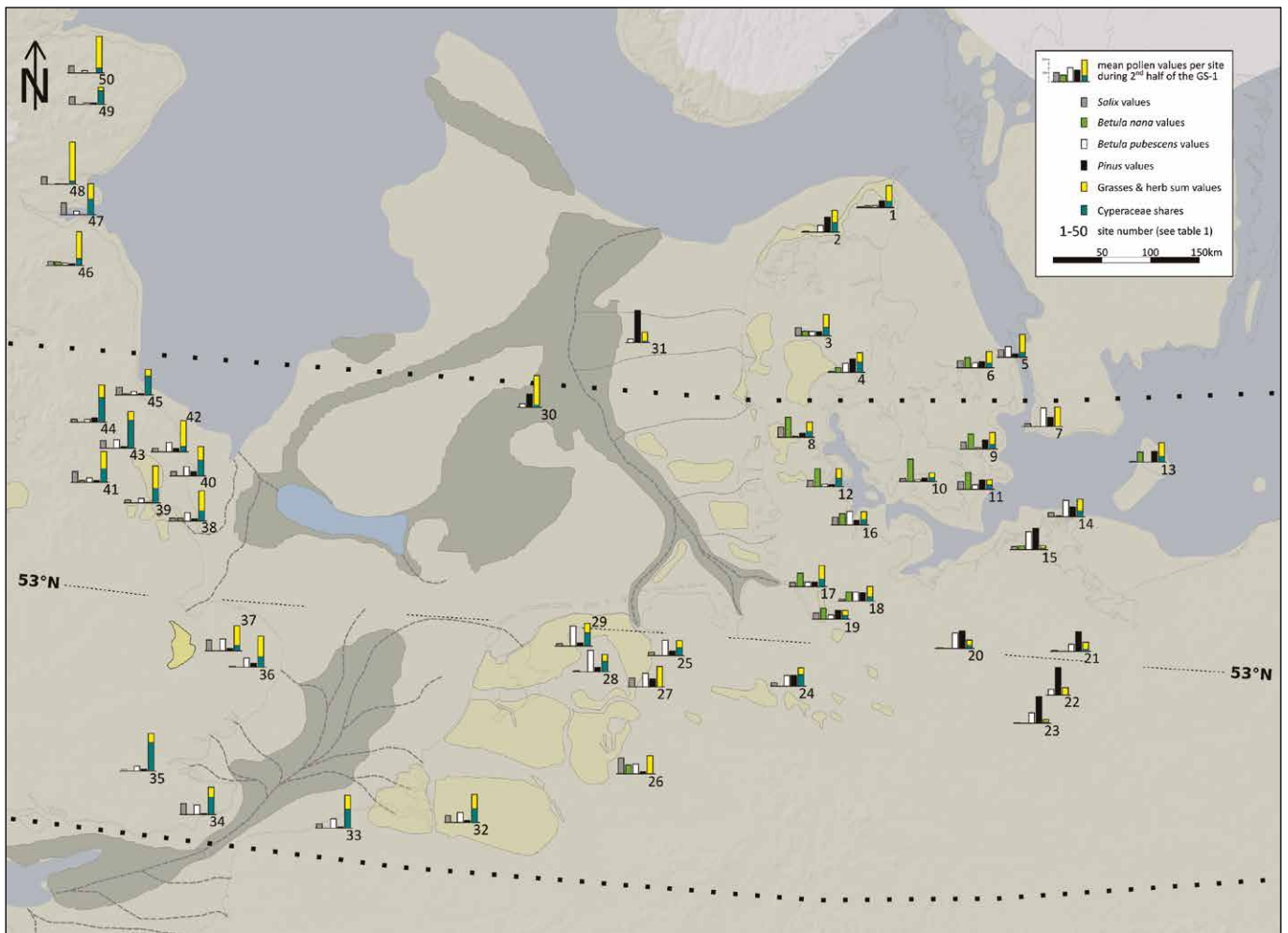


Figure 2: Overview map on the assumed topography of Doggerland of the second half of the GS-1 including mean pollen frequency (percentage of total terrestrial pollen) of selected pollen types from locations given in table 1.

occurs with values exceeding 10%. Despite these high values, these insect-pollinated species are still underrepresented in the diagrams, and it can be assumed that *Salix* made up a significant proportion of the vegetation in this area during GS-1. The high distribution was probably related to the combination of high humidity (which is also indicated by the Cyperaceae), the low temperatures and the strong winds. Simmonds *et al.* (2021) describe the vegetation in Britain as dominated by *B. nana* and *Salix* sp., although *B. pubescens* was also present (Walker *et al.* 2003) and had a higher proportion in the *Betula-Salix*-woodland to the east, towards northern Belgium and the south-western Netherlands (Verbruggen 1979). According to Sparks and West (1972), however, Britain was characterised as an almost treeless but highly variable tundra.

Walker *et al.* (1994) mentions *Salix reticulata* (snow willow) – alongside the widespread *S. herbacea* – as a component of this variable birch-willow shrubland/tundra in Britain, thus emphasizing the open character of the landscape of southern Britain in contrast to, for example, central Lower Saxony or Mecklenburg-Western Pomerania. Moreover, Walker *et al.* (1994) highlight the widespread

low Alpine scrub vegetation in Britain, which Lang (1994) describes as oceanic tundra due to the high occurrence of *Salix* sp. as compared to *Betula* sp.

Due to the assumed strong geomorphological dynamics of the wetland between Britain and the Netherlands (in what is now the Southern Bight), it can be said that probably only a few trees were part of the vegetation. In analogy to the surrounding mainland, the wetland was probably likewise dominated by herbaceous *Salix* species, *B. nana*, shrubby *B. pubescens* and many Cyperaceae (Walker *et al.* 1994).

Across central Britain and Northumberland, the distribution of Cyperaceae is higher, compared to the south (Vyle and Degenhardt 1967). Cyperaceae often exceed the values of grasses, which may be interpreted as large-scale waterlogging of wide areas. Hunt and Birks (1982) as well as Godwin (1975) describe this as waterlogging due to permafrost formation. Such an effect can also be assumed for the wetland area in the centre of Doggerland. It is likely that extensive but shallow marshy areas with a lot of Cyperaceae (possibly including *Eriophorum* sp., cottongrass) prevailed and created a landscape that likely resembled thermokarst regions due to the discontinuous permafrost (Fig. 3).



Figure 3: The arctic/subarctic landscapes of Doggerland during the GS-1 likely featured a diversity of low growing plants. 3a: *Empetrum hermaphroditum* – crowberry. 3b: *Salix herbacea* – dwarf willow. 3c: *Eriophorum scheuchzeri* – arctic cottongrass. 3d: *Betula glandulosa* – glandular (dwarf) birch (close relative of *B. nana*). All pictures taken in southern and western Greenland in summer 2021 by the author.

The shallow permafrost would also have led to a high level of erosion in the central wetland of Doggerland as far as England and provide space for numerous heliophytes (Hunt and Birks 1982; Godwin 1975; Walker 2004), which are reflected in the herbs and herbaceous *Salix* species in England (especially *S. herbacea*; Blackburn 1952), as well as in the grasses and heathland elements of DOG 1/site 30 (Krüger *et al.* 2017).

As in Schleswig-Holstein and the Danish islands, the northernmost distribution of *B. pubescens* in Britain, as evidenced by macrofossils (Blackburn 1952; Walker *et al.* 2003), correlates approximately to the boundary between discontinuous and continuous permafrost (Isarin 1997). By analogy, the treeline-ecotone extended across Doggerland between the central wetland of Doggerland and the ‘land bridge’ to the south (Mills 2022). From Schleswig-Holstein, the treeline-ecotone was shaped by *B. pubescens* and *B. nana*, presumably crossing the heath-covered sand belt to the west. Westwards, the ecotone

featured a fewer and more southerly distributions of *B. pubescens* towards Britain, with rapidly increasing proportions of *Salix*.

The elevated Dogger Hills were presumably very sparsely vegetated. It is assumed that there were many barren grounds, or scattered grass-covered areas. A speculative survey is particularly challenging here, as studies from this region by Behre and Menke (1969) and others have investigated Holocene peats, which only formed when this area was already an island.

Scotland lies in the area of continuous permafrost during GS-1. Here, *Artemisia* dominates large parts of the landscape (Birks and Mathewes 1978; Pennington 1977; Webb and Moore 1982; Walker *et al.* 1994). The only woody species here were the sparsely represented *Salix herbacea* (Beerling 1998). Many heathland elements, especially *Empetrum*, are partially represented (Huntley 1994; Walker and Lowe 2019). In contrast, grasses and sedges are common and testify to a barren



Figure 4: Overview map on hypothesized biomes and ecotones across Doggerland as outlined in the text.

landscape with elements of a meagre grassland-biome, which were also found in northern Jutland. The analogy suggests that the area north of the Dogger Hills, on Ling Bank, was likewise sparsely vegetated, with few grasses and probably *Artemisia* and *Rumex*, typical of thin, minerogenic soils.

The compilation of pollen and macrofossil data and the extrapolation into the North Sea Basin illustrates, albeit hypothetically, how diverse the landscape and vegetation of Doggerland already was even during a comparatively short time slice of the Late Glacial. Doggerland was certainly no homogeneous tundra (Fig. 4).

However, Coles (1998) is likely correct in her assumption that the GS-1 did not manage to completely displace tree growth from Doggerland. As summarized by Theuerkauf and Joosten (2012), the greatest change between the GI-1 and the GS-1 occurred in the treeline-ecotone, which supposedly formed a wide band across Doggerland, passing sand belts and wetlands.

Nevertheless, this contribution is only a speculative study and there are large knowledge gaps until core material becomes available from preferably small-scale lakes across the North Sea Basin.

## Conclusions of a speculative vegetation survey

Based on a brief overview on climate, geomorphology and vegetation records it is possible to perform a speculative vegetation survey of Doggerland during the second half of the Greenland Stadial 1. The survey cannot claim to be entirely spatially precise but offers important conclusions and novel, testable hypotheses. From comparison and resulting analogy to many records of the surrounding current dryland, gradients and zones can be identified (Fig. 4). These are at least five large-scale biomes and a treeline-ecotone across Doggerland:

1. Wide, meagre, grasslands in the western expansion of Jutland towards the EPV.
2. Central wetlands with potential thermokarst features and an abundance of sedges.
3. A corridor between Britain and the Netherlands towards northern Germany that – limited by a sand belt and the central wetlands – likely corresponded to an East-West treeline-ecotone across Doggerland.
4. Large scale, high energetic and highly dynamic wetlands with birch shrubs, herbal willows and sedges

in the area of the present Southern Bight and the English Channel.

5. Highly erosive environments with open grounds and grassland across the Dogger Hills and the Ling Bank.
6. A hypothetical SW-NE directed (cover-)sand belt dominated by heath elements (mainly crowberry) in eastern Doggerland.

As can be seen from Fig. 2, the survey has distinct limitations, particularly the lack of Late Glacial pollen and macrofossil records from the North Sea Basin. In addition, records with very different properties are compared to each other. Nevertheless, the conclusions drawn by analogy stand on firm foundations, especially due to the increasing knowledge on the geomorphology of Doggerland, Late Glacial climatic reconstructions and the generalisation of large vegetation units. This allows for the formulation of hypotheses, such as the treeline-ecotone or the heathland-belt and thus provides directions for future research.

## References

- Abegunrin, A. Hepp, D. A., Gugliotta, M. and Mörz, T. 2023. The submerged Palaeo-Ems River in the Quaternary stratigraphic context of the German North Sea. *The Holocene* 33(12), 1504–1516.
- Andresen, K. J., Hepp, D. A., Keil, H. and Spiess, V. 2024. Seismic morphologies of submerged late glacial to Early Holocene landscapes at the eastern Dogger Bank, central North Sea Basin—implications for geo-archaeological potential. *Geological Society, London, Special Publications* 525(1), SP525-2021-2155.
- Antoine, P., Catt, J., Lautridou, J. P. and Sommé, J. 2003. The loess and coversands of northern France and southern England. *Journal of Quaternary Science: Published for the Quaternary Research Association* 18(3-4), 309–318.
- Bakke, J., Lie, Ø., Heegaard, E. Dokken, T., Haug, G. H., Birks, H. H., Dulski, P. and Nilsen, T. 2009. Rapid oceanic and atmospheric changes during the Younger Dryas cold period. *Nature Geoscience* 2(3), 202–205.
- Baldini, J. U. L., Brown, R. J. and Mawdsley, N. 2018. Evaluating the link between the sulfur-rich Laacher See volcanic eruption and the Younger Dryas climate anomaly. *Climate of the Past* 14(7), 969–990.
- Bartley, D. D. 1962. The stratigraphy and pollen analysis of lake deposits near Tadgaster, Yorkshire. *New Phytologist* 61(3), 277–287.
- Bartley, D. D., Chambers, C. and Hart-Jones, B. 1976. The vegetational history of parts of south and east Durham. *New Phytologist* 77(2), 437–468.
- Beckett, S. 1981. Pollen diagrams from Holderness, north Humberside. *Journal of Biogeography*. 177–198.
- The formulated zones illustrate how Doggerland constituted a European centre of transition as, for example, this is where the treeline-ecotone stretched during the GS-1. Doggerland was the link between the birch and pine dominated woodlands of North-Northeastern Germany and the open oceanic tundra of central Britain, where tree species are dominated by shrubby willows.
- The results of the survey are a clear statement of the floral diversity of Doggerland, which was equally relevant to humans, animals and ultimately archaeological understanding in the present day.

## Acknowledgements

The authors would like to thank Morten Fischer Mortensen for insights into yet unpublished pollen data from Denmark. Also, we are grateful to Will Mills, Daniel Hepp, Ole Bennike and Katrine Juul Andresen for intense discussions of Doggerland's geomorphology. We also like to thank two anonymous reviewers for helpful suggestions and comments.

- Björck, S., Walker, M. J. C., Cwynar, L. C. Johnsen, S., Knudsen, K. L., Lowe, J. J. and Wohlfarth, B. 1998. An event stratigraphy for the Last Termination in the North Atlantic region based on the Greenland ice-core record: a proposal by the INTIMATE group. *Journal of Quaternary Science* 13(4), 283–292.
- Blackburn, K. B. 1952. The dating of a deposit containing an elk skeleton found at Neasham near Darlington, County Durham. *The New Phytologist* 51(3), 364–377.
- Bos, J. A. A., Bohncke, S. J. P. and Janssen, C. R. 2006. Lake-Level Fluctuations and Small-Scale Vegetation Patterns During the Late Glacial in The Netherlands. *Journal of Paleolimnology* 35(2), 211–238.
- Brauer, A., Haug, G. H., Dulski, P., Sigman, D. M. and Negendank, J. F. 2008. An abrupt wind shift in western Europe at the onset of the Younger Dryas cold period. *Nature Geoscience* 1(8), 520–523.
- Bronk Ramsey, C., Albert, P. G., Blockley, S. P. E., Hardiman, M., Housley, R. A., Lane, C. S., Lee, S., Matthews, I. P., Smith, V. C. and Lowe, J. J. 2015. Improved age estimates for key Late Quaternary European tephra horizons in the RESET lattice. *Quaternary Science Reviews* 118, 18–32.
- Brooks, A. J., Bradley, S. L., Edwards, R. J. and Goodwyn, N. 2011. The palaeogeography of Northwest Europe during the last 20,000 years. *Journal of Maps* 7, 573–587.
- Brown, A., Russell, J., Scaife, R., Tizzard, L., Whittaker, J. and Wyles, S. F. 2018. Lateglacial/early Holocene palaeoenvironments in the southern North Sea Basin: new data from the Dudgeon offshore wind farm. *Journal of Quaternary Science* 33(6), 597–610.
- Casparie, W. A. and van Zeist, W. 1960. A late-glacial lake deposit near Waskemeer (Prov. of Friesland). *Acta Botanica Neerlandica* 9(2), 191–196.
- Chapman, H. P. and Lillie, M. C. 2004. Investigating Doggerland through analogy: the example of Holderness, east Yorkshire, UK. In: Flemming, N. C. (ed.) *Submarine Prehistoric Archaeology of the North Sea*. CBA Research Report 141, 41–45.
- Coles, B. J. 1998. Doggerland: a Speculative Survey. *Proceedings of the Prehistoric Society* 64, 45–81.
- Cotterill, C., Dove, D., Long, D., James, L., Duffy, C., Mulley, S., Forsberg, C. F. and Tjelta, T. I. 2012. Dogger Bank-A Geo Challenge. *SUT Offshore Site Investigation and Geotechnics*. SUT, SUT-OSIG-12-10.
- Danukalova, G., Lefort, J.-P., Monnier, J.-L., Osipova, E., Pustoc'h, F. and Le Bannier, J. C. 2017. Sedimentological and malacological comparisons between the Upper Saalian and Upper Weichselian loess superimposed in the Nantois cliff (Brittany, France): Reconstruction of their environments south of the British Ice Sheet. *Archéosciences* 41(2), 63–84.
- De Klerk, P. 2002. Changing vegetation patterns in the Endinger Bruch area (Vorpommern, NE Germany) during the Weichselian Lateglacial and Early Holocene. *Review of Palaeobotany and Palynology* 119, 275–309.
- De Klerk, P. 2004. Confusing concepts in Lateglacial stratigraphy and geochronology: origin, consequences, conclusions (with special emphasis on the type locality Bøllingsø). *Review of Palaeobotany and Palynology* 129(4), 265–298.
- Degerbøl, M. and Krog, H. 1959. *The reindeer (Rangifer tarandus L.) in Denmark: zoological and geological investigations of the discoveries in Danish Pleistocene deposits*. København, Munksgaard.
- Dreibrodt, S., Krüger, S., Weber, J. and Feeser, I. 2020. Limnological response to the Laacher See eruption (LSE) in an annually laminated Allerød sediment sequence from the Nahe palaeolake, northern Germany. *Boreas* 50(1), 167–183.
- Emery, A. R., Hodgson, D.M., Barlow, N. L., Carrivick, J. L., Cotterill, C. J. and Phillips, E. 2019. Left high and dry: deglaciation of Dogger Bank, North Sea, recorded in proglacial lake evolution. *Frontiers in Earth Science* 234.
- Erdtman, G. 1925. Some micro-analyses of 'Moorlog' from the Doggerbank. *Essex Nat* 21: 107–112.
- Fitch, S., Gaffney, V. and Thomson, K. 2007. In Sight of Doggerland: From speculative survey to landscape exploration. *internet archaeology - the premier e-journal for archaeology* (22).
- Fitch, S., Thomson, K. and Gaffney, V. 2005. Late Pleistocene and Holocene depositional systems and the palaeogeography of the Dogger Bank, North Sea. *Quaternary Research* 64(2), 185–196.
- Gaffney, V. 2007. *Mapping Doggerland - The Mesolithic Landscapes of the Southern North Sea*. Oxford, Archaeopress.
- Gaffney, V. and Fitch, S. 2022a. *Europe's Lost Frontiers: Volume 1: Context and Methodology*. Oxford, Archaeopress.
- Gaffney, V. and Fitch, S. 2022b. Europe's Lost Frontiers: context and development. In: Gaffney, V. and Fitch, S. (eds.), *Europe's Lost Frontiers: Context and Methodology*. Oxford, Archaeopress, 1–15.
- Gearey, B. 2008. Late-glacial vegetation change in East Yorkshire: A radiocarbon dated pollen diagram from Routh Quarry, Beverley. *Proceedings of the Yorkshire Geological Society* 57(2), 45–54.
- Gearey, B., Hopla, E.-J., Boomer, I., Smith, D., Marshall, P., Fitch, S., Griffiths, S. and Tappin, D. R. 2017. Multi-proxy palaeoecological approaches to submerged landscapes: a case study from 'Doggerland', in the southern North Sea. In: Williams, M., Hill, T., Boomer, I. and Wilkinson, I. P. (eds.), *The archaeological and forensic applications of microfossils: a deeper understanding of human history*. The Micropalaeontological Society, 35–53.

- Godwin, H. 1975. The history of the British flora: a factual basis for phytogeography. 541.
- Godwin, H. and Godwin, M. 1933. British Maglemose harpoon sites. *Antiquity* 7(25), 36–48.
- Grimm, S. B., Eriksen, B. V., Krüger, S., Reuter, T., Wild, M. and Weber, M.-J. 2021. Late Glacial occupation of northern Germany and adjacent areas. Revisiting the archives. In: Gaudzinski-Windheuser, S. and Jöris, O. (eds.), *The Beef behind all Possible Pasts – The Tandem Festschrift in Honour of Elaine Turner and Martin Street*. Monographien des Römisch-Germanischen Zentralmuseums 157. Mainz, Verlag des Römisch-Germanischen Zentralmuseums, 433–457.
- Harff, J., Flemming, N., Groh, A., Hünicke, B., Lericolais, G., Meschede, M., Rosentau, A., Sakellariou, D., Uścinowicz, S., Zhang, W. and Zorita, E. 2017. Sea Level and Climate. In *Submerged Landscapes of the European Continental Shelf: Quaternary Paleoenvironments*. In: Flemming, N. C., Harff, J., Moura, D., Burgess, A. and Bailey, G. N. (eds.), *Submerged Landscapes of the European Continental Shelf*. Hoboken: John Wiley & Sons Ltd. Hoboken, NJ, USA.
- Hepp, D. A., Romero, O. E., Mörz, T., De Pol-Holz, R. and Hebbeln, D. 2019. How a river submerges into the sea: a geological record of changing a fluvial to a marine paleoenvironment during early Holocene sea level rise. *Journal of Quaternary Science* 34(7), 581–592.
- Hepp, D. A., Warnke, U., Hebbeln, D. and Mörz, T. 2017. Tributaries of the Elbe palaeovalley: features of a hidden palaeolandscape in the German Bight, North Sea. In: Bailey, G., Harff, J., Sakellariou, D. (eds), *Under the Sea: Archaeology and Palaeolandscapes of the Continental Shelf*. Coastal Research Library 20. Cham, Springer, 211–222. DOI: 10.1007/978-3-319-53160-1\_14
- Hjelstuen, B. O., Sejrup, H. P., Valvik, E. and Becker, L. W. 2018. Evidence of an ice-dammed lake outburst in the North Sea during the last deglaciation. *Marine Geology* 402, 118–130.
- Hoebe, P., Cohen, K., Busschers, F. S., van Heteren, S. and Peeters, J. H. M. 2024. Early Holocene inundation of Doggerland and its impact on hunter-gatherers: An inundation model and dates-as-data approach. *Quaternary International* 694, 26–50.
- Hoek, W. Z. and Bohncke, S. J. P. 2002. Climatic and environmental events over the Last Termination, as recorded in The Netherlands: a review. *Netherlands Journal of Geoscience - Geologie en Mijnbouw* 81(1), 123–137.
- Hunt, T. G. and Birks, H. 1982. Devensian late-glacial vegetational history at Sea Mere, Norfolk. *Journal of Biogeography* 9(6), 517–538.
- Huntley, B. 1994. Late Devensian and Holocene palaeoecology and palaeoenvironments of the Morrone Birkwoods, Aberdeenshire, Scotland. *Journal of Quaternary Science* 9(4), 311–336.
- Innes, J., Rutherford, M., O'Brien, C., Bridgland, D. R., Mitchell, W. A. and Long, A. J. 2009. Late Devensian environments in the Vale of Mowbray, North Yorkshire, UK: evidence from palynology. *Proceedings of the Geologists' Association* 120(4), 199–208.
- Innes, J. B., Rutherford, M. M., Bridgland, D. R., Gearey, B. R., Lillie, M. C., Mitchell, W. A., O'Brien, C. E., Jones, R. T. and Thompson, G. J. 2024. Lateglacial Interstadial to mid-Holocene stratigraphy and palynology at Pepper Arden Bottoms, North Yorkshire, UK. *Proceedings of the Geologists' Association*, 135(5), 569–588. DOI: 10.1016/j.pgeola.2024.08.005
- Isarin, R. F. 1997. Permafrost distribution and temperatures in Europe during the Younger Dryas. *Permafrost and Periglacial Processes* 8(3), 313–333.
- Iversen, J. 1942. En pollenanalytisk Tidfæstelse af Ferskvandslagene ved Nørre Lyngby. *Meddelelser fra Dansk Geologisk Forening* 10, 130–151.
- Johns, S. 2001. On the Late Pleistocene and Holocene history of vegetation and human impact in the Ücker valley, north-eastern Germany. *Vegetation History and Archaeobotany* 10, 97–104.
- Johns, S. 2007. Palynological investigations into the Late Pleistocene and Holocene history of vegetation and settlement at the Löddigsee, Mecklenburg, Germany. *Vegetation History and Archaeobotany* 16(2), 157–169.
- Kobe, F., Bittner, M. K., Leipe, C., Hoelzmann, P., Long, T., Wagner, M., Zibulski, R. and Tarasov, P. E. 2019. Lateglacial and early Holocene environments and human occupation in Brandenburg, eastern Germany. *Geography, Environment, Sustainability* 12(2), 132–147.
- Kolstrup, E. 2007. Lateglacial older and younger coversand in northwest Europe: chronology and relation to climate and vegetation. *Boreas* 36(1), 65–75.
- Kolstrup, E. and Jørgensen, J. B. 1981. Older and Younger Coversand in southern Jutland. *Bulletin of the Geological Society of Denmark* 30, 71–77.
- Krüger, S. 2020. *Lateglacial environmental transformations in northern Europe evidenced by high-resolution palynology and tephrochronology from Lake Bølling and the Nahe palaeolake. New insights into terminology, vegetation development and human-environmental interaction*. PhD thesis. Kiel, Christian-Albrechts University Kiel.
- Krüger, S. 2024. Diverse phenotypes of Late Glacial – Early Holocene downy birch (*Betula pubescens* Erh.) and the morphology of early Preboreal tree stands in southern Schleswig-Holstein. *E&G Quaternary Science Journal* 73, 23–40.
- Krüger, S. and Bogaard, C. 2020. Small shards and long distances – three cryptotephra layers from the Nahe palaeolake including the first discovery of Laacher

- See Tephra in Schleswig-Holstein (Germany). *Journal of Quaternary Science* 36(1), 8–19.
- Krüger, S. and Damrath, M. 2019. In search of the Bølling-Oscillation: a new high resolution pollen record from the locus classicus Lake Bølling, Denmark. *Vegetation History and Archaeobotany* 29(2): 189–211.
- Krüger, S., Dörfler, W., Bennike, O. and Wolters, S. 2017. Life in Doggerland – palynological investigations of the environment of prehistoric hunter-gatherer societies in the North Sea Basin. *Eiszeitalter und Gegenwart* 66(1), 3–13.
- Krüger, S., Mortensen, M. F. and Dörfler, W. 2020. Sequence completed – palynological investigations on Lateglacial/Early Holocene environmental changes recorded in sequentially laminated lacustrine sediments of the Nahe palaeolake in Schleswig-Holstein, Germany. *Review of Palaeobotany and Palynology* 280, 104271. DOI:10.1016/j.revpalbo.2020.104271
- Lampe, R., Janke, W., Schult, M., Meng, S. and Lampe, M. 2016. Multiproxy-Untersuchungen zur Paläoökologie und-hydrologie eines spätglazial-bis frühholozänen Flachsees im nordostdeutschen Küstengebiet (Glowe-Paläosee/Insel Rügen). *E&G Quaternary Science Journal* 65(1), 41–75.
- Lang, G. 1994. *Quartäre Vegetationsgeschichte Europas*. Jena/Stuttgart/New York, Gustav Fischer.
- Lowe, J., Matthews, I., Mayfield, R., Lincoln, P., Palmer, A., Staff, R. and Timms, R. 2019. On the timing of retreat of the Loch Lomond (‘Younger Dryas’) Readvance icefield in the SW Scottish Highlands and its wider significance. *Quaternary Science Reviews* 219, 171–186.
- Menke, B. 1996. Palynologische Untersuchung des Vibrokerns “Gauss 1987/5“ aus der südlichen Nordsee. *Geologisches Jahrbuch Reihe A* 146. 177–182.
- Merkt, J. and Müller, H. 1999. Varve chronology and palynology of the Lateglacial in Northwest Germany from lacustrine sediments of Hämelsee in Lower Saxony. *Quaternary International* 6(1), 41–59.
- Mills, W. 2022. *Late glacial geography of the Channel river network. Southeastern England and its central position in the British peninsula and ties with Northwestern Europe*. PhD thesis. Oxford. University of Oxford.
- Mortensen, M. F., Birks, H. H., Christensen, C., Holm, J., Noe-Nygaard, N., Odgaard, B.V., Olsen, J. and Rasmussen, K. L. 2011. Lateglacial vegetation development in Denmark – New evidence based on macrofossils and pollen from Slotseng, a small-scale site in southern Jutland. *Quaternary Science Reviews* 30(19–20), 2534–2550.
- Mortensen, M. F., Henriksen, P. S. and Bennike, O. 2014a. Living on the good soil: relationships between soils, vegetation and human settlement during the late Allerød period in Denmark. *Vegetation History and Archaeobotany* 23(3), 195–205.
- Mortensen, M. F., Henriksen, P. S., Christensen, C., Petersen, P. V. and Olsen, J. 2014b. Late glacial and early Holocene vegetation development in southeast Denmark – palaeoenvironmental studies from a small lake basin close to the Palaeolithic site of Hasselø. In: Gulløv, H. C. (ed.) *Northern Worlds - landscapes, interactions and dynamics*. Copenhagen: Publications from the National Museum Studies in Archaeology & History, 169–188.
- Neugebauer, I., Brauer, A., Dräger, N., Dulski, P., Wulf, S., Plessen, B., Mingram, J., Herzsuh, U. and Brande, A. 2012. A Younger Dryas varve chronology from the Rehwise palaeolake record in NE Germany. *Quaternary Science Reviews* 36, 91–102.
- Palmer, A., Rose, J. and Rasmussen, S. 2012. Evidence for phase-locked changes in climate between Scotland and Greenland during GS-1 (Younger Dryas) using micromorphology of glaciolacustrine varves from Glen Roy. *Quaternary Science Reviews* 36, 114–123.
- Patton, H., Hubbard, A., Andreassen, K., Auriac, A., Whitehouse, P. L., Stroeve, A. P., Shackleton, C., Winsborrow, M., Heyman, J. and Hall, A. M. 2017. Deglaciation of the Eurasian ice sheet complex. *Quaternary Science Reviews* 169, 148–172.
- Pennington, W. 1977. The Late Devensian flora and vegetation of Britain. *Philosophical Transactions of the Royal Society of London. B, Biological Sciences* 280(972), 247–271.
- Preece, R. and Bridgland, D. 1999. Holywell Coombe, Folkestone: a 13,000 year history of an English chalkland valley. *Quaternary Science Reviews* 18(8–9), 1075–1125.
- Prins, L. T. and Andresen, K. J. 2019. Buried late Quaternary channel systems in the Danish North Sea—Genesis and geological evolution. *Quaternary Science Reviews* 223, 105943. DOI:10.1016/j.quascirev.2019.105943
- Prochnow, M., Hepp, J., Strobel, P., Zech, R., Acharya, S., Szidat, S., Rius, D., Millet, L., Glaser, B. and Zech, M. 2024. Late Glacial summer paleohydrology across Central Europe. *Scientific Reports* 14(1), 30546.
- Rasmussen, S. O., Andersen, K. K., Svensson, A. M., Steffensen, J. P., Vinther, B. M., Clausen, H. B., Siggaard-Andersen, M. L., Johnsen, S. J., Larsen, L. B., Dahl-Jensen, D. and Bigler, M. 2006. A new Greenland ice core chronology for the last glacial termination. *Journal of Geophysical Research* 111, D06102. DOI:10.1029/2005JD006079
- Rasmussen, S. O., Bigler, M., Blockley, S. P., Blunier, T., Buchardt, S. L., Clausen, H. B., Cvijanovic, I., Dahl-Jensen, D., Johnsen, S. J., Fischer, H. and Gkinis, V. 2014. A stratigraphic framework for abrupt climatic changes during the Last Glacial period based on three synchronized Greenland ice-core records: refining and extending the INTIMATE event stratigraphy. *Quaternary Science Reviews* 106, 14–28.

- Reid, C. 1913. *Submerged forests*. London *et al.*, Cambridge University Press.
- Ruddiman, W. F. and McIntyre, A. 1981. The North Atlantic Ocean during the last deglaciation. *Palaeogeography, Palaeoclimatology, Palaeoecology* 35, 145–214.
- Schenk, F., Väiliranta, M., Muschitiello, F., Tarasov, L., Heikkilä, M., Björck, S., Brandefelt, J., Johansson, A. V., Näslund, J. O. and Wohlfarth, B. 2018. Warm summers during the Younger Dryas cold reversal. *Nature communications* 9(1), 1634. DOI:10.1038/s41467-018-04071-5
- Simmonds, M., Branch, N., Marshall, P., Hosfield, R. and Black, S. 2021. New insights into Late Devensian Lateglacial and early Holocene environmental change: Two high-resolution case studies from SE England. *Review of Palaeobotany and Palynology* 287, 104364.
- Simmons, I. G., Cummins, G. E., Taylor, B. and Innes, J. B. 2022. Lateglacial to mid-Holocene vegetation history in the eastern Vale of Pickering, northeast Yorkshire, UK: Pollen diagrams from palaeolake Flixton. *Quaternary* 5(4), 52.
- Sparks, B. W. and West, R. G. 1972. *The Ice Age in Britain*. London, Methuen.
- Theuerkauf, M. and Joosten, H. 2009. Substrate dependency of Lateglacial forests in north-east Germany: untangling vegetation patterns, ecological amplitudes and pollen dispersal in the past by downscaling regional pollen. *Journal of Biogeography* 36(5), 942–953.
- Theuerkauf, M. and Joosten, H. 2012. Younger Dryas cold stage vegetation patterns of central Europe - climate, soil and relief controls. *Boreas* 41(3), 391–407.
- Usinger, H. 1975. *Pollenanalytische und stratigraphische Untersuchungen an zwei Spätglazial-Vorkommen in Schleswig-Holstein*. Mitteilungen der Arbeitsgemeinschaft Geobotanik in Schleswig-Holstein und Hamburg 25. Kiel, Prof. Dr. E. W. Raabe.
- Usinger, H. 1978. Bölling-Interstadial und Laacher Bimstuff in einem neuen Spätglazial-Profil aus dem Vallensgaard Mose/Bornholm. Mit pollen-größenstatistischer Trennung der Birken. *DGU Årbog* 1977, 5-29.
- Usinger, H. 1981. Zur spät- und frühpostglazialen Vegetationsgeschichte der schleswig-holsteinischen Geest nach dem Pollen und Pollendichtediagramm aus dem Esinger Moor. *Pollen et Spores* XXIII(3–4), 389–433.
- Usinger, H. 2004. Vegetation and climate of the lowlands of northern Central Europe and adjacent areas around the Younger Dryas - Preboreal transition - with special emphasis on the Preboreal oscillation. In: Terberger, T. and Eriksen, B.V. (eds), *Hunters in a changing world - Environment and Archaeology of the Pleistocene - Holocene Transition (ca. 11000 – 9000 B.C.) in Northern Central Europe*. Internationale Archäologie Arbeitsgemeinschaft Kongress 5. Rahden/Westf., Verlag Marie Leidorf, 1–26.
- Usinger, H. and Wolf, A. 1982. Zur vegetations- und klimageschichtlichen Gliederung des Alleröds nach Untersuchungen im Blixmoor und Kubitzbergmoor (Schleswig-Holstein). *Schriften Naturwissenschaftlicher Verein Schleswig-Holstein* 52, 29–45.
- van der Hammen, T. 1949. De Allerød-oscillatie in Nederland, pollenanalytisch onderzoek van een laatglaciale meerafzetting in Drente, I & II. *Koninklijke Nederlandse Academie van Wetenschappen Proceedings* 52, 69–75 and 169–176.
- van der Hammen, T. 1951. Late-Glacial flora and periglacial phenomena in The Netherlands. *Leidse Geologische Mededelingen* 17, 71–183.
- van Geel, B., Coope, G. and van der Hammen, T. 1989. Palaeoecology and Stratigraphy of the Lateglacial Type Section at Usselo (The Netherlands). *Review of Palaeobotany and Palynology* 60(1–2), 25–129.
- Verbruggen, C. 1979. Vegetational and palaeoecological history of the Late-Glacial period in Sandy Flanders (Belgium). *Acta Universitatis Ouluensis* 82(3), 133–142.
- Vermeer-Louman, G. G. 1934. Pollen-analytisch onderzoek van den West Nederlandschen bodem.
- Vyle, C. and Degenhardt, C. 1967. Evolution of the natural landscape in the Corbridge area of Northumberland: A Group Study. *Planning Outlook* 3(1-2), 53–70.
- Walker, M. 2004. A Lateglacial pollen record from Hallsenna Moor, near Seascale, Cumbria, NW England, with evidence for arid conditions during the Loch Lomond (Younger Dryas) Stadial and early Holocene. *Proceedings of the Yorkshire Geological Society* 55(1), 33–42.
- Walker, M., Bohncke, S., Coope, G., O'Connell, M., Usinger, H. and Verbruggen, C. 1994. The Devensian/Weichselian Late-glacial in northwest Europe (Ireland, Britain, north Belgium, The Netherlands, northwest Germany). *Journal of Quaternary Science* 9(2), 109–118.
- Walker, M., Coope, G. and Lowe, J. 1993. The Devensian (Weichselian) Lateglacial palaeoenvironmental record from Gransmoor, East Yorkshire, England: a contribution to the 'North Atlantic seaboard programme' of IGCP-253, 'Termination of the Pleistocene'. *Quaternary Science Reviews* 12(8), 659–680.
- Walker, M. and Lowe, J. 2019. Lateglacial environmental change in Scotland. *Earth and Environmental Science Transactions of the Royal Society of Edinburgh* 110(1-2), 173–198.
- Walker, M. J. C., Coope, G. R., Sheldrick, C., Turney, C.S., Lowe, J. J., Blockley, S. P. E. and Harkness, D. D. 2003. Devensian Lateglacial environmental changes in

- Britain: a multi-proxy environmental record from Llanilid, South Wales, UK. *Quaternary Science Reviews* 22(5-7), 475–520.
- Webb, J. and Moore, P. 1982. The late Devensian vegetational history of the Whitlaw Mosses, southeast Scotland. *New Phytologist* 91(2), 341–398.
- Whitehead, H. 1920. More about “Moorlog”—a peaty deposit from the Dogger Bank in the North Sea. *Essex Nat* 19, 242–250.
- Whitehead, H. and Goodchild, H. 1912. Some Notes on Moorlog, a Peaty Deposit from the Dogger Bank in the North Sea. With a Report on the Plant Remains by Clement Reid and Cleanor M. Reid. *Essex Naturalist. Geologiska Föreningen i Stockholm Förhandlingar* 34(7), 809–809.
- Whittington, G., Edwards, K. J. and Caseldine, C. J. 1991. Late-and post-glacial pollen-analytical and environmental data from a near-coastal site in north-east Fife, Scotland. *Review of Palaeobotany and Palynology* 68(1-2), 65–85.
- Whittington, G., Fallick, A. E. and Edwards, K. J. 1996. Stable oxygen isotope and pollen records from eastern Scotland and a consideration of Late-glacial and early Holocene climate change for Europe. *Journal of Quaternary Science* 11(4), 327–340.
- Woldstedt, P. 1954. *Das Eiszeitalter. Grundlinien einer Geologie des Quartärs*. Stuttgart, Ferdinand Enke.
- Wolters, S. 2002. *Vegetationsgeschichtliche Untersuchungen zur spätglazialen-und holozänen Landschaftsentwicklung in der Döberitzer Heide - (Brandenburg)*. Dissertationes Botanicae 366. Berlin/Stuttgart, J. Kramer.
- Wolters, S., Zeiler, M. and Bungenstock, F. 2010. Early Holocene environmental history of sunken landscapes: pollen, plant macrofossil and geochemical analyses from the Borkum Riffgrund, southern North Sea. *International Journal of Earth Sciences* 99(8), 1707–1719.

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# Isotopic niche partitioning between reindeer and horse in Northwest Europe during the Final Upper Palaeolithic

Dorothee G. Drucker

## Abstract

The Final Upper Palaeolithic (c. 15000–11500 cal BP) in northwestern Europe witnessed the demise of the rich and productive ecosystem of the so-called mammoth steppe, marked by the extinction or extirpation of much of the megafauna. This study examines the diet and habitat of reindeer (*Rangifer tarandus*) and horse (*Equus ferus*) from northern Germany, southwestern Britain, the Meuse Basin, and the Rhine Basin using the stable isotope ratios of carbon, nitrogen and sulphur ( $\delta^{13}\text{C}$ ,  $\delta^{15}\text{N}$  and  $\delta^{34}\text{S}$  values) in bone collagen. Between c. 16000–12850 cal BP (Late Pleniglacial and Late Glacial Interstadial or GS-2.1a/GI-1), reindeer consistently exhibit higher  $\delta^{13}\text{C}$  values than horses across all regions, reflecting their preferential foraging on lichens. In contrast, no clear distinction is observed in  $\delta^{15}\text{N}$  or  $\delta^{34}\text{S}$  values between species. From c. 12850 to 11650 cal BP (Younger Dryas or GS-1), the difference in  $\delta^{13}\text{C}$  between reindeer and horse increases, due to a simultaneous rise in reindeer and decrease in horses. This pattern suggests the intensification of tundra-like conditions during the GS-1, which likely favoured the re-expansion of reindeer populations in response to increased lichen availability. A slight increase in  $\delta^{15}\text{N}$  values in both species may reflect increased aridity during the GS-1. A marked reduction in the range of  $\delta^{34}\text{S}$  values is observed in both reindeer and horses during this period, with a potential regional pattern. This may reflect homogenization of the isotopic composition of biologically available sulphur and/or reduced variability in animal home range.

**Keywords:** Collagen, stable isotopes, dietary reconstruction, Palaeolithic

## Introduction

During a large part of the Upper Palaeolithic (c. 50000 to 11500 cal BP), terrestrial ecosystems in Eurasia were dominated by a nonanalog steppe-tundra mosaic landscape that developed under generally cold and dry context (e.g. Guthrie 1982). This so-called Mammoth Steppe (or *Mammuthus-Coelodonta* faunal complex) was characterized by a large community of herbivores and carnivores, including many megafaunal species. The co-existence of such a diverse assemblage was supported by unexpectedly high productivity under colder and drier conditions than those found today at comparable latitudes (e.g. Guthrie 2001; Zimov *et al.* 2012). Dietary partitioning among large herbivores was first demonstrated through plant macroremains associated with herbivore fossils in Alaska and

Siberia (Guthrie 2001) and was later supported on broader temporal and geographical scales through stable isotope analyses (review in Drucker 2022).

Stable carbon ( $^{13}\text{C}/^{12}\text{C}$ ) and nitrogen ( $^{15}\text{N}/^{14}\text{N}$ ) isotope ratios in terrestrial animals reflect characteristics of their habitat, specifically the environmental conditions of plant photosynthesis in peri-arctic, boreal and temperate environments where the  $\text{C}_3$  photosynthetic pathway predominates (review in Kohn 2010). In these contexts, humidity, and, to a lesser extent, temperature are the driving factors of the stable carbon isotope values in plants following a negative correlation (review in Diefendorf *et al.* 2010; Kohn 2010). Stable nitrogen isotope values in herbivore bone collagen depend both on their foraging sources and on climatic conditions. Grazing (consumption of graminoids and forbs) generally leads to higher  $^{15}\text{N}/^{14}\text{N}$  ratios than browsing (consumption of tree and shrub leaves). In addition, higher temperatures and/or increased aridity result in higher  $^{15}\text{N}/^{14}\text{N}$  ratios in plants and their consumers (*e.g.* Amundson *et al.* 2003; Craine *et al.* 2009).

More recently, stable sulphur isotope ratios ( $^{34}\text{S}/^{32}\text{S}$ ) in the bone collagen of terrestrial herbivores have been found to depend on local geochemical processes and the geological background of their foraging territories, with further influences from hydrological inputs (*e.g.* rain, groundwater) and atmospheric deposition (*e.g.* sea-spray, volcanic emission) (review in Nehlich 2015). In continental contexts, anaerobic conditions, such as those occurring in waterlogged soils during episodes of permafrost thaw, lead to lower  $^{34}\text{S}/^{32}\text{S}$  ratios in plants (review in Stevens *et al.* 2025).

The species-specific clustering in carbon and nitrogen isotope ratios among large herbivores of the mammoth steppe in western Europe appears to decline after the Last Glacial Maximum (LGM or Greenland Stadial 3, *c.* 27200–23500 cal BP). Indeed, lower isotopic contrasts are observed among the surviving species, such as horse (*Equus ferus*) and reindeer (*Rangifer tarandus*) (*e.g.* Drucker 2022; Schwartz-Narbonne *et al.* 2019). Differences in carbon isotope ratios were nevertheless maintained, albeit to a lesser extent, with the highest values found in reindeer, reflecting their preferential consumption of lichen over vascular plants, and the lowest in horse until the Greenland Stadial 2.1 (GS-2.1) (*e.g.* Drucker 2022; Schwartz-Narbonne *et al.* 2019). The Final Upper Palaeolithic (*c.* 15000–11500 cal BP) occurs after most megafaunal species had become extinct or extirpated in northwestern Europe, and during the northward retreat of cold-adapted species such as reindeer (*e.g.* Sommer *et al.* 2014; Stuart 2015).

This paper aims to examine niche partitioning (diet and habitat) between horse and reindeer in northwestern Europe during two key periods: (1) the end of the Pleniglacial and Late Glacial Interstadial or GS-2.1a/GI-1

(*c.* 16000–12850 cal BP), following the extinction of much of the megafauna and coinciding with the first episodes of global warming after the Pleniglacial; (2) the Younger Dryas or GS-1 (*c.* 12850–11650 cal BP), when colder conditions returned allowing a final re-expansion of reindeer before the onset of Holocene warming. For this purpose, carbon, nitrogen and sulphur isotope data were considered to explore potential differences in diet and habitat use between reindeer, likely showing migratory behaviour, and horse, which is typically more sedentary.

## Material and methods

Carbon and nitrogen isotope data for reindeer and horse ( $n=200$ ) were compiled from published studies conducted in regions where both GS-2.1a/GI-1 (*c.* 16000–12840 cal BP) and GS-1 (12830–11750 cal BP) are documented, as confirmed by direct radiocarbon dating of some specimens (Fig. 1; Tabs. S1 and S2). The dataset includes material from the Ahrensburg Tunnel Valley (Ahrensburg TV) in northern Germany (Drucker *et al.* 2011b; 2016; Rivals *et al.* 2020), southwestern Britain (SW Britain) in southwestern United-Kingdom (Jacobi and Higham 2009a; 2009b; 2011; Kaagan 2000; Reade *et al.* 2023; Schulting *et al.* 2013; Stevens and Hedges 2004; Stevens *et al.* 2008; 2010), the Meuse Basin in southern Belgium and northern France (Bridault, pers. comm., 2025; Cromb e *et al.* 2024; Drucker *et al.* 2016; Germonpr e *et al.* 2009; Hedges *et al.* 1994; Reade *et al.* 2023; Stevens and Hedges 2004; Stevens *et al.* 2009b), and the Rhine Basin in western Germany (Bronk Ramsey *et al.* 2002; Hedges *et al.* 1987; 1989; Higham, pers. comm., 2015; Reade *et al.* 2023; Stevens and Hedges 2004; Stevens *et al.* 2009a; Stevens, pers. comm., 2017). Unpublished isotopic measurements on one reindeer from Borneck, directly dated to the GI-1 (Riede *et al.* 2010), was also added to this database (Tab. S1 and S2).

Sulfur isotope data were recently published by Stevens *et al.* (2025) and were included for the specimens already compiled for carbon and nitrogen isotopes ( $n=42$ ) from the Rhine Basin (Andernach, G nnersdorf, Bedburg-K nigshoven), Meuse Basin (Goyet, Trou de Chaleux, Trou du Frontal, Trou des Nutons) and SW Britain (Aveline’s Hole, Sun Hole, Cathole, Foxhole cave, Chelm’s Combe, Kent’s Cavern, Pixies’s Hole, Three Holes Cave, King Arthur’s Cave). In addition, this study includes new sulphur isotope data ( $n=31$ ) from Gough’s Cave (SW Britain, one GS-1 reindeer, one GS-2.1a/GI-1 reindeer, and eight GS-2.1a/GI-1 horses), Remouchamps (Meuse Basin, thirteen GS-1 reindeer, one GS-1 horse), Nichet-2 (Meuse Basin, one GS-1 horse), Borneck (Ahrensburg TV, one GI-1 reindeer), Meiendorf (Ahrensburg TV, one GS-2.1a/GI-1 horse) and Stellmoor (Ahrensburg TV, four GS-1 horses) (Tabs. S1 and S2).

As far as new isotopic measurements are concerned, the samples were treated in the facilities of the Biogeology research group at the Department of Geosciences of the

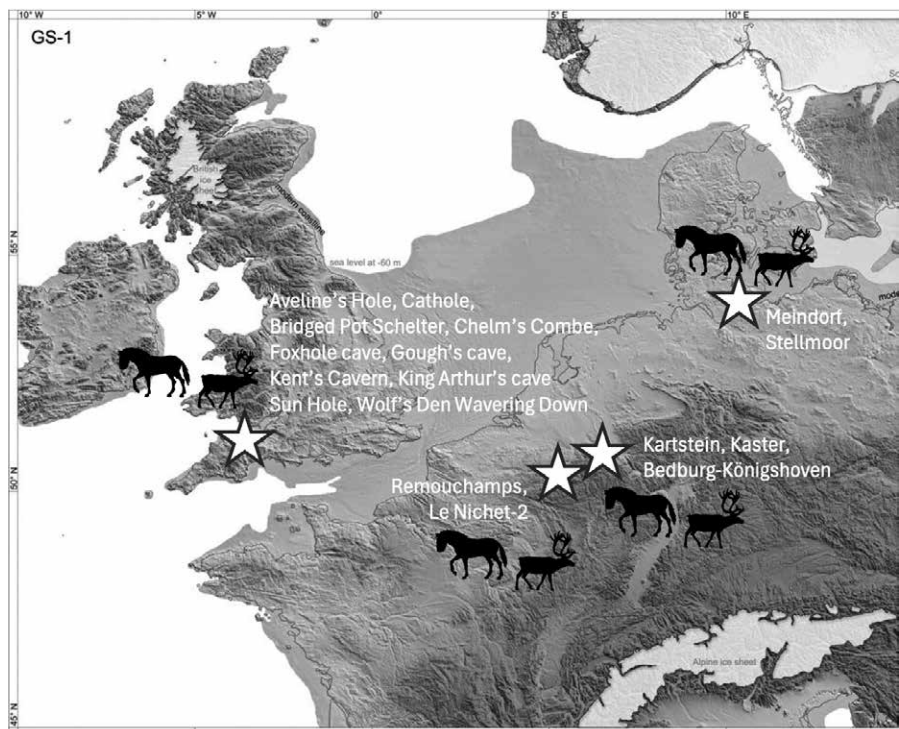
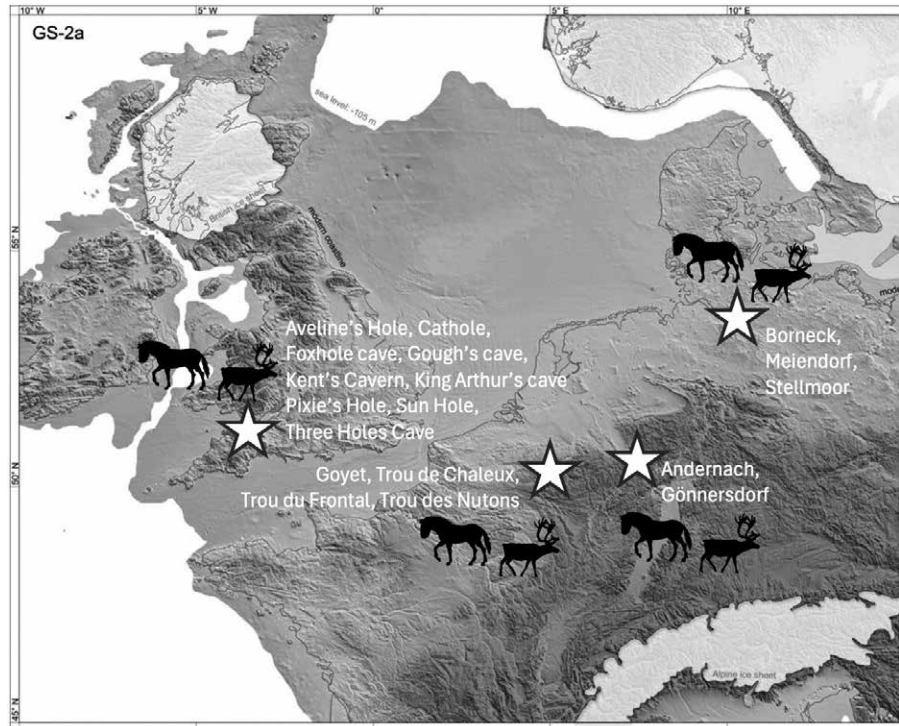


Figure 1: Geographical location of the archaeological sites from the Ahrensburg Tunnel Valley, the Rhine Basin, the Meuse Basin, and southwestern Britain. Map background from Grimm (2007).

University of Tübingen. Following Krajcarz *et al.* (2024b), chunks of bones were manually ground into powder after successive cleaning in Milli-Q water and acetone using an ultrasonic bath. Collagen extraction was conducted following the Acid-Base-Acid protocol described in Krajcarz *et al.* (2024a) with a first demineralization step in HCl

(1M), followed by a soaking step in NaOH (0.125 M) and a final step of gelatinization at pH=3 and freeze-drying. Isotopic measurements were carried out at the Isotope Geochemistry laboratory of the Department of Geosciences of the University of Tübingen on c. 1 mg of collagen. Elemental analysis of carbon, nitrogen and sulphur (C,

N, S) and isotopic measurements ( $\delta^{13}\text{C}$ ,  $\delta^{15}\text{N}$ ,  $\delta^{34}\text{S}$ ) were performed using an NC2500 CHN-elemental analyser coupled to a Thermo Quest Delta+XL mass spectrometer. The reproducibility for the content measurement of N, C and S is 5 %. The  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values are expressed in marine carbonate (V-PDB) and atmospheric nitrogen (AIR), respectively. The measurements were calibrated using international reference materials USGS24 ( $\delta^{13}\text{C} = -16.00\text{‰}$ ) and IAEA-N-2 ( $\delta^{15}\text{N} = +20.30\text{‰}$ ) and monitored using the two in-house standards consisting in modern collagen of camel ( $\delta^{13}\text{C} = -14.76\text{‰}$ ,  $\delta^{15}\text{N} = +8.03\text{‰}$ ) and elk ( $\delta^{13}\text{C} = -23.87\text{‰}$ ,  $\delta^{15}\text{N} = +2.66\text{‰}$ ). Analytical error was  $\pm 0.1\text{‰}$  for  $\delta^{13}\text{C}$ ,  $\pm 0.2\text{‰}$  for  $\delta^{15}\text{N}$ , based on within-run replicate measurement of laboratory standards (albumen, modern collagen, USGS 24, IAEA-N-2). The biochemical reliability of the collagen was confirmed by considering its chemical composition, specifically a collagen C/N atomic ratio (C:N) ranging from 2.9 to 3.6 (DeNiro 1985), and a carbon content above 13% (Ambrose 1990; Guiry and Szpak 2021).

The  $\delta^{34}\text{S}$  measurements were performed with a reproducibility of  $\pm 0.4\text{‰}$  in a separate run and expressed in Canyon Diablo Troilite (V-CDT) after calibration using international reference materials NBS-123 ( $\delta^{34}\text{S} = +17.10\text{‰}$ ), NBS-127 ( $\delta^{34}\text{S} = +20.30\text{‰}$ ), IAEA-S-1 ( $\delta^{34}\text{S} = -0.30\text{‰}$ ), and IAEA-S-3 ( $\delta^{34}\text{S} = -32.30\text{‰}$ ). Retained  $\delta^{34}\text{S}$  for these new measurements are those whose C/S and N/S atomic ratios (C:S and N:S) fell within the range of 300–900 and 100–300, respectively (Nehlich and Richards 2009), and whose collagen sulphur content (S) ranged from 0.13 to 0.26%, as observed in modern mammalian collagen (Aldrich collagen  $\delta^{34}\text{S} = +1.84\text{‰}$ , modern camel  $\delta^{34}\text{S} = +13.63\text{‰}$ , and modern elk  $\delta^{34}\text{S} = +6.68\text{‰}$ ) measured in the same sets.

## Results and discussion

### Carbon and nitrogen stable isotopes

During the GS-2.1a/GI-1, reindeer  $\delta^{13}\text{C}$  values varied from -20.2 to -18.6‰ overall. The lowest values were observed in the Rhine Basin (-20.2 to -19.2‰) and the highest in the Meuse Basin (-19.3 to -18.6‰) (Fig. 2; Tab. 1). Over the period, reindeer  $\delta^{15}\text{N}$  values ranged from +0.4 to +3.2‰. Generally lower  $\delta^{15}\text{N}$  values occurred in the Meuse Basin (+0.4 to +2.8‰) and the Rhine Basin (+0.6 to +2.9‰) compared with the SW Britain values (+1.8 to +3.1‰) and the Ahrensburg TV values (+1.0 to +3.2‰) (Fig. 2; Tab. 1). Reindeer from the Meuse Basin therefore exhibited the highest  $\delta^{13}\text{C}$  values and among the lowest  $\delta^{15}\text{N}$  values for this period. In contrast, reindeer from the Ahrensburg TV and SW Britain fall within similar  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  ranges. During the GS-1, reindeer showed a tendency toward higher  $\delta^{13}\text{C}$  values across all regions compared with the previous period (Fig. 3; Tab. 1). This increase was particularly marked in the Ahrensburg TV, where GS-1 reindeer  $\delta^{13}\text{C}$  values ranged from -18.9 to -17.5‰ (n=12), compared

with a range of -19.7 to -18.8‰ (n=19) for their GS-2.1a/GI-1 counterparts. This pattern most likely reflects the return of cold and tundra-like conditions that favour lichen growth. Dental microwear analysis of GS-1 reindeer of the Ahrensburg TV indeed indicates an increased lichen consumption compared with the GI-1 (Rivals *et al.* 2020).

Interestingly, the range of  $\delta^{15}\text{N}$  values does not change substantially between the two periods in the Ahrensburg TV as well as in the Rhine Basin and the Meuse Basin. In contrast, reindeer from SW Britain display higher  $\delta^{15}\text{N}$  values during the GS-1 (+3.3 to +7.1‰, n=8) compared with the GS-2.1a/GI-1 (+1.8 to +3.1‰, n=3). Although based on a limited number of specimens, the GS-1 reindeer from SW Britain show higher  $\delta^{15}\text{N}$  values than those from all other regions during the same period (+1.2 to +3.5‰ altogether). This pattern of increasing  $\delta^{15}\text{N}$  values toward more northwestern locations in western Europe is consistent with the isoscape reconstruction proposed by Reade *et al.* (2023). However, it is difficult to attribute this difference solely to temperature, given the relatively high-latitude position of SW Britain. As a matter of fact, the strong correlation between faunal  $\delta^{15}\text{N}$  and Mean Annual Temperature, observed from the LGM to the Late Glacial, appears to weaken during the Younger Dryas and Early Holocene (Reade *et al.* 2023). In addition, potential large-scale movements of reindeer complicate interpretations based only on local environmental factors. Nevertheless, more oceanic conditions in SW Britain compared to the more inland settings of the other regions have been proposed to explain the higher  $\delta^{15}\text{N}$  values (Drucker *et al.* 2011b).

Horse  $\delta^{13}\text{C}$  values during the GS-2.1a/GI-1 period ranged from -21.7‰ to -19.8‰ without clear distinction among the selected regions (Fig. 2; Tab. 1). Similarly, horse  $\delta^{15}\text{N}$  values clustered between -0.2‰ and +3.9‰ without a clear regional pattern. During the GS-1, horse  $\delta^{13}\text{C}$  values ranged from -21.9‰ to -20.9‰ (Fig. 3; Tab. 1). Interestingly, GS-1 horses from the Ahrensburg TV and SW Britain showed lower  $\delta^{13}\text{C}$  values (-21.9 to -21.4‰ and -21.9 and -21.3‰, respectively) than horses from the same locations during the GS-2.1a/GI-1 period (-21.4 to -19.8‰ and -21.3 to -20.0‰, respectively). Horse  $\delta^{15}\text{N}$  values ranged from +1.9 to +4.5‰, with the highest values recorded in the Meuse Basin (+4.3‰ and +4.4‰) and SW Britain (+4.5‰) (Fig. 3; Tab. 1). As a matter of fact,  $\delta^{15}\text{N}$  values in horses were similar to or higher during the GS-1 than during the GS-2.1a/GI-1 in these two regions, as well as in the Ahrensburg TV.

During the GS-2.1a/GI-1 period, the greatest  $\delta^{13}\text{C}$  contrast between horse and reindeer occurs in the Meuse Basin (Fig. 2). In this region, reindeer, so far represented by only three samples, show the highest  $\delta^{13}\text{C}$  values among all areas, suggesting substantial lichen consumption in a tundra-like environment (*e.g.* Drucker *et al.* 2010; Iacumin 2000). In contrast, no clear distinction in  $\delta^{15}\text{N}$  values appears

Time period	Region	Species	N	$\delta^{13}\text{C}$ min	$\delta^{13}\text{C}$ max	$\delta^{13}\text{C}$ mean	$\delta^{13}\text{C}$ SD	N	$\delta^{15}\text{N}$ min	$\delta^{15}\text{N}$ max	$\delta^{15}\text{N}$ mean	$\delta^{15}\text{N}$ SD	N	$\delta^{34}\text{S}$ min	$\delta^{34}\text{S}$ max	$\delta^{34}\text{S}$ mean	$\delta^{34}\text{S}$ SD
GS-1	Ahrensburg TV	Reindeer	12	-18.9	-17.5	-18.2	0.4	12	1.2	3.2	2.0	0.6	0	-	-	-	-
GS-1	Ahrensburg TV	Horse	4	-21.9	-21.4	-21.6	0.2	4	2.9	3.9	3.3	0.5	4	-1.6	5.3	1.9	3.9
GS-2.1a/GI-1	Ahrensburg TV	Reindeer	19	-19.7	-18.8	-19.3	0.3	19	1.0	3.2	1.8	0.5	1	1.1	1.1	1.1	0.0
GS-2.1a/GI-1	Ahrensburg TV	Horse	4	-21.4	-19.8	-20.6	0.7	4	1.5	2.7	2.2	0.5	1	-10.0	-10.0	-10.0	0.0
GS-1	Rhine Basin	Reindeer	1	-17.6	-17.6	-17.6	0.0	1	2.5	2.5	2.5	0.0	0	-	-	-	-
GS-1	Rhine Basin	Horse	5	-21.8	-21.3	-21.5	0.2	5	1.9	3.7	2.8	0.7	1	-0.7	-0.7	-0.7	0
GS-2.1a/GI-1	Rhine Basin	Reindeer	16	-20.2	-19.2	-19.7	0.3	16	0.6	2.9	1.9	0.6	1	-6.8	-6.8	-6.8	0
GS-2.1a/GI-1	Rhine Basin	Horse	49	-21.7	-20.1	-21.0	0.3	55	0.6	3.6	1.9	1.9	13	-14.6	-0.8	-10.1	3.4
GS-1	Meuse Basin	Reindeer	14	-19.2	-17.6	-18.5	0.5	14	1.3	3.5	2.3	0.6	13	6.4	8.8	7.8	0.8
GS-1	Meuse Basin	Horse	2	-21.5	-20.9	-21.2	0.5	2	4.3	4.4	4.4	0.1	2	4.8	5.3	5.0	0.4
GS-2.1a/GI-1	Meuse Basin	Reindeer	3	-19.3	-18.6	-19.0	0.4	3	0.4	2.8	1.9	1.3	2	-6.6	7.3	0.3	9.9
GS-2.1a/GI-1	Meuse Basin	Horse	19	-21.1	-20.3	-20.8	0.2	20	0.4	3.9	2.0	0.7	7	-13.2	0.6	-9.1	4.6
GS-1	SW Britain	Reindeer	8	-19.5	-17.6	-18.7	0.5	11	3.3	7.1	4.2	1.1	10	6.3	15.0	10.8	2.9
GS-1	SW Britain	Horse	3	-21.9	-21.3	-21.6	0.3	5	2.0	4.5	3.6	1.0	2	8.0	12.0	10.0	2.8
GS-2.1a/GI-1	SW Britain	Reindeer	3	-19.7	-19.0	-19.3	0.4	5	1.8	3.1	2.6	0.5	3	-16.9	12.4	-1.7	14.7
GS-2.1a/GI-1	SW Britain	Horse	17	-21.3	-20.0	-20.5	0.3	25	-0.2	3.1	1.2	0.7	19	-13.6	9.1	-6.9	6.1

Table 1: Minimum (min), maximum (max), mean and standard-deviations (SD) of  $\delta^{13}\text{C}$ ,  $\delta^{15}\text{N}$  and  $\delta^{34}\text{S}$  values for reindeer (*Rangifer tarandus*) and horse (*Equus ferus*) according to the time period and region. N: number of samples.

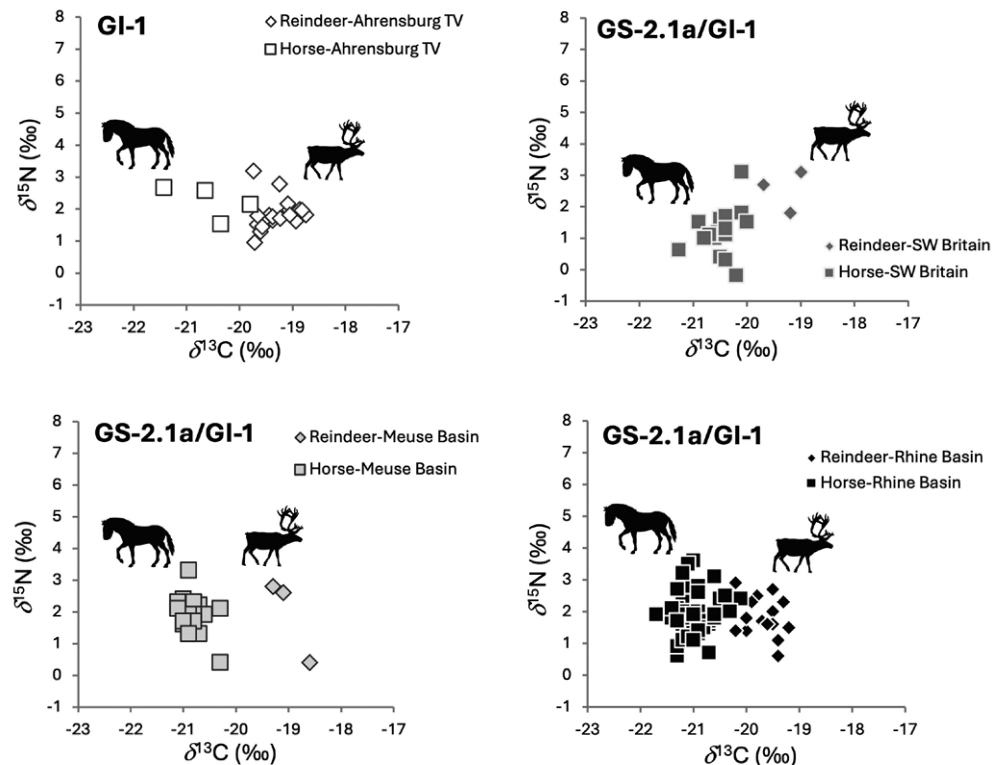


Figure 2:  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values of reindeer (*Rangifer tarandus*) and horse (*Equus ferus*) from the Ahrensburg Tunnel Valley (Ahrensburg TV), southwestern Britain (SW Britain), the Meuse Basin and the Rhine Basin during the GS-2.1a/GI-1 period.

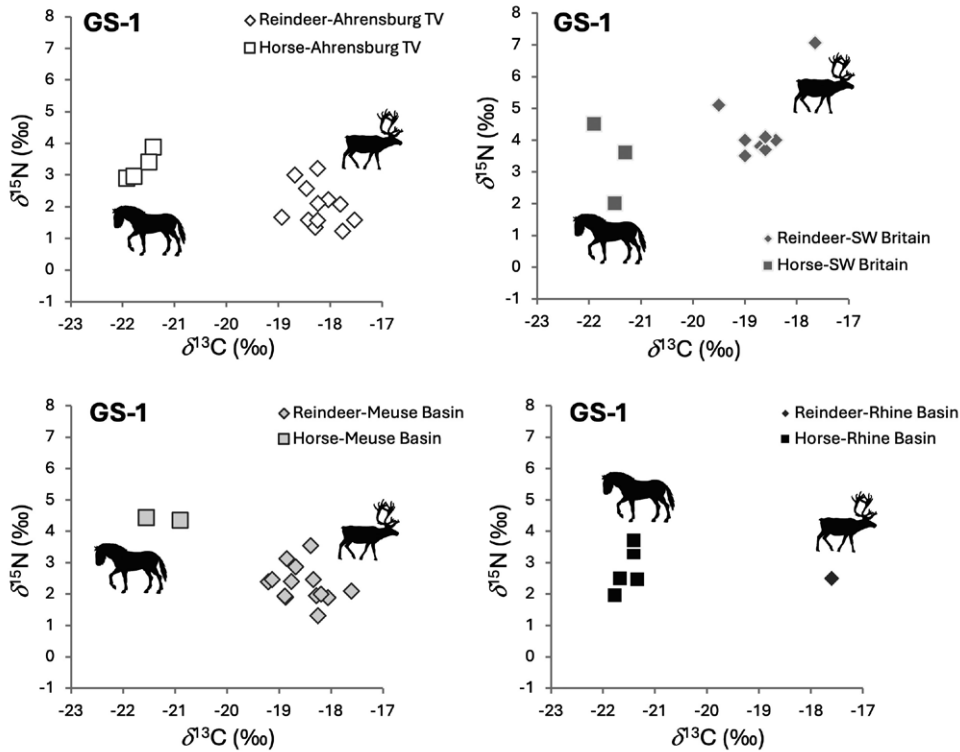


Figure 3:  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values of reindeer (*Rangifer tarandus*) and horse (*Equus ferus*) from the Ahrensburg Tunnel Valley (Ahrensburg TV), southwestern Britain (SW Britain), the Meuse Basin and the Rhine Basin during the GS-1 period.

between the two species, although higher  $\delta^{15}\text{N}$  values associated with higher grass consumption might have been expected in horse (e.g. Schwartz-Narbonne *et al.* 2019). Dental microwear analysis of Late Glacial horse from the Paris Basin, however, indicates a tendency toward browsing not seen in their Last Glacial Maximum counterparts (Bignon-Lau *et al.* 2021). Conversely, lichen consumption by reindeer, a known mixed-feeder, does not consistently result in higher or lower  $\delta^{15}\text{N}$  values, given the variability documented in modern peri-arctic ecosystems (review in Drucker 2022).

During the GS-1, elevated  $\delta^{13}\text{C}$  values observed in reindeer together with lower horse  $\delta^{13}\text{C}$  values compared with the preceding GS-2.1a/GI-1 period indicate a stronger isotopic partitioning between the two species. The increased contrast is well-illustrated in the Ahrensburg TV and SW Britain (Fig. 3). In the Rhine Basin, the only reindeer specimen available for GS-1 shows a notably high  $\delta^{13}\text{C}$  value (-17.6‰), contrasting sharply with contemporaneous horses (-21.8‰ to -21.3‰) and with reindeer from the previous period (-20.2‰ to -19.2‰). Even in the Meuse Basin, where  $\delta^{13}\text{C}$  differences between reindeer and horse were already pronounced during the GS-2.1a/GI-1 period, the contrast appears to have increased further during the GS-1, at least based on the available sample. Elevated  $\delta^{13}\text{C}$  values in reindeer have been linked to higher availability of lichen resulting from colder conditions during the Younger Dryas in northern Germany (e.g. Drucker *et al.* 2016), which may have affected all studied regions, and/or the broader

migratory range of reindeer herds. In contrast, horse  $\delta^{15}\text{N}$  values in SW Britain remain close to or slightly lower than those of reindeer, whereas they are similar to or slightly higher than reindeer values in the Ahrensburg TV and Meuse Basin. However, these contrasts are based on a limited number of specimens and do not yet provide clear evidence of dietary or habitat partitioning.

### Sulphur stable isotopes

Based on a limited number of individuals (n=3),  $\delta^{34}\text{S}$  values of GS-2.1a/GI-1 reindeer from SW Britain varied from -16.9 to +12.4‰, a wide range that encompasses the values found in other regions based on one to two individuals (Fig. 4; Tab. 1). For the GS-1 period, reindeer  $\delta^{34}\text{S}$  values were available only from SW Britain and the Meuse Basin, ranging from +6.3 to +15.0‰ (n=10) and +6.4 to +8.8‰ (n=13), respectively. This corresponds to a notably reduced range of variation (2.4 to 8.7‰) compared with the GS-2.1a/GI-1 period (29.3‰ for SW Britain alone), which cannot be explained solely by difference in sample size. It is noteworthy that all Meuse Basin reindeer originated from the site of Remouchamps, whereas SW Britain reindeer were collected from six different archaeological sites. The relatively higher homogeneity of  $\delta^{34}\text{S}$  values in reindeer during the GS-1 could reflect either a more limited territory, resulting in low sulphur isotope variability, or the presence of larger migratory herds averaging sulphur isotope signatures across different regions. The latter scenario aligns better with the expected large migration pattern

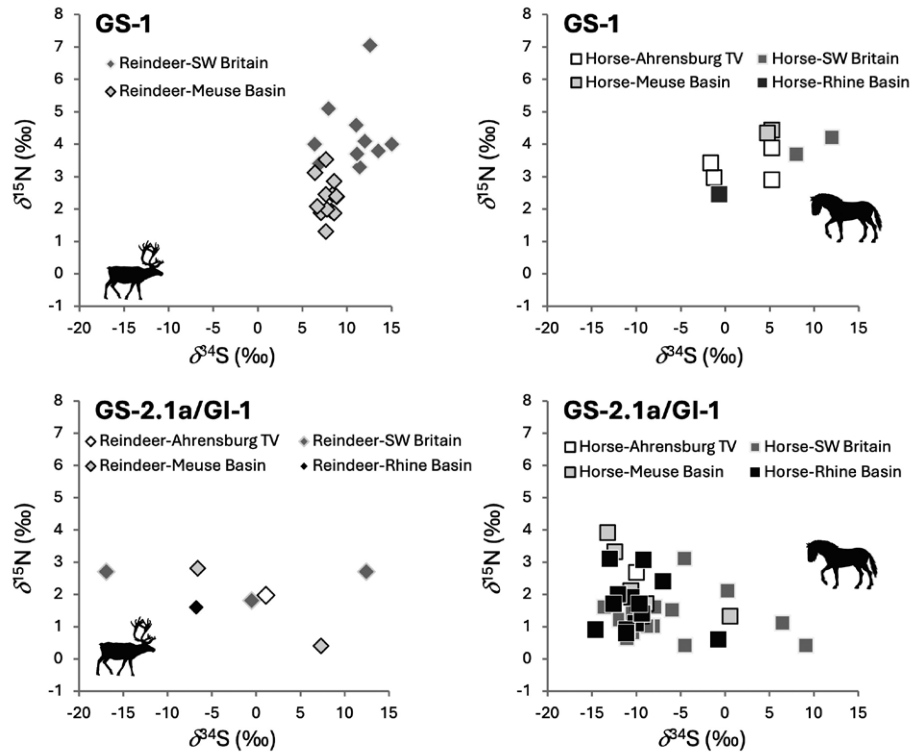


Figure 4:  $\delta^{34}\text{S}$  and  $\delta^{15}\text{N}$  values of reindeer (*Rangifer tarandus*) and horse (*Equus ferus*) from the Ahrensburg Tunnel Valley (Ahrensburg TV), southwestern Britain (SW Britain), the Meuse Basin and the Rhine Basin during the GS-2.1a/GI-1 and GS-1 period.

hypothesized for Younger Dryas reindeer populations (e.g. Price *et al.* 2017). In contrast, smaller, highly territorial groups during the GS-2.1a/GI-1 may explain the high  $\delta^{34}\text{S}$  variability observed in SW Britain.

During the GS-2.1a/GI-1, horses from SW Britain displayed a wide range of  $\delta^{34}\text{S}$  values (-13.6 to +9.1‰), encompassing nearly all values found in the other regions. An exception was observed for one individual from the Meuse Basin, which showed a value of -14.6‰ (Fig. 4; Tab. 1). As with reindeer, no clear regional pattern could be detected in horse  $\delta^{34}\text{S}$  values. Indeed, the range of variability (23.7‰ altogether) is roughly equivalent to that observed in reindeer from the same period. Given that horses are typically expected to have a relatively restricted annual range, this wide spread of  $\delta^{34}\text{S}$  values likely reflect a broad variability in the isotopic composition of biologically available sulfur at the regional scale.

Horse  $\delta^{34}\text{S}$  values during the GS-1 ranged from -1.6‰ to +12.0‰, representing the highest values recorded for this species across the studied regions during the GS-2.1a/GI-1. Horses from SW Britain appear to exhibit distinctly higher  $\delta^{34}\text{S}$  values, although this observation is based on a very limited number of samples (n=2). A larger dataset would be needed to confirm whether any specimens displayed  $\delta^{34}\text{S}$  values lower than -2‰ during the GS-1. Such information would help determine whether the apparent homogenisation of the  $\delta^{34}\text{S}$  values observed in the reindeer reflects reduced sulphur isotopic variability or a reduced home range.

No clear differences in  $\delta^{34}\text{S}$  were observed between horse and reindeer from the same region and time period. However, the patchy chronological and regional record may not allow full capture of the  $\delta^{34}\text{S}$  variability in either species.

### Carbon, nitrogen and sulphur isotopes on directly dated specimens

Chronological tendency can be further explored by considering the directly dated specimens of reindeer and horse, as reported in Figs. 5 and 6.

The colder and drier condition of the GS-1 likely favoured the re-expansion of lichens in northwestern Europe, which may explain the higher  $\delta^{13}\text{C}$  values observed in reindeer (Fig. 5). In horses, relatively higher  $\delta^{15}\text{N}$  values during the GS-1 may be better explained by increased aridity, whereas lower  $\delta^{13}\text{C}$  values may reflect reduced temperatures (Fig. 6). The GS-1 environmental conditions likely enhanced dietary partitioning between horse and reindeer, as indicated by the greater contrast in  $\delta^{13}\text{C}$  values compared with the GS-2.1a/GI-1.

Higher  $\delta^{15}\text{N}$  and  $\delta^{34}\text{S}$  values in plants consumed by large herbivores are generally associated with soils characterized by high microbial activity, good drainage, and warmer temperatures (e.g. Drucker *et al.* 2011a, 2012; Reade *et al.* 2021; Stevens *et al.* 2025). However, these conditions do not fully match those reconstructed within the Younger Dryas in northern Europe (e.g. Isarin *et al.* 1998). Several studies suggest a climatic bipartition within

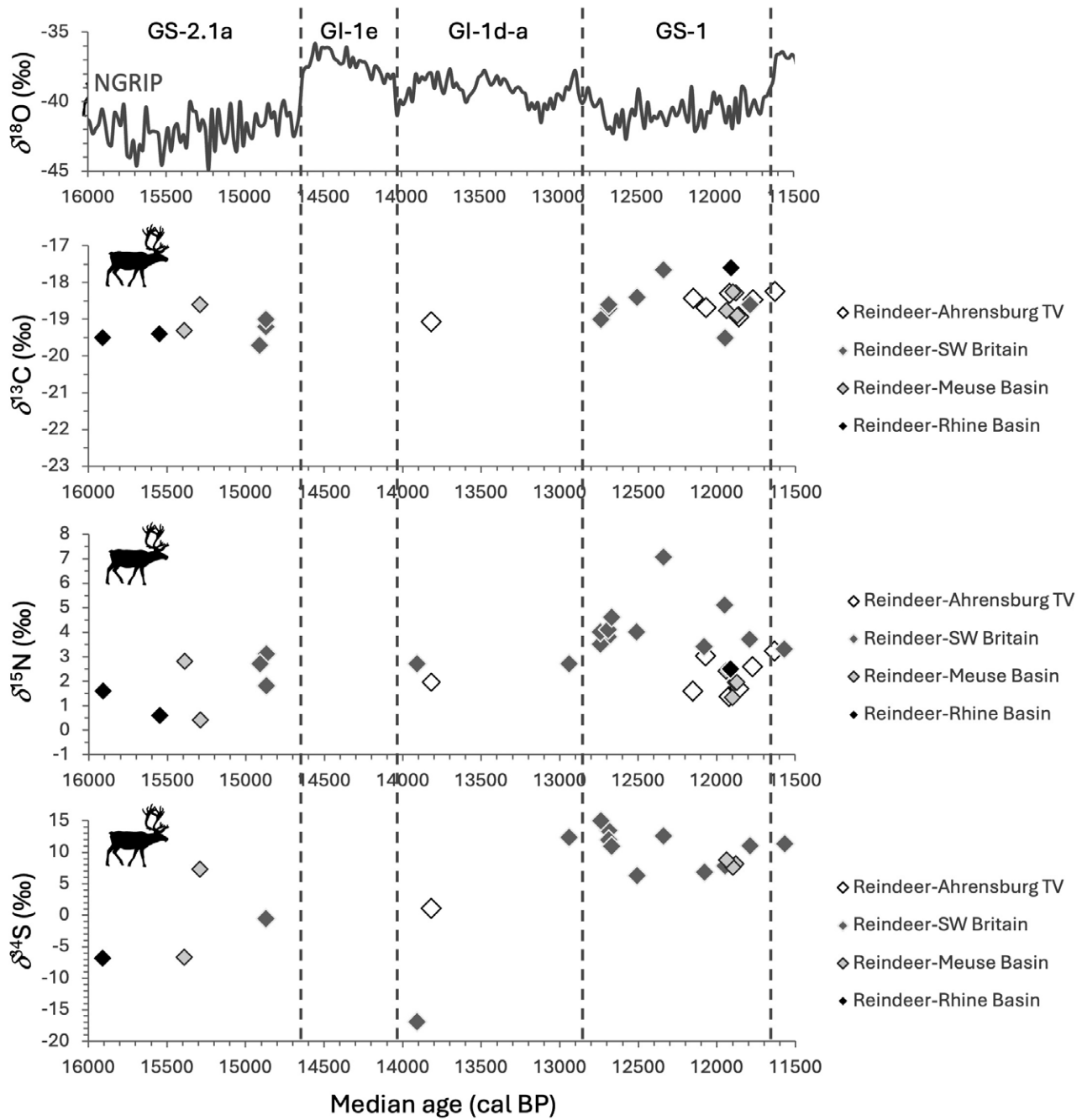


Figure 5:  $\delta^{13}\text{C}$ ,  $\delta^{15}\text{N}$ ,  $\delta^{34}\text{S}$  values of reindeer (*Rangifer tarandus*) from the Ahrensburg Tunnel Valley (Ahrensburg TV; Drucker *et al.* 2011b; Rivals *et al.* 2020), southwestern Britain (SW Britain; Jacobi and Higham 2009a; 2009b; 2011; Reade *et al.* 2023; Schulting *et al.* 2013; Stevens *et al.* 2008; 2010; 2025), the Meuse Basin (Crombé *et al.* 2024; Drucker *et al.* 2016; Germonpré *et al.* 2009; Reade *et al.* 2023), and the Rhine Basin (Bronk Ramsey *et al.* 2002; Reade *et al.* 2023; Stevens *et al.* 2009a; 2025). Radiocarbon data were calibrated using OxCal v.4.4 (©Bronk Ramsey 2021) according to the IntCal20 calibration dataset (Reimer *et al.* 2020).

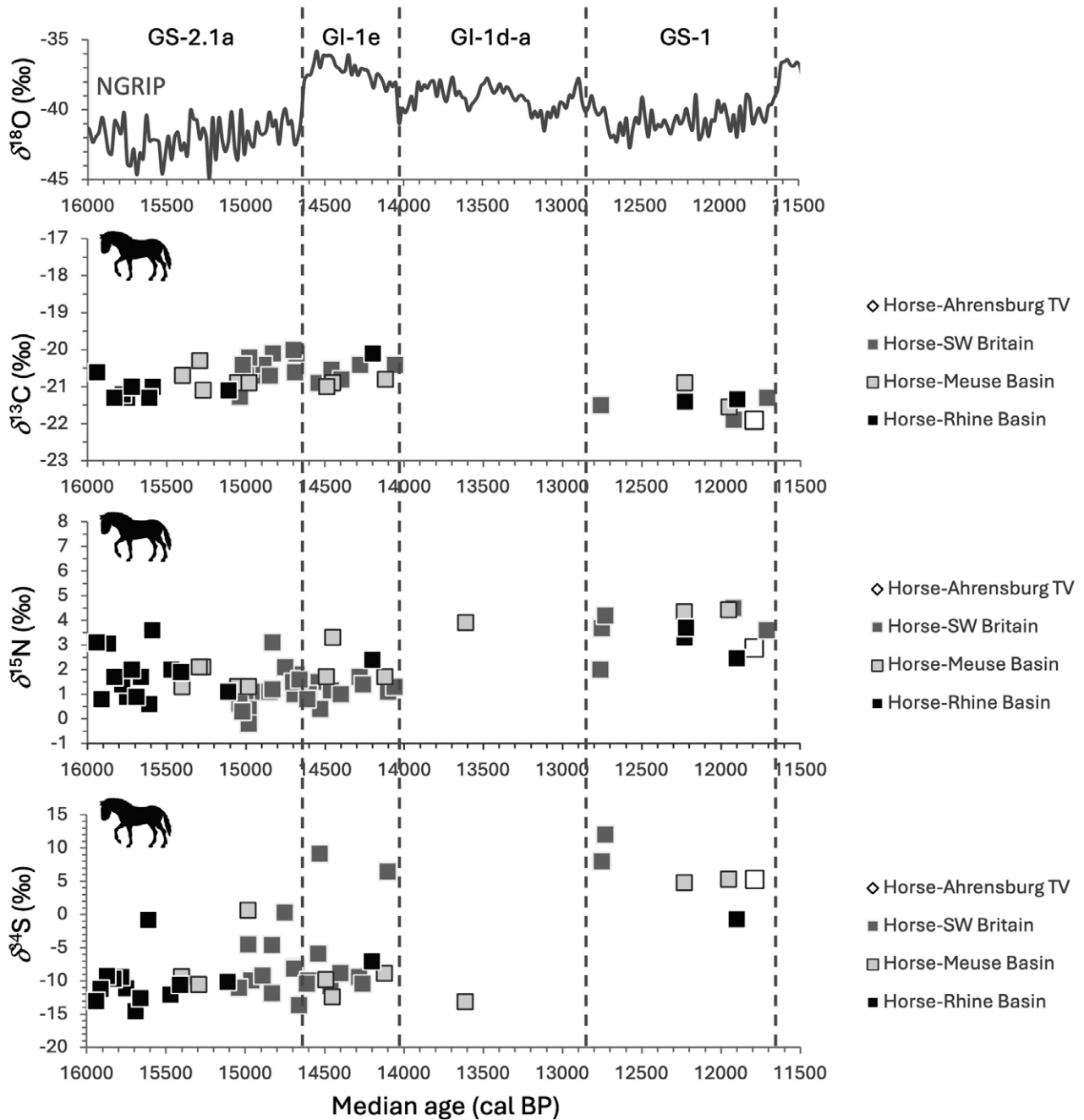


Figure 6:  $\delta^{13}\text{C}$ ,  $\delta^{15}\text{N}$ ,  $\delta^{34}\text{S}$  values of horse (*Equus ferus*) from the Ahrensburg Tunnel Valley (Ahrensburg TV; Drucker *et al.* 2016; Rivals *et al.* 2020), southwestern Britain (SW Britain; Jacobi and Higham 2009a; 2009b; 2011; Kaagan 2000; Reade *et al.* 2023; Schulting *et al.* 2013; Stevens and Hedges 2004; Stevens *et al.* 2008; 2010; 2025), the Meuse Basin (Bridault, pers. comm., 2025; Crombé *et al.* 2024; Drucker *et al.* 2016; Germonpré *et al.* 2009; Hedges *et al.* 1994; Reade *et al.* 2023; Stevens and Hedges 2004; Stevens *et al.* 2009b), and the Rhine Basin (Bronk Ramsey *et al.* 2002; Hedges *et al.* 1987; 1989; Higham, pers. comm., 2015; Reade *et al.* 2023; Stevens and Hedges 2004; Stevens *et al.* 2009a; Stevens, pers. comm., 2017). Radiocarbon data were calibrated using OxCal v.4.4 (©Bronk Ramsey 2021) according to the IntCal20 calibration dataset (Reimer *et al.* 2020).

the Younger Dryas, with an initial phase of maximum cold followed by a second, somewhat milder and drier, phase (e.g. Isarin *et al.* 1998). Nevertheless, no clear chronological trend is evident in the isotopic values of horse and reindeer collagen directly dated to the GS-1 (Figs. 5 and 6).

## Conclusions

Niche partitioning between horse and reindeer is reflected in the contrast in their  $\delta^{13}\text{C}$  values, which consistently indicate dietary differences, particularly the preferential foraging of lichens by reindeer. Although some overlap in  $\delta^{13}\text{C}$  values is observed during the GS-2.1a/GI-1, such as in the Rhine Basin, this may be attributed to a decline in lichen availability towards the end of the Pleniglacial. A systematic  $\delta^{13}\text{C}$  difference between the two species is evident across all regions studied during the GS-1, likely reflecting the re-expansion of tundra-like conditions and increased lichen availability. Inter-species competition, reflected in dietary and isotopic partitioning, was a characteristic feature of Eurasian ecosystems before the extinction of major megafaunal species such as the woolly mammoth (*Mammuthus primigenius*) and woolly rhinoceros (*Coelodonta antiquitatis*) (e.g. Drucker 2022; Schwartz-Narbonne *et al.* 2019). However, during the Younger Dryas, the reduced faunal diversity and smaller body sizes (e.g. Puzachenko and Markova 2019) suggest that limited foraging resources, rather than intense herbivore competition, may better explain the strong dietary partitioning between reindeer and horses.

In contrast, neither  $\delta^{15}\text{N}$  nor  $\delta^{34}\text{S}$  values effectively distinguish between the species, suggesting that both foraged under similar environmental conditions influencing soil and plant nitrogen and sulphur isotopic compositions. Notably, both species show a marked

reduction in the range of  $\delta^{34}\text{S}$  values during the GS-1. A potential regional difference is apparent, particularly between the Meuse Basin and SW Britain, with the latter showing higher  $\delta^{34}\text{S}$  values. Future research is needed to clarify emerging geographical patterns, which may be influenced by species-specific behaviours. Of particular interest is whether reindeer exhibit a narrower  $\delta^{34}\text{S}$  range than horses, which would support the hypothesis of a broader annual distribution linked to migratory behaviour. This question could be explored further through analyses of tooth dentine, which provides more seasonally resolved isotopic signals.

## Acknowledgements

I would like to thank Sascha Krüger and Daniel Groß for their invitation to contribute a paper to this anthology. I am also grateful to the colleagues who have supported my research on stable isotope of the Final Upper Palaeolithic in northwest Europe, including Mara-Julia Weber (Landesmuseum, Schloss Gottorf, Schleswig, Germany), Anne Bridault (CNRS-UMR 7041, Nanterre, France), Jean-Marie Cordy (University of Liège, Belgium), and Martin Street (LEIZA Monrepos, Neuwied, Germany). Thanks are due to Tom Higham (University of Vienna, Austria) and Rhiannon Stevens (University College London, UK) for valuable discussions and for sharing unpublished data. This work benefited from the technical support of the Biogeology Group for the bone collagen pretreatment and of Bernd Steinhilber (Geoscience Department, University of Tübingen, Germany) for the isotopic measurements. Last but not least, Berit Eriksen (Museum of Archaeology Schloss Gottorf, Schleswig, Germany), as an enthusiastic scientist and open-minded researcher, has been a true inspiration for my research.

## Supplementary material

Table S1: Detailed results of elemental analysis (C, N, S), isotopic measurement ( $\delta^{13}\text{C}$ ,  $\delta^{15}\text{N}$ ,  $\delta^{34}\text{S}$ ) and radiocarbon dating (Date  $^{14}\text{C}$ ) with standard-deviations (SD  $^{14}\text{C}$ ) on collagen.

Table S2: Radiocarbon dates (Date  $^{14}\text{C}$ ) with standard-deviations (SD  $^{14}\text{C}$ ) on collagen and results of calibration with median age (median) with 1 sigma (68.3%) and 2 sigmas (95.4%) range of confidence. Calibrations were conducted according to the IntCal20 (Reimer *et al.* 2020) calibration dataset using OxCal v.4.4 (© Bronk Ramsey, 2021).

The supplementary material is available at DOI:10.5281/zenodo.19068418

## References

- Ambrose, S. H. 1990. Preparation and characterization of bone and tooth collagen for isotopic analysis. *Journal of Archaeological Science* 17(4), 431–451.
- Amundson, R., Austin, A. T., Schuur, E. A., Yoo, K., Matzek, V., Kendall, C., Uebersax, A., Brenner, D. and Baisden, W. T. 2003. Global patterns of the isotopic composition of soil and plant nitrogen. *Global Biogeochemical Cycles* 17(1), 1031.
- Bignon-Lau, O., Catz, N., Bemilli, C., Bodu, P., Hinguant, S., Lacarrière, J., Merceron, G., Montoya, C. and Paris, C. 2021. The Last Glacial Maximum and the Late Glacial in northern France-Palaeoecological implications of animal community structuration and feeding behaviours based on dental microwear texture analysis. *Bulletin de la Société préhistorique française* 118, 195–219.
- Bronk Ramsey, C., Higham, T. F., Owen, D. C., Pike, A. W. G. and Hedges, R. E. 2002. Radiocarbon dates from the Oxford AMS system: Archaeometry datelist 31. *Archaeometry* 44, 1–150.
- Craine, J. M., Elmore, A. J., Aidar, M. P., Bustamante, M., Dawson, T. E., Hobbie, E. A., Kahmen, A., Mack, M. C., McLauchlan, K. K., Michelsen, A. and Nardoto, G.B. 2009. Global patterns of foliar nitrogen isotopes and their relationships with climate, mycorrhizal fungi, foliar nutrient concentrations, and nitrogen availability. *New Phytologist* 183(4), 980–992.
- Crombé, P., Pironneau, C., Robert, P., van der Sloot, P., Boudin, M., De Groote, I., Verheyden, S. and Vandendriessche, H. 2024. Human response to the Younger Dryas along the southern North Sea basin, Northwest Europe. *Scientific Reports* 14(1), 18074.
- DeNiro, M. J. 1985. Postmortem preservation and alteration of in vivo bone collagen isotope ratios in relation to palaeodietary reconstruction. *Nature* 317(6040), 806–809.
- Diefendorf, A. F., Mueller, K. E., Wing, S. L., Koch, P. L. and Freeman, K. H. 2010. Global patterns in leaf  $^{13}\text{C}$  discrimination and implications for studies of past and future climate. *Proceedings of the National Academy of Sciences* 107(13), 5738–5743.
- Drucker, D. G. 2022. The isotopic ecology of the mammoth steppe. *Annual Review of Earth and Planetary Sciences* 50(1), 395–418.
- Drucker, D. G., Hobson, K. A., Ouellet, J. P. and Courtois, R. 2010. Influence of forage preferences and habitat use on  $^{13}\text{C}$  and  $^{15}\text{N}$  abundance in wild caribou (*Rangifer tarandus caribou*) and moose (*Alces alces*) from Canada. *Isotopes in Environmental and Health Studies* 46(1), 107–121.
- Drucker, D. G., Bridault, A., Cupillard, C., Hujic, A. and Bocherens, H. 2011a. Evolution of habitat and environment of red deer (*Cervus elaphus*) during the Late-glacial and early Holocene in eastern France (French Jura and the western Alps) using multi-isotope analysis ( $\delta^{13}\text{C}$ ,  $\delta^{15}\text{N}$ ,  $\delta^{18}\text{O}$ ,  $\delta^{34}\text{S}$ ) of archaeological remains. *Quaternary International* 245(2), 268–278.
- Drucker, D. G., Kind, C. J. and Stephan, E. 2011b. Chronological and ecological information on Late-glacial and early Holocene reindeer from northwest Europe using radiocarbon ( $^{14}\text{C}$ ) and stable isotope ( $^{13}\text{C}$ ,  $^{15}\text{N}$ ) analysis of bone collagen: case study in southwestern Germany. *Quaternary International* 245(2), 218–224.
- Drucker, D. G., Bridault, A. and Cupillard, C. 2012. Environmental context of the Magdalenian settlement in the Jura Mountains using stable isotope tracking ( $^{13}\text{C}$ ,  $^{15}\text{N}$ ,  $^{34}\text{S}$ ) of bone collagen from reindeer (*Rangifer tarandus*). *Quaternary International* 272, 322–332.
- Drucker, D. G., Rosendahl, W., Van Neer, W., Weber, M.-J., Görner, I. and Bocherens, H. 2016. Environment and subsistence in north-western Europe during the Younger Dryas: An isotopic study of the human of Rhünda (Germany). *Journal of Archaeological Science: Reports* 6, 690–699.
- Germonpré, M., Sablin, M. V., Stevens, R. E., Hedges, R. E., Hofreiter, M., Stiller, M. and Després, V. R. 2009. Fossil dogs and wolves from Palaeolithic sites in Belgium, the Ukraine and Russia: osteometry, ancient DNA and stable isotopes. *Journal of Archaeological Science* 36(2), 473–490.
- Grimm, S. B. 2007. Maps of Late glacial NW-Europe. An update. NW-EU 10W–20E 45–60N. [https://www.academia.edu/17127515/Maps\\_of\\_late\\_glacial\\_NW\\_Europe\\_NW\\_EU\\_10W\\_20E\\_45\\_60N](https://www.academia.edu/17127515/Maps_of_late_glacial_NW_Europe_NW_EU_10W_20E_45_60N)
- Guiry, E. J. and Szpak, P. 2021. Improved quality control criteria for stable carbon and nitrogen isotope measurements of ancient bone collagen. *Journal of Archaeological Science* 132, 105416.
- Guthrie, R. D. 1982. Mammals of the mammoth steppe as paleoenvironmental indicators. In: Hopkins, D. M., Matthews Jr., J. V., Schweger, C. E., Young, S. B. (eds.), *Paleoecology of Beringia*. New York, Academic Press, 307–326.
- Guthrie, R. D. 2001. Origin and causes of the mammoth steppe: a story of cloud cover, woolly mammal tooth pits, buckles, and inside-out Beringia. *Quaternary Science Reviews* 20(1-3), 549–574.
- Hedges, R. E., Housley, R. A., Law, I. A., Perry, C. and Gowlett, J. A. 1987. Radiocarbon dates from the Oxford AMS system: Archaeometry datelist 6. *Archaeometry* 29(2), 289–306.
- Hedges, R. E. M., Housley, R. A., Law, I. A. and Bronk, C. R. 1989. Radiocarbon dates from the Oxford AMS system: Archaeometry datelist 9. *Archaeometry* 31(2), 207–234.

- Hedges, R. E. M., Housley, R. A., Ramsey, C. B. and Van Klinken, G. J. 1994. Radiocarbon dates from the Oxford AMS system: Archaeometry datelist 18. *Archaeometry* 36(2), 337–374.
- Iacumin, P., Nikolaev, V. and Ramigni, M. 2000. C and N stable isotope measurements on Eurasian fossil mammals, 40 000 to 10 000 years BP: herbivore physiologies and palaeoenvironmental reconstruction. *Palaeogeography, Palaeoclimatology, Palaeoecology* 163(1-2), 33–47.
- Isarin, R. F., Renssen, H. and Vandenberghe, J. 1998. The impact of the North Atlantic Ocean on the Younger Dryas climate in northwestern and central Europe. *Journal of Quaternary Science* 13(5), 447–453.
- Jacobi, R. M. and Higham, T. F. G. 2009a. The early Lateglacial re-colonization of Britain: new radiocarbon evidence from Gough's Cave, southwest England. *Quaternary Science Reviews* 28(19–20), 1895–1913.
- Jacobi, R., Higham, T., Burdukiewicz, J. M., Cyrek, K., Dyczek, P. and Szymczak, K. 2009b. Radiocarbon Dating of the Later Upper Palaeolithic Human Occupation of Kent's Cavern, Devon, England: New AMS Results. *Understanding the Past. Papers offered to Stefan K. Kozłowski*, 137–154.
- Jacobi, R. and Higham, T. 2011. The Later Upper Palaeolithic recolonisation of Britain: new results from AMS radiocarbon dating. In: Ashton, N., Lewis, S. and Stringer, C. (eds.). *The Ancient Human Occupation of Britain*. Developments in Quaternary Science 14, Elsevier, 223–247.
- Kaagan, L. M. 2000. *The Horse in the Late Pleistocene and Holocene Britain*. Ph.D. thesis. London, University College London.
- Kohn, M. J. 2010. Carbon isotope compositions of terrestrial C3 plants as indicators of (paleo) ecology and (paleo) climate. *Proceedings of the National Academy of Sciences* 107(46), 19691–19695.
- Krajcarz, M. T., Drucker, D. G., Krajcarz, M. and Bocherens, H. 2024a. Collagen extraction from pretreated bone/tooth samples. protocols.io. DOI:10.17504/protocols.io.8epv5rrp4g1b/v1
- Krajcarz, M. T., Krajcarz, M., Drucker, D. G. and Bocherens, H. 2024b. Bone/tooth sampling and cleaning for collagen extraction. protocols.io. DOI:10.17504/protocols.io.eq2lyw6mrvx9/v1
- Nehlich, O. 2015. The application of sulphur isotope analyses in archaeological research: A review. *Earth-Science Reviews* 142, 1–17.
- Nehlich, O. and Richards, M. P. 2009. Establishing collagen quality criteria for sulphur isotope analysis of archaeological bone collagen. *Archaeological and Anthropological Sciences* 1(1), 59–75.
- Price, T. D., Meiggs, D., Weber, M.-J. and Pike-Tay, A. 2017. The migration of Late Pleistocene reindeer: isotopic evidence from northern Europe. *Archaeological and Anthropological Science* 9(3), 371–394.
- Puzachenko, A. Y. and Markova, A. K. 2019. Evolution of mammal species composition and species richness during the Late Pleistocene-Holocene transition in Europe: A general view at the regional scale. *Quaternary International* 530, 88–106.
- Reade, H., Grimm, S. B., Tripp, J. A., Neruda, P., Nerudová, Z., Roblíčková, M., Sayle, K. L., Kearney, R., Brown, S., Douka, K. and Higham, T. F. 2021. Magdalenian and Epimagdalenian chronology and palaeoenvironments at Kůlna Cave, Moravia, Czech Republic. *Archaeological and Anthropological Sciences* 13(1), 4.
- Reade, H., Tripp, J. A., Frémondeau, D., Sayle, K. L., Higham, T. F., Street, M. and Stevens, R. E. 2023. Nitrogen palaeo-isoscapes: changing spatial gradients of faunal  $\delta^{15}\text{N}$  in late Pleistocene and early Holocene Europe. *PLoS ONE* 18(2), e0268607.
- Reimer, P. J., Austin, W. E., Bard, E., Bayliss, A., Blackwell, P. G., Ramsey, C. B., Butzin, M., Cheng, H., Edwards, R. L., Friedrich, M. and Grootes, P. M. 2020. The IntCal20 Northern Hemisphere radiocarbon age calibration curve (0–55 cal kBP). *Radiocarbon* 62(4), 725–757.
- Riede, F., Weber, M.-J., Grimm, S. B. and Fahlke, J. M. 2010. Neue daten für alte grabungen—ein beitrag zur Spätglazialen Archäologie und Faunengeschichte Norddeutschlands. *Archäologisches Korrespondenzblatt* 40(3), 297–316.
- Rivals, F., Drucker, D. G., Weber, M.-J., Audouze, F. and Enloe, J. G. 2020. Dietary traits and habitats of the reindeer (*Rangifer tarandus*) during the Late Glacial of Northern Europe. *Archaeological and Anthropological Sciences* 12(5).
- Schulting, R., Fibiger, L., Macphail, R., McLaughlin, R., Murray, E., Price, C. and Walker, E. A. 2013. Mesolithic and Neolithic human remains from Foxhole Cave, Gower, South Wales. *The Antiquaries Journal* 93, 1–23.
- Schwartz-Narbonne, R., Longstaffe, F. J., Kardynal, K. J., Druckenmiller, P., Hobson, K. A., Jass, C. N., Metcalfe, J. Z. and Zazula, G. 2019. Reframing the mammoth steppe: insights from analysis of isotopic niches. *Quaternary Science Reviews* 215, 1–21.
- Sommer, R. S., Kalbe, J., Ekström, J., Benecke, N. and Liljegren, R. 2014. Range dynamics of the reindeer in Europe during the last 25,000 years. *Journal of Biogeography* 41(2), 298–306.
- Stevens, R. E. and Hedges, R. E. 2004. Carbon and nitrogen stable isotope analysis of northwest European horse bone and tooth collagen, 40,000 BP–present: Palaeoclimatic interpretations. *Quaternary Science Reviews* 23(7-8), 977–991.

- Stevens, R. E., Jacobi, R., Street, M., Germonpré, M., Conard, N. J., Münzel, S. C. and Hedges, R. E. 2008. Nitrogen isotope analyses of reindeer (*Rangifer tarandus*), 45,000 BP to 9,000 BP: Palaeoenvironmental reconstructions. *Palaeogeography, Palaeoclimatology, Palaeoecology* 262(1–2), 32–45.
- Stevens, R. E., O’Connell, T. C., Hedges, R. E. and Street, M. 2009a. Radiocarbon and stable isotope investigations at the Central Rhineland sites of Gönnersdorf and Andernach-Martinsberg, Germany. *Journal of Human Evolution* 57(2), 131–148.
- Stevens, R. E., Germonpré, M., Petrie, C. A. and O’Connell, T. C., 2009b. Palaeoenvironmental and chronological investigations of the Magdalenian sites of Goyet Cave and Trou de Chaleux (Belgium), via stable isotope and radiocarbon analyses of horse skeletal remains. *Journal of Archaeological Science* 36(3), 653–662.
- Stevens, R. E., Jacobi, R. M. and Higham, T. F. 2010. Reassessing the diet of upper palaeolithic humans from Gough’s cave and sun hole, cheddar gorge, Somerset, UK. *Journal of Archaeological Science* 37(1), 52–61.
- Stevens, R. E., Reade, H., Sayle, K.L., Tripp, J. A., Frémondeau, D., Lister, A., Barnes, I., Germonpré, M., Street, M., Murton, J. B. and Bottrell, S. H. 2025. Major excursions in sulfur isotopes linked to permafrost change in Eurasia during the last 50,000 Years. *Nature Geoscience* 18, 961–965.
- Stuart, A. J. 2015. Late Quaternary megafaunal extinctions on the continents: a short review. *Geological Journal* 50(3), 338–363.
- Zimov, S. A., Zimov, N. S., Tikhonov, A. N. and Chapin Iii, F. S. 2012. Mammoth steppe: a high-productivity phenomenon. *Quaternary Science Reviews* 57, 26–45.

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# Looking for diachronic patterns in Danish Mesolithic diets

John Meadows and Anders Fischer

## Abstract

After more than 40 years of stable isotope research, the stark contrast between Late Mesolithic Ertebølle and Early Neolithic Funnel Beaker culture diets observed by Tauber (1981) is still evident and is still probably the most-discussed question in European palaeodiet research. We (Meadows and Fischer 2024) found no diachronic dietary patterns within the Ertebølle epoch (~5400–3900 cal BCE), however: most Ertebølle individuals in Denmark depended overwhelmingly on marine resources, particularly species from eelgrass (*Zostera marina*) meadows, but exceptions occurred throughout the 1500-year period. By contrast, data from 18 earlier Mesolithic humans, spanning ~8500–5500 cal BCE, appear to show a steadily increasing reliance on marine foods, although terrestrial resources always predominated. This trend obviously tracks sea-level rise over the same period. Indirectly, it also highlights the main barrier to observing diachronic patterns in Mesolithic diets: in most of Denmark, coastal sites older than about 6000 cal BCE are deeply submerged. In this paper, we question whether this dietary trend corresponds to changes in subsistence strategy and resource availability, or reflects natural developments in the isoscape, or whether the data are still too sparse to draw conclusions.

*Keywords: Palaeodiet, stable isotopes, human remains, Mesolithic, radiocarbon*

## Introduction

Palaeodiet research occupies a privileged position within prehistoric archaeology, as it deals with data that reflect personal preferences, over an extended period of the lifetime of each individual sampled. Other specialisms often focus on evidence of specific events in a human life (e.g. an injury), or on evidence that cannot be easily disaggregated and attributed to an individual. Animal bones in kitchen middens, for example, reflect group-level subsistence strategies over varying time spans, but cannot provide insights into personal choices and experiences. Like osteological evidence of chronic illness or biomechanical exertion, however, palaeodietary evidence from human remains, usually in the form of collagen stable isotopes ( $\delta^{13}\text{C}$ ,  $\delta^{15}\text{N}$ ,  $\delta^{34}\text{S}$ ), allows us to compare the habits of different individuals. Nevertheless, this type of evidence is often aggregated to facilitate comparisons between groups (e.g. from different periods or regions), even if so doing creates additional interpretative challenges, such as where to draw the line between periods (Meadows *et al.* 2018), or how to interpret anomalous individuals. Individual life-histories, including reconstructions of diet at different ages, are increasingly popular,

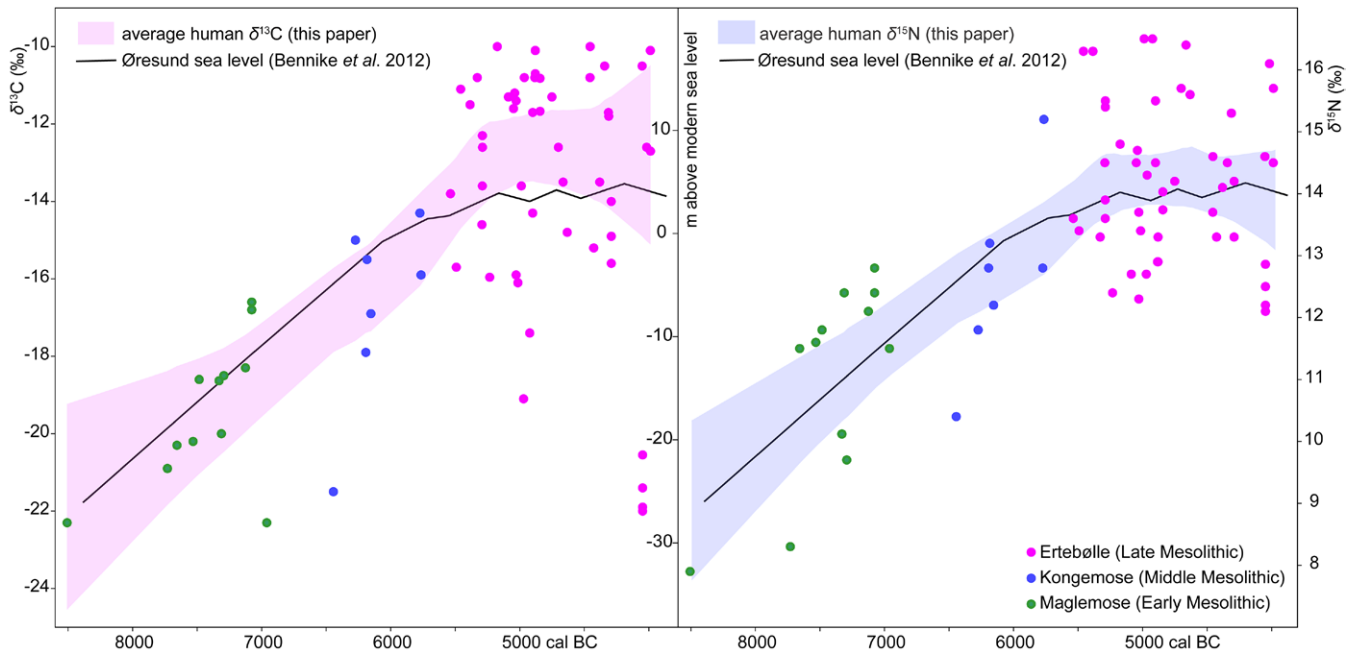


Figure 1:  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values (left and right vertical scales respectively) in directly dated Mesolithic human bones in Denmark. Data compiled by Fischer *et al.* (in review), timescale (horizontal scales) based on dietary reservoir-effect corrections in the same article. Shaded bands are bootstrapped 95% confidence ranges for average  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$ , obtained by LOESS smoothing (smoothing factor 0.66) using PAST v5.0.2 (Hammer *et al.* 2001) ([www.nhm.uio.no/english/research/resources/past/](http://www.nhm.uio.no/english/research/resources/past/)), which are wider where data points are sparse or more dispersed. For comparison, Bennike *et al.*'s (2012) sea-level curve (central vertical scale) is overlaid on both panels.

in both historic and prehistoric contexts (e.g. Fischer *et al.* 2024; in review).

In this brief review of published data from Mesolithic Denmark, we are instead concerned with dietary differences between individuals, attempting to distinguish between synchronic variation (how diets varied among contemporaneous individuals) and diachronic patterns (whether the incidence of specific diets increased or declined over time). We are concerned with isotopic evidence, which is only helpful in estimating the relative importance of isotopically distinct food sources, particularly sources of dietary protein. In the mid-Holocene Danish context, using stable isotopes it is difficult to separate wild plant foods from the flesh of wild herbivores, or indeed domestic from wild terrestrial food sources. We should, however, be able to recognise up to four isotopically distinct food sources: terrestrial (plants and animals), freshwater (fish and invertebrates), and two marine biotopes, based ultimately on primary production by pelagic phytoplankton and eelgrass (*Zostera marina*) respectively (pelagic species have lower  $\delta^{13}\text{C}$  and higher  $\delta^{15}\text{N}$  and  $\delta^{34}\text{S}$  values than eelgrass species; Meadows and Fischer 2024).

Most prehistoric faunal isotope data for Denmark are from terrestrial animals (e.g. Maring and Riede 2019), or marine species predominantly associated with the intensive exploitation of the eelgrass biotope in the

Late Mesolithic (Guiry and Robson 2024; Meadows and Fischer 2024). The isotopic signature of freshwater species, in particular, is poorly defined; fish isotope values probably varied between freshwater bodies, and modern analogues may be misleading (Fischer *et al.* in review). When diet reconstructions are based on only two isotopes ( $\delta^{13}\text{C}$ ,  $\delta^{15}\text{N}$ ), the problem of equifinality (different diets leading to the same isotope values) is also far more prominent if there are four potential food sources rather than three; for this reason, Meadows and Fischer (2024) disregarded freshwater food sources in discussing isotopic variation in Ertebølle (Late Mesolithic) human bones, which is primarily driven by differential dependence on primary production by pelagic phytoplankton and eelgrass. This approach is less realistic when interpreting human isotope data from earlier Mesolithic epochs, when marine foods were less important, but it may be equally misleading to try to quantify the dietary importance of freshwater food sources if they are isotopically poorly defined.

Palaeodiet research has often returned to discussing the abrupt shift in  $\delta^{13}\text{C}$  values between Late Mesolithic and Early Neolithic individuals in Denmark, first observed by Tauber (1981), e.g. Fischer *et al.* (2007a), McLaughlin *et al.* (2025), Milner *et al.* (2004), Richards *et al.* (2003), Schulting (2010). This shift, from high  $\delta^{13}\text{C}$  values associated with diets based on marine foods to consistently low  $\delta^{13}\text{C}$  (and



Figure 2: Typical examples of human skeletal remains of Early and Late Mesolithic date, here represented with the single-individual Maglemosian epoch find from lake deposits at Strøby Grøftemark (left) and the group of five Ertebølle epoch humans revealed at the coastal shell midden site of Koed (right). Note the ochre staining of mainly the skull shown lower right (Photos: Anders Fischer and John Lee, Danish National Museum).

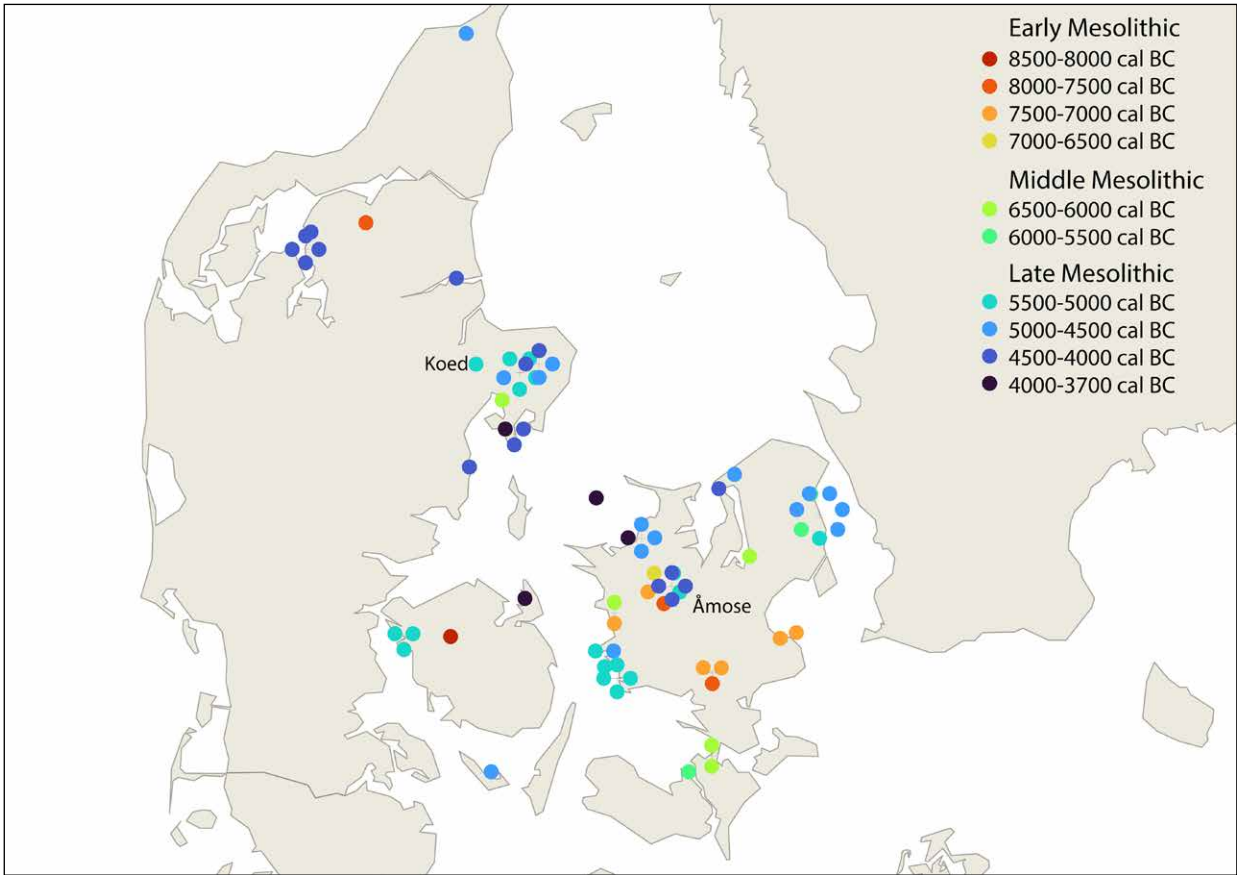


Figure 3: Location and date of directly dated Mesolithic human remains in Denmark. Base map indicates modern coastline. Created by John Meadows using QGIS 3.40 (<https://qgis.org/>) and median corrected dates from Fischer *et al.* (in review). Where multiple individuals are known from the same location, points are displaced around the find-site (+).

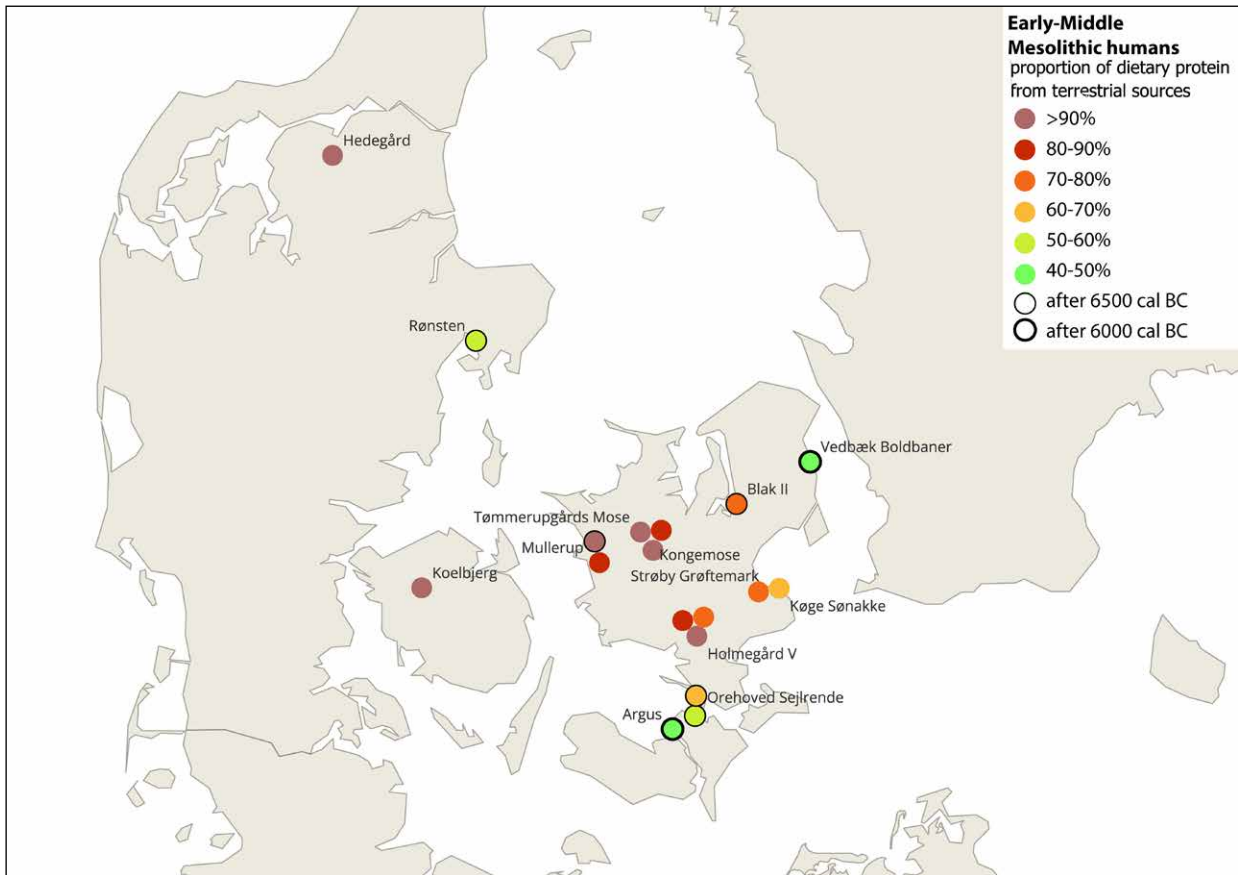


Figure 4: Locations of directly dated Early-Middle Mesolithic human remains. Colours reflect the importance of terrestrial protein sources in individual diets (see legend). Base map indicates modern coastline. Created by John Meadows using QGIS 3.40 (<https://qgis.org/>) and diet reconstructions discussed in the text.

$\delta^{15}\text{N}$ ) values associated with predominantly terrestrial food sources, coincided with a major population turnover, with indigenous Western Hunter-Gatherer ancestry being replaced by farmers with predominantly Anatolian ancestry (Allentoft *et al.* 2024). There has not been much interest in isotopic variation during the Mesolithic period, when no population turnovers are recorded, but we see both large  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  differences between contemporaneous individuals and large shifts over time in average  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  (Fig. 1). The steady rise during the Early and Middle Mesolithic of average  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$ , followed by a plateau during the Late Mesolithic, obviously tracks sea-level rise over the same period (*e.g.* Bennike *et al.* 2012). Indirectly, it also highlights the main barrier to observing diachronic patterns in Mesolithic diets: in most of Denmark, coastal sites older than about 6000 cal BCE are deeply submerged.

### Human remains

Thanks to Berit Eriksen's work (Eriksen and Andersen 2016), we know that genuine inhumation burials, including the use of ochre staining, took place in Early Mesolithic

Denmark. The same certainly applied to the Middle and Late Mesolithic, from which several sites with a number of inhumations have been properly excavated, and where ochre staining is frequently observed on human bones, for example in five individuals salvaged from burials at the Ertebølle epoch coastal shell midden site of Koed (Figs. 2 and 3). Early Mesolithic Maglemosian human remains from Koelbjerg, Tømmerupgårds Mose, Holmegård V and Strøby Grøftemark (Figs. 2 and 4) exemplify a distinctly different way of dealing with human bodies. These remains were found in lacustrine sediments, and considered individually, were once thought to represent tragic episodes of drowning (Brøste *et al.* 1956, 10–12; Jensen 2001, 124; Troels-Smith 1943). Considered in their totality, however, including the contextual evidence that three humans were deposited next to the lake shore on the outskirts of the Holmegård V habitation site, it appears more likely they result from a specific mortuary practice, such as being exposed on platforms over the lake water. This dichotomy in Early Mesolithic ways of handling dead bodies should be explored further; it may even contribute

to explaining the dichotomy in dietary isotopic profiles of Danish Mesolithic humans presented in the following.

The most recent survey (Fischer *et al.* in review) includes 66 individuals with direct  $^{14}\text{C}$  dates, and both  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$ , allowing the  $^{14}\text{C}$  dates to be calibrated using a three-source diet reconstruction model (Meadows and Fischer 2024; Fischer *et al.* in review). The temporal density of Late Mesolithic remains (three individuals every century, on average) is five times that of Early-Middle Mesolithic remains (three individuals every 500 years). Figure 3 shows the locations and approximate dates of these remains. Early Mesolithic (Maglemose, ~8500–6900 cal BCE) human remains are all, with one exception, from what were at the time inland sites, and their isotope values unsurprisingly reflect diets based mainly on terrestrial (and perhaps freshwater) resources. The exception is Køge Sønakke, found in beach sediments, either from the close of the Ancyclus freshwater stage or the early brackish water stage of the Baltic Basin (Fischer and Petersen 2018). Some Middle Mesolithic (Kongemose) human remains from coastal sites have been recovered (*e.g.* Fischer *et al.* 2007b), dating to ~6500–5500 cal BCE, when the rate of sea-level rise decreased. All Late Mesolithic (Ertebølle) human remains are from coastal regions, aside from the Åmose valley in northwestern Zealand, an intensively researched inland area that (uniquely) has produced human remains spanning almost the entire Mesolithic.

### Diet reconstructions

Using faunal collagen  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values from prehistoric sites across Denmark, we were able to estimate realistic average  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values in dietary protein derived from wild terrestrial, pelagic marine and eelgrass-biotope species (Meadows and Fischer 2024), which can be used in quantitative diet reconstruction models to estimate the contribution of these food sources to each individual's diet. The addition of  $\delta^{34}\text{S}$  in one case study suggests that in this instance, reliance on only  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  might have overestimated the importance of pelagic marine species (Fischer *et al.* in review), but without  $\delta^{34}\text{S}$  values for all humans, and for prehistoric fauna from multiple sites, we cannot apply this approach to the rest of the data set. Our three-source, two-isotope model (Meadows and Fischer 2024) allows variation in median estimated diets of all 66 directly dated Mesolithic individuals to be visualised in a ternary diagram (Fig. 5). This figure, based on data and diet reconstructions reported by Fischer *et al.* (in review), shows that Late Mesolithic (Ertebølle) diets were overwhelmingly marine, often relying on just the eelgrass biotope for the majority of dietary protein.

There was apparently a great deal of variation in individual Ertebølle diets, however, particularly in the importance of pelagic species (*e.g.* marine mammals, and fish such as haddock, mackerel, herring, *etc.*). No consistent

pattern emerges separating male and female diets, or juvenile and adult diets; instead, burial location appears to be the best predictor of dietary variation among Late Mesolithic individuals (Fischer *et al.* in review). This makes intuitive sense, as the accessibility and productivity of different marine species would have varied according to the coastline, seabed, and currents. The same factors will also have influenced isotopic signatures in local marine species, however, so using uniform parameter values in diet reconstruction models may exaggerate geographic variation in diets. Nevertheless, geographic patterning of diets suggests limited mobility during the Late Mesolithic. A small handful of Late Mesolithic cases from inland sites appear to have had almost fully terrestrial diets (Fig. 5), but this is misleading, as freshwater fish, which is not accounted for in our model, was probably a leading protein source in these cases. There is no indication of dietary trends within the Late Mesolithic, but the contrast between Early-Middle Mesolithic (Maglemose-Kongemose) diets and the Late Mesolithic (Ertebølle) cases is obvious (Fig. 5). Almost all the earlier Mesolithic individuals had mainly or overwhelmingly terrestrial diets, particularly Maglemosian individuals.

In the earlier Mesolithic, variation in diets appears to be more a function of date than of site location (Fig. 4). With the possible exception of Køge Sønakke (~7300 cal BCE), all Maglemose diets were >70% terrestrial. Earlier Kongemose diets could be mainly or overwhelmingly terrestrial (Blak II), or more mixed (Rønsten, Orehoved Sejlrende). An indirectly dated Kongemose male from Argus (Fischer *et al.* 2007b) would have had a diet like the Orehoved Sejlrende individuals. The first individuals with >50% marine diets appear towards the end of the Kongemose epoch (Argus female, Vedbæk Boldbaner).

### Discussion

These observations could support up to four contrasting interpretations of diachronic patterns:

1. Extrapolating directly from the sampled individuals, it appears that the use of marine foods increased steadily during the earlier Mesolithic, but people did not subsist on mainly marine diets until the start of the Late Mesolithic after ~5400 cal BCE, perhaps because they continuously adapted subsistence strategies as terrestrial resources diminished and marine resources increased with sea-level rise, within their geographically restricted territories.
2. Had the rise in relative sea-level not taken place, we would have had data from many more earlier Mesolithic skeletons, which might show the same range of diets as Late Mesolithic human remains, *i.e.* all observed dietary variation could be synchronic, not diachronic.
3. The productivity and isotopic signatures of wild resources (terrestrial, freshwater and marine) may

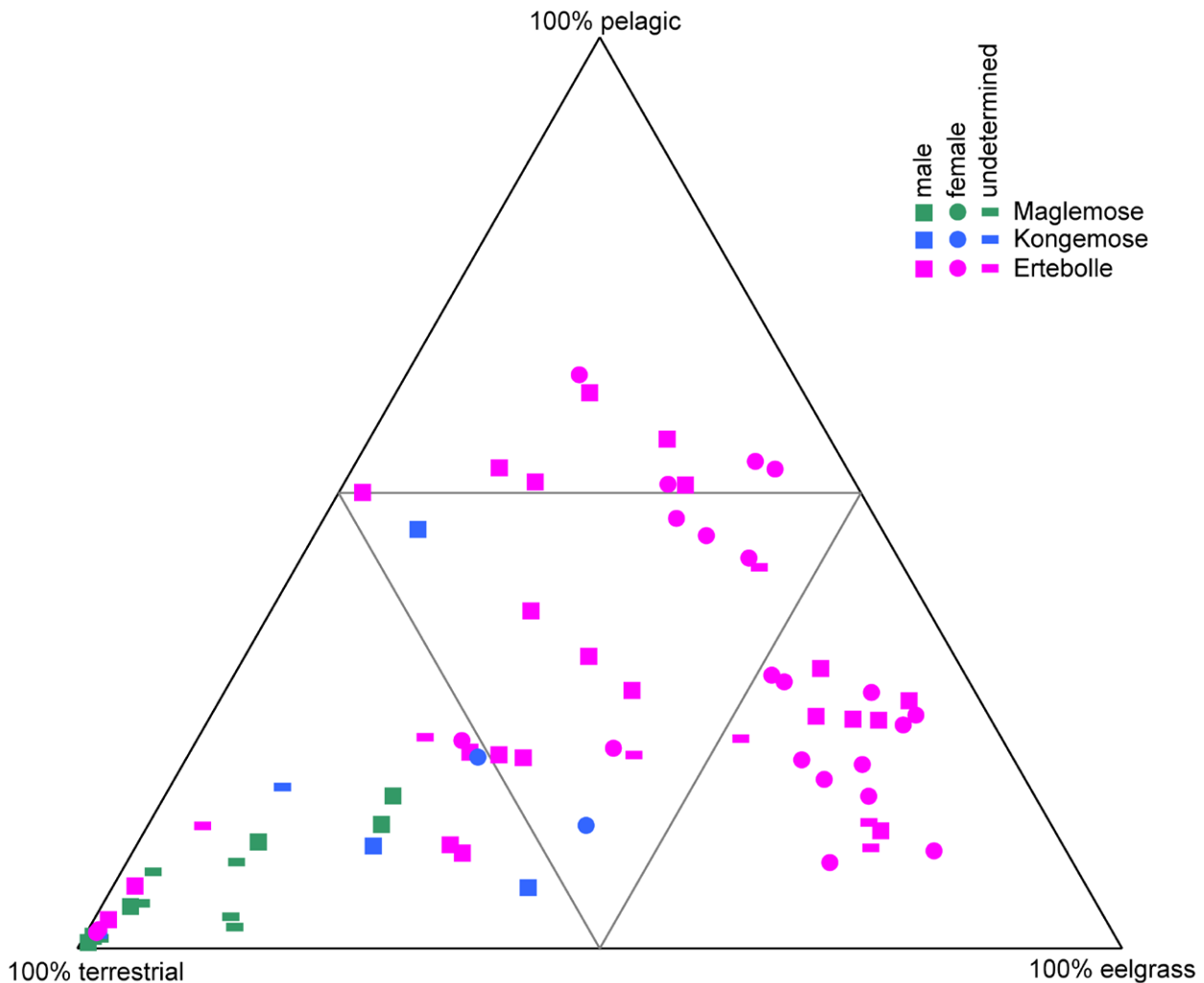


Figure 5: Ternary diagram showing median estimated contributions of terrestrial, pelagic and eelgrass-biotope protein to individual human diets (diet reconstructions in Fischer *et al.* (in review), using the same three-source model parameter values in all cases). Figure created by John Meadows using PAST v5.0.2 (Hammer *et al.* 2001) ([www.nhm.uio.no/english/research/resources/past/](http://www.nhm.uio.no/english/research/resources/past/)) and diet reconstructions discussed in the text.

have changed profoundly over the course of the Mesolithic, which would amplify (exaggerate) any diachronic patterns in human diets. Investigating these environmental changes would provide insights into human adaptations and their long-term impacts.

4. The paucity of faunal isotopic data from earlier Mesolithic sites – particularly of marine species – and the sparse human record before the Late Mesolithic preclude any realistic interpretation. Gaps in our knowledge should be identified and remedied through future research.

We regard the first option as a (deliberately) unrealistic null hypothesis. The second option is also an extreme and slightly implausible position, but one not easily rejected without extensive research on submerged earlier Mesolithic

sites, and on inland sites of all epochs in more regions. For example, there are ten dated Maglemose individuals from inland sites but only three or four inland Ertebølle cases (spanning a similar length of time), which may support the idea of diachronic change in subsistence strategies. If the human population increased over the course of the Mesolithic, as usually assumed (cf. Boethius *et al.* 2020), we could expect an even greater number of inland Ertebølle cases. Population growth may have intensified territoriality, favouring dietary specialisation, which may explain the wide range of diets observed in the Late Mesolithic. Indeed, the diets of coastal Kongemose humans were apparently less specialised than those of most Ertebølle coastal individuals.

The third option of profound environmental change is intriguing. For example, if the eelgrass biotope was not as productive or extensive in the earlier Mesolithic

as in the Mid-Holocene, all marine species would have been isotopically more pelagic (as the share of primary production from phytoplankton in marine food webs would have been higher). With a lower contribution to marine food webs from eelgrass primary productivity, a marine-based subsistence strategy would have been less attractive, and with lower  $\delta^{13}\text{C}$  values in marine foods (due to the increased share of primary production from phytoplankton), any marine food consumption would be harder to detect in human samples. Without an extended dietary isotopic reference assemblage of Early Holocene marine fauna from Danish sites, this idea cannot be tested. There are marine faunal isotope data from Early Mesolithic sites on the west coast of Sweden (Boethius and Ahlström 2018), but the eelgrass biotope is not expected to have been as productive here as in Danish waters at any stage (Meadows and Fischer 2024), so the Swedish data are not good proxies for Early Mesolithic Denmark. A relatively high  $\delta^{13}\text{C}$  combined with low  $\delta^{15}\text{N}$  in two Late Maglemose (~7300 cal BCE) Danish individuals (Kongemose *locus classicus* and Mullerup adult) could be the first isotopic evidence that the eelgrass biotope was highly productive, but this is harder to assess in mainly terrestrial diets.

Over-hunting of large herbivores in the earlier Mesolithic might have contributed to forests becoming denser (Nikulina *et al.* 2025), reducing hunting opportunities and even lowering faunal  $\delta^{13}\text{C}$  values, due to increasing canopy effects. Some Danish faunal isotope data are available, from Early Mesolithic bone points, made from cervid and bovid bones (Jensen *et al.* 2020). We do see a slight fall (~0.6‰) in average cervid/bovid  $\delta^{13}\text{C}$  between Early and Late Mesolithic (data from Maring and Riede 2019), and a slightly greater increase in  $\delta^{15}\text{N}$  (~1.0‰), probably attributable to long-term soil development. Similar isotopic shifts are visible in Mesolithic cervid/bovids from southern Sweden (our analysis of data compiled by Boethius and Ahlström 2018). These shifts are too small to meaningfully affect the diet reconstructions given by the uniform three-source model applied here, considering the isotopic spacing between terrestrial species and both marine biotopes.

A more complex situation may apply to freshwater species, which we cannot easily disregard in the earlier Mesolithic. Most of the sparse faunal reference data are from early Maglemosian assemblages, and show remarkably elevated  $\delta^{13}\text{C}$  values in pike, and also otter (as a proxy for local fish), which at coastal sites might be interpreted as proof of marine or estuarine residence (Fischer *et al.* 2007a). At inland Holmegård, in particular, this explanation is untenable, particularly given the distance that had to be traversed to reach the coast at this time (Fischer 2003). Fischer *et al.* (2007a) posited that in the Early Mesolithic (and not subsequently), lake water was saturated with dissolved carbonate from glacial moraines. This phenomenon, associated with marl precipitation, is familiar from other Early Holocene lakes

on the margins of formerly glaciated areas in northern Europe, and appears a plausible explanation for the Maglemosian freshwater fish  $\delta^{13}\text{C}$  values. Thus, the modest intake of marine foods at Holmegård indicated by our diet reconstruction models most likely reflects consumption of local freshwater fish, not seasonal residence at the coast. From this point of view, notwithstanding differences in  $\delta^{13}\text{C}$  values, Maglemosian and Ertebølle diets at inland sites may not have been very different. An added complication is that dietary  $^{14}\text{C}$ -reservoir-effect correction for the Maglemosian cases is far more challenging, both because Early Holocene freshwater reservoir-effects are unknown and potentially much higher than in later periods, and because the smaller the isotopic spacing between terrestrial and freshwater species, the greater the intake of freshwater species that would account for the slightly elevated  $\delta^{13}\text{C}$  values of some Maglemosian humans. Moreover, it is more difficult to construct meaningful average isotope values for freshwater species, if the flux of post-glacial carbonate dissolution into freshwater bodies varied over time and space. Quantification of the importance of freshwater species in Early Mesolithic diets on the basis of human  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values therefore appears to be almost impossible.

Our fourth option, that the data are too sparse to reach any conclusion about diachronic variation in Mesolithic diets, is not an admission of defeat. Naturally, a more temporally and spatially balanced set of faunal isotopic data would allow better parameterisation of diet reconstruction models, and a higher temporal density of Early-Middle Mesolithic human remains would make it easier to disentangle diachronic and synchronic patterns, but the quality of our data is as important as their quantity. Analyses of collagen  $\delta^{34}\text{S}$  or compound-specific  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values might help to separate freshwater from marine fish consumption or reveal variation in the dietary importance of plants. Basic research on the chronological development of terrestrial, marine and freshwater ecosystems, their productive potential and their isotopic signatures, is obviously required to better understand the choices of Mesolithic foragers. We suspect that they really did shift from a mainly terrestrial orientation to a primarily coastal economy during the Middle Mesolithic, but that there was always synchronic variation in diets, which is particularly inaccessible to us in the earlier Mesolithic epochs.

## Conclusions

Our study is a first attempt to make sense of the remarkable isotopic variation among Danish Mesolithic human bones. Part of this variation is almost certainly due to spatio-temporal variation in the isotopic signatures of potential food sources, rather than to differences between individual diets, although variation in food-source isotopic signatures is also inextricably linked to their productivity and attractiveness as food sources. Residual isotopic variation

in human bones appears to have both synchronic and diachronic dimensions. Synchronic isotopic variation arises from dietary specialisation, which at this stage appears to be visible only in the Late Mesolithic and be most clearly related to territoriality. This does not, of course, exclude synchronic variation and territoriality in earlier epochs, but sparse and uneven spatio-temporal coverage, of human bones and critically of marine and freshwater species, mean that a three-source diet reconstruction model which appears to be applicable to nearly all Late Mesolithic individuals is potentially misleading in earlier material, limiting our ability to detect dietary differences between earlier Mesolithic individuals. Nevertheless, there are clues in the current evidence suggesting that earlier Mesolithic foragers may have had more broadly based

diets, relying on both terrestrial and aquatic resources, and that environmental changes may have accelerated a shift towards more specialised subsistence strategies.

## Acknowledgements

We express our sincere gratitude towards Berit for bringing us together and providing us opportunities to intensively research topics of shared interest in biomolecular Stone Age archaeology. During our years of pleasant scientific cooperation and social interaction with Berit, we have noted her preferences for the Danish Mesolithic as well as her joy of present-day culinary qualities, not least sea food. Berit stands out as one colleague who could step back from the detail of a case study or method and confidently explain its significance to the wider research agenda, especially for Danish prehistory.

## References

- Allentoft, M. E., Sikora, M., Fischer, A., Sjögren, K.-G., Ingason, A., Macleod, R., Rosengren, A., Schulz Paulsson, B., Jørkov, M. L. S., Novosolov, M., Stenderup, J., Price, T. D., Fischer Mortensen, M., Nielsen, A. B., Ulfeldt Hede, M., Sørensen, L., Nielsen, P. O., Rasmussen, P., Jensen, T. Z. T., Refoyo-Martínez, A., Irving-Pease, E. K., Barrie, W., Pearson, A., Sousa da Mota, B., Demeter, F., Henriksen, R. A., Vimala, T., McColl, H., Vaughn, A., Vinner, L., Renaud, G., Stern, A., Johannsen, N. N., Ramsøe, A. D., Schork, A. J., Ruter, A., Gotfredsen, A. B., Henning Nielsen, B., Brinch Petersen, E., Kannegaard, E., Hansen, J., Buck Pedersen, K., Pedersen, L., Klassen, L., Meldgaard, M., Johansen, M., Uldum, O. C., Lotz, P., Lysdahl, P., Bangsgaard, P., Petersen, P. V., Maring, R., Iversen, R., Wåhlin, S., Anker Sørensen, S., Andersen, S. H., Jørgensen, T., Lynnerup, N., Lawson, D. J., Rasmussen, S., Korneliussen, T. S., Kjær, K. H., Durbin, R., Nielsen, R., Delaneau, O., Werge, T., Kristiansen, K. and Willerslev, E. 2024. 100 ancient genomes show repeated population turnovers in Neolithic Denmark. *Nature* 625(7994), 329–337.
- Bennike, O., Andreasen, M. S., Jensen, J. B., Moros, M. and Noe-Nygaard, N. 2012. Early Holocene sea-level changes in Øresund, southern Scandinavia. *Geological Survey of Denmark and Greenland Bulletin* 26, 29–32.
- Boethius, A. and Ahlström, T. 2018. Fish and resilience among Early Holocene foragers of southern Scandinavia: A fusion of stable isotopes and zooarchaeology through Bayesian mixing modelling. *Journal of Archaeological Science* 93, 196–210.
- Boethius, A., Bergsvik, K. A. and Nilsson, B. 2020. Knowledge from the ancient sea – a long-term perspective of human impact on aquatic life in Mesolithic Scandinavia. *The Holocene* 30(5), 632–645.
- Bröste, K., Jørgensen, J. B., Becker, C. J. and Brøndsted, J. 1956. *Prehistoric man in Denmark: a study in physical anthropology*. Copenhagen, Munksgaard.
- Eriksen, B. V. and Andersen, H. C. H., 2016. Hammelev. An Early Mesolithic cremation grave from Southern Jutland, Denmark, in: Grünberg, J. M., Gramsch, B., Larsson, L., Orschiedt, J. and Meller, H. (eds.), *Mesolithic Burials – Rites, Symbols and Social Organisation of Early Postglacial Communities. Mesolithische Bestattungen – Riten, Symbole und soziale Organisation früher postglazialer Gemeinschaften*. Tagungen des Landesmuseums für Vorgeschichte Halle 13. Halle (Saale), Landesamt für Denkmalpflege und Archäologie Sachsen-Anhalt – Landesmuseum für Vorgeschichte, 73–80.
- Fischer, A., 2003. Trapping up the rivers and trading across the sea—steps towards the neolithisation of Denmark. In: Larsson, L., Kindgren, H., Knutsson, K., Loeffler, D. and Åkerlund, A. (eds.), *Mesolithic on the move. Papers presented at the Sixth International Conference on the Mesolithic in Europe, Stockholm 2000*. Oxford, Oxbow, 405–413.
- Fischer, A., Meadows, J., Jørkov, M. L., Sjögren, K.-G., Alexandersen, V., Gotfredsen, A. B., Price, T. D., Gröcke, D. R., Henriksen, P. S., Jensen, T. Z. T., Refoyo-Martínez, A., Stenderup, J., Ahlström, T., Sikora, M., Willerslev, E., Allentoft, M. E. and Kristiansen, K. in review. Rødhals Man: a life at the end of the Mesolithic world. *Antiquity*.
- Fischer, A., Olsen, J., Richards, M., Heinemeier, J., Sveinbjörnsdóttir, Á. E. and Bennike, P. 2007a. Coast-inland mobility and diet in the Danish Mesolithic and Neolithic: evidence from stable isotope values of humans and dogs. *Journal of Archaeological Science* 34(12), 2125–2150.
- Fischer, A., Richards, M., Olsen, J., Robinson, D. E., Bennike, P., Kubiak-Martens, L. and Heinemeier, J.

- 2007b. The composition of Mesolithic food: evidence from the submerged settlement on the Argus Bank, Denmark. *Acta Archaeologica* 78(2), 163–178.
- Fischer, A. and Petersen, P. V., 2018. Denmark—a sea of archaeological plenty. In: Fischer, A. and Pedersen, L. (eds.), *Oceans of Archaeology*. Højbjerg, Jutland Archaeological Society, 68–83.
- Fischer, A., Sjögren, K.-G., Jensen, T. Z. T., Jørkov, M. L., Lysdahl, P., Vimala, T., Refoyo-Martínez, A., Scorrano, G., Price, T. D., Gröcke, D. R., Gotfredsen, A. B., Sørensen, L., Alexandersen, V., Wåhlin, S., Stenderup, J., Bennike, O., Ingason, A., Iversen, R., Sikora, M., Racimo, F., Willerslev, E., Allentoft, M. E. and Kristiansen, K. 2024. Vittrup Man – the life-history of a genetic foreigner in Neolithic Denmark. *PLoS ONE* 19(2), e0297032.
- Guiry, E. and Robson, H. K. 2024. Deep antiquity of seagrasses supporting European eel fisheries in the western Baltic. *Proceedings of the Royal Society B: Biological Sciences* 291(2027), 20240674.
- Hammer, Ø., Harper, D. A. T. and Ryan, P. D. 2001. PAST: Paleontological Statistics Software Package for Education and Data Analysis. *Palaeontologia Electronica* 4(1).
- Jensen, J., 2001. *Danmarks Oldtid. Bind 1: Stenalder 13.000-2.000 f.kr.* Copenhagen, Gyldendal.
- Jensen, T. Z. T., Sjöström, A., Fischer, A., Rosengren, E., Lanigan, L.T., Bennike, O., Richter, K. K., Gron, K. J., Mackie, M., Mortensen, M. F. and Sørensen, L. 2020. An integrated analysis of Maglemose bone points reframes the Early Mesolithic of Southern Scandinavia. *Scientific Reports* 10(1), 17244.
- Maring, R. and Riede, F. 2019. Possible wild boar management during the Ertebølle Period. A carbon and nitrogen isotope analysis of Mesolithic wild boar from Fannerup F, Denmark. *Environmental Archaeology* 24(1), 15–27.
- McLaughlin, T. R., Robson, H. K., Maring, R., Boethius, A., Guiry, E., Groß, D., Koivisto, S., Philippsen, B., Milner, N., Bailey, G. and Craig, O. E. 2025. Marine exploitation and the arrival of farming: resolving the paradox of the Mesolithic-Neolithic transition in Denmark. *Quaternary Science Reviews* 363, 109447.
- Meadows, J., Bērziņš, V., Legzdina, D., Lübke, H., Schmöcke, U., Zagorska, I. and Zariņa, G. 2018. Stone-age subsistence strategies at Lake Burtnieks, Latvia. *Journal of Archaeological Science: Reports* 17, 992–1006.
- Meadows, J. and Fischer, A. 2024. Productivity of the eelgrass biotope and the resilience of fisher-hunter-gatherers in prehistoric Denmark. *Quaternary Science Reviews* 336, 108745.
- Milner, N., Craig, O. E., Bailey, G. N., Pedersen, K. and Andersen, S. H. 2004. Something fishy in the Neolithic? A re-evaluation of stable isotope analysis of Mesolithic and Neolithic coastal populations. *Antiquity* 78(299), 9–22.
- Nikulina, A., Zapolska, A., Serge, M. A., Roche, D. M., Mazier, F., Davoli, M., Pearce, E. A., Svenning, J. C., van Wees, D., Fyfe, R. and MacDonald, K. 2025. On the ecological impact of prehistoric hunter-gatherers in Europe: Early Holocene (Mesolithic) and Last Interglacial (Neanderthal) foragers compared. *PLoS ONE* 20(10), e0328218.
- Richards, M. P., Price, T. D. and Koch, E. 2003. Mesolithic and Neolithic subsistence in Denmark: New stable isotope data. *Current Anthropology* 44(2), 288–295.
- Schulting, R. 2010. Holocene environmental change and the Mesolithic-Neolithic transition in north-west Europe: revisiting two models. *Environmental Archaeology* 15(2), 160–172.
- Tauber, H. 1981. <sup>13</sup>C evidence for dietary habits of prehistoric man in Denmark. *Nature* 292(5821), 332–333.
- Troels-Smith, J. 1943. Geologisk datering af Koelbjerg-skelettet [Datation géologique du squelette de Koelbjerg]. *Aarbøger for nordisk Oldkyndighed og Historie* 1943, 232–238.

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# Becoming Mesolithic

## Reflections on the *mesolithisation* in southern Scandinavia and northern Germany

Mikkel Sørensen

### Abstract

In this article, the definition of the Mesolithic and the Palaeolithic-Mesolithic transition is discussed for southern Scandinavia and northern Germany. It is criticized that this transition is defined by geological classification (the Holocene) and not by an archaeological analysis of the period and its material culture. Different methodological ideas to analyse the *mesolithisation* of the period are suggested: A diachronous typological method, a settlement intensity analysis method, and a qualitative analysis of specific, significant artefact types and technologies. It is further concluded that these methods can reveal different aspects of the *mesolithisation* that, in combination, can promote a more nuanced discussion and definition of the Mesolithic. It is concluded that a Mesolithic society can be defined as one that lives less mobile in the landscape than a late Palaeolithic society, has a more local resource exploitation, has more technological possibilities of transforming their world, and has more permanent settlements. From this definition, it is suggested that the *mesolithisation* in southern Scandinavia and northern Germany constitutes a gradual process, starting in the Late Palaeolithic in the Bølling chronozone and is seen fully developed from the c. 9<sup>th</sup> millennium BCE onwards.

*Keywords: Mesolithic, mesolithisation, enculturation, settlement intensity, lithic typology*

### Introduction and problem

This paper discusses how we can define the Mesolithic in an archaeological sense and from a current archaeological point of view. I am aware that, in practice, it will be challenging to modify the definition of the Mesolithic. Thus, it is not attempted here to present a bulletproof new definition of the Mesolithic, but rather to make us aware of what the Palaeolithic-Mesolithic transition means archaeologically and how this transition, if it can be argued in the archaeological material, should be understood. Most importantly, this article discusses how we can methodologically study the *mesolithisation*. A range of analytical methods such as typology, technology, settlement intensity, qualitative and quantitative methods, and the concept of enculturation are presented and employed in a case study of sites from southern Scandinavia and northern Germany. But other prominent European early Mesolithic sites are also regarded as parallels. This case study primarily serves as an example, and the goal of this article is rather to stimulate discussion and further research than to solve the problems of the *mesolithisation* and the definition of the Mesolithic.

The current definition of the Mesolithic can be criticized for several reasons. Firstly, the definition of the beginning of Holocene as the start of the Mesolithic, following

the end of the Pleistocene. No other cultural period in archaeology is defined by geological classification, and it seems reasonable that neither the Mesolithic should be. Archaeology is rooted in humanities, has developed into social science traditions, and is today generally placed within these fields, even though it has a sound relationship to earth and environmental sciences. Thus, archaeologists should be able to discuss cultural transformations and terminologies based on theory of human cultural processes and material culture. The problem of a geological definition is more than instrumental, as the Mesolithic defines a research field and constitutes a way of thinking about, and understanding of, our early prehistory. Further, one can argue that the acceptance of the geological definition for the Mesolithic prevents us from discussing societal change in the period. This, because geology does not give archaeologists possibilities to argue with material culture as a main discriminant for cultural processes.

I will depart from the historical definitions of the Mesolithic and apply Marek Zvelebil's (2009) ethnographic understanding, which includes the important concept of 'enculturation'. Enculturation is defined as the process by which people learn the dynamics of their surrounding culture and acquire values and norms appropriate or necessary to that culture and its worldviews. In an archaeological sense, the enculturation process will concern changes in material culture that point to altered worldviews and lifeways. A main problem is, how and when do we see an enculturation in Late Glacial–Early Holocene cultural contexts?

### **The definition of the Mesolithic and its inherited problems**

The 'Mesolithic' time period was suggested by Westropp already in 1872, only seven years after Lubbock (1865) introduced a 'Palaeolithic' and a 'Neolithic' Stone Age. Before that, the definition of the Stone Age was coined by Thomsen (1836) in his 'Three Period System'. However, already in 1859, Worsaae had suggested to divide the Stone Age of southern Scandinavia into two stages: an 'early' and a 'late' Stone Age – based on artefact comparisons from kitchen middens and megalithic tombs. In Westrop's definition, the Mesolithic was characterized by artefacts not coming from gravel pits (*i.e.* glacial contexts), and he exemplified the Mesolithic period with lithic assemblages from Denmark and Ireland. Generally, his idea was to classify stages and 'modes', *i.e.* technologies and type fossils, that were intermediate in age between the Palaeolithic and Neolithic (Westrop 1872). The early archaeological classifications following Thomsen's work often attempted to follow geological classifications and tentatively defined the Palaeolithic as Pleistocene and the Neolithic as Holocene. However, as it was shown that the Neolithic did not necessarily coincide with the Holocene, the

'Mesolithic' became relevant to fill out "the gap" between the Pleistocene and the Neolithic (Childe 1956, 25; Rowley-Conwy 1996). From the beginning, the term 'Mesolithic' was controversial and not agreed upon. In Western Europe, the term 'Mesolithic' was reluctantly accepted by archaeologists since 1921 (Childe 1956, 25), defining a cultural period starting with the end of the Pleistocene, *i.e.* the beginning of the Holocene, and ending with the Neolithic, where the Neolithic was defined by societies that employed a farming economy and had polished stone tools. It might thus be said that the 'Mesolithic' was born due to a problem of archaeologists not being able to correlate culture with nature, *i.e.* the Neolithic with the start of the Holocene. This definition is sometimes also referred to as "Clark's modern sense definition" (Price 2015, 61) after the British Mesolithic archaeologist Grahame Clark. However, there is still no consensus on it. In Western Asia and southern Europe, the term 'Epi-Palaeolithic' is often preferred for prehistoric Holocene hunter-gatherer societies, and in Eastern Europe and Finland, the notion 'Neolithic' or 'Boreal Neolithic' is in use for Holocene hunter-gatherers when ceramic technologies occur.

While the termination of the Mesolithic and the Neolithisation process is discussed extensively concerning both its definition and its cultural processes, less attention has been given to the start of the Mesolithic. Only archaeologists with specialisation in the Late Palaeolithic–Early Mesolithic periods have addressed this question (*e.g.* Terberger and Eriksen 2004). Recently, Warren (2025, 20–21) has argued that the Mesolithic should rather start with the end of the Late Glacial Maximum (the Bølling-Allerød interstadials), as these climatically match a Holocene climate and generally signify a reoccupation, or the colonisation, of Northern Europe.

In opposition to the Mesolithic defined merely as a time period, Zvelebil (2009) proposed a definition rooted in Siberian ethno-history. Zvelebil defines the Mesolithic by a history of shared knowledge and a cognitive world marked on the one hand by an adaptation to a 'deglaciation' and, on the other, by an 'enculturation' in which people gradually familiarised themselves with the world through actively engaging with it. With this definition, he proposes a Mesolithic tradition that extends in time and includes modern groups of Siberian hunter-gatherers.

### **Methodologies**

A chosen methodology will inherently include an underlying theoretical paradigm, yet also determine the methods employed, the material studied and consequently define the outcome of the analysis. Thus, a methodology needs to be addressed explicitly. Methodologies applied to analyse the *mesolithisation* can concern morpho-typology, technology, settlement intensity, economy, worldviews, and cosmologies through studies of art and ritual practice. And

they can be qualitative or quantitative. The *mesolithisation* is a process that concerns ‘Mesolithic life’ and society, and it should therefore be studied within a range of questions and methods that can analyse many aspects of the Palaeolithic-Mesolithic. Thus, a crucial question concerns how to methodologically analyse the *mesolithisation*? It is the combination of methods, perspectives, and analysis that forms an appropriate methodology. In this analysis I combine a chronological comparative method mostly concerned with technology and typology of lithic artefacts with an analysis of settlement size and intensity. In this way, several important aspects of Mesolithic life are studied. However, some artefact types and processes are important to be discussed in terms of their social and cosmological meaning, adding these perspectives to the methodology. Thus, by combining three perspectives and methods, a broader discussion and understanding of the *mesolithisation* is reached. Briefly described, the three perspectives, methods and analysis are:

- A. A comparative method in which transitional Late Palaeolithic-Mesolithic site assemblages of Southern Scandinavia and Northern Germany are analysed for a comparison of artefact types, technology, and radiocarbon dating. This analysis is employed to define diachronous changes in material culture. It has its roots in typological studies developed in the 19<sup>th</sup> century, supplemented by absolute dating methods developed during the 20<sup>th</sup> century.
- B. A study of settlement intensity. Settlement intensity as an analytical term was formulated and addressed as part of a processual archaeology where the term was essential in assessing the “complexity” of cultural history and evolution (Price and Brown 1985). In the analysis attempted here, a simple method is used where the quantity of formal tools is compared to the quantity of the lithic debitage for some of the best excavated site-assemblages that characterize the Pleistocene–Holocene transition of southern Scandinavia and northern Germany. Analyses of settlement intensity have previously been carried out on Southern Scandinavian assemblages for the Late Palaeolithic by *e.g.* Pedersen (2008; 2009) and for the Mesolithic by Sobotta (1991), Johansen (2006) and Kleijne *et al.* (2025).
- C. A qualitative analysis and discussion of particular artefact types and technologies: the microlith, the adze, and lithic blade technology. This discussion can employ ethnographic analogies and is based on anthropological studies of cosmology, ritual, and symbolic practice, thus drawing from social science ideas as seen both in processual and post-processual archaeology.

It has to be stressed that the goal is not to present a final or in-depth analysis, but rather to illustrate the diversity

of possibilities and interpretations by applying different methods into a methodology. Further, it needs to be mentioned that each of these methods has limitations and that there are source-critical problems bound to their applications.

### **A diachronous comparative typological approach**

Quite a number of sites can be considered when analysing the transition from the Late Palaeolithic to the Mesolithic in Southern Scandinavia and Northern Germany (Petersen 2009; Sørensen *et al.* 2018). In Figure 1, archaeological sites considered most appropriate for analysis due to their excavation quality and publication are listed and compared with respect to typology, technology, and radiocarbon dating. The radiocarbon dating for each site is plotted from the earliest endpoint to the latest endpoint of calibrated radiocarbon dates from the site (at 1 $\sigma$ ).

Despite the long <sup>14</sup>C spans for each site (which is partly reasoned by old conventional dates) only a few sites have an absolute dating to the period most relevant when discussing the Holocene transition, *i.e.*, the 10<sup>th</sup> millennium BCE. These sites are Lundby 1, 2 and 6 (Hansen *et al.* 2004; Jessen *et al.* 2015), Stellmoor (Fischer and Tauber 1986; Rust 1943), Potsdam Schlaatz (Benecke *et al.* 2002), and Bedburg-Köningshoven (Street 1991). However, neither of these sites represents habitation sites. Instead, they are interpreted as kill sites or deposition sites, where faunal remains have been left in a context with very few or no human-made artefacts. We might add the sites Nørregård VI (Sørensen and Steinke 2004) and Årup 1 (Karsten and Nilsson 2006) to this transition period despite their lack of direct absolute dating, due to the presence of Zohnhoven-type microliths and long blade technology (Conneller *et al.* 2016). The earliest Holocene habitation sites in southern Scandinavia and Northern Germany are: Årup Context 2 (Karsten and Nilsson 2006), Duvensee 9 (Bokelmann 1991; Kleijne *et al.* 2025), the earliest phase of Friesack 4 and Friesack 27A (Gramsch 2002). These sites are absolutely and palynologically dated to the latest part of the 10<sup>th</sup> millennium BCE, before hazel appears in the landscape and hazel nuts in the site inventories. They are generally interpreted as short-term campsites placed at lakeshores, and they have relatively small lithic assemblages (typically less than 20.000 artefacts), and are typologically characterized by the appearance of simple microliths and adze productions. Further, they are dominated by the use of local flint, often of modest quality, and it is seen that blade production can exploit low-quality flints (Berg-Hansen 2018). In eastern England, the earliest occupations at the site of Star Carr are dated to the same period (Conneller *et al.* 2012; 2016).

When typology, technology, and radiocarbon dating for Ahrensburgian and early Mesolithic sites are

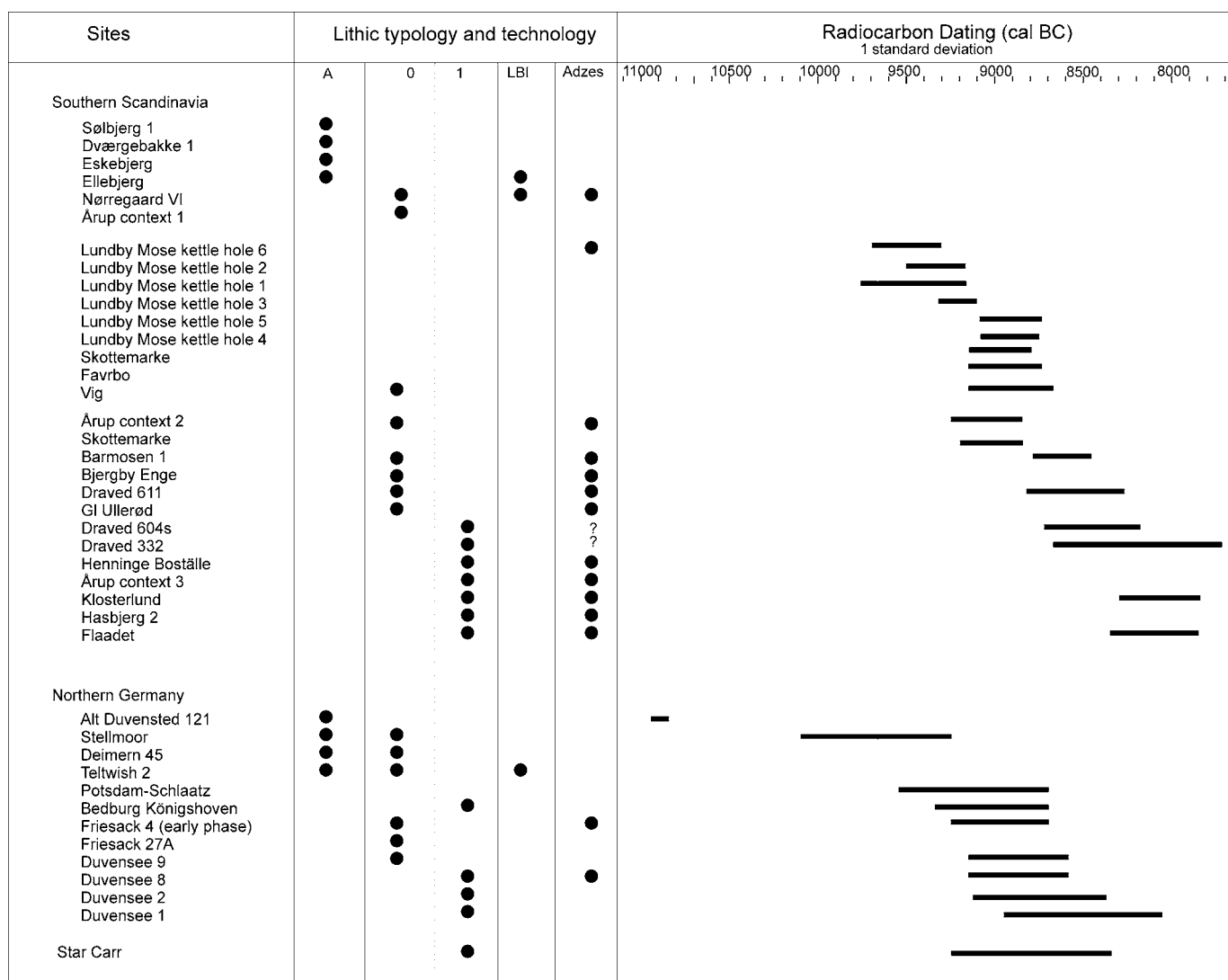


Figure 1: Comparative analysis of north European sites from the Younger Dryas-Preboreal transition. Sites are analysed for typology, technology, and radiocarbon dating and are ordered chronologically and regionally. Armature typology is classified by defining the appearance of A) Ahrensburgian type tanged points (Taute 1968), 0) microliths of simple oblique type (Petersen 1973) including Zohnhoven points, 1) microliths of simple type with lateral retouch and scalene triangles, LBI) Long blade Industry, *i.e.* long blades and bruised blades (more than 12 cm), Adze technology. The radiocarbon dating for each site is plotted from the earliest endpoint to the latest endpoint of the calibrated radiocarbon dates from the site (at 1σ) (see Pedersen 2009 for references to Late Glacial sites, Sørensen *et al.* 2018 for references to Holocene sites). Graphics by the author.

compared, a diachronous gradual change appears in typology and technology (Fig. 1). This is specifically seen where several typologies and technologies coexist at a site: the site Ellebjerg has long blades and tanged points (Pedersen 2009), Stellmoor has tanged points and simple/Zohnhoven microliths (Taute 1968), the site Nørregaard has simple/Zohnhoven microliths, long blade industry, and adzes (Sørensen and Sternke 2004). The gradual transition of typology and technology represents a chronological development, however, with possibilities of variability and co-occurrence between sites (Fig. 1).

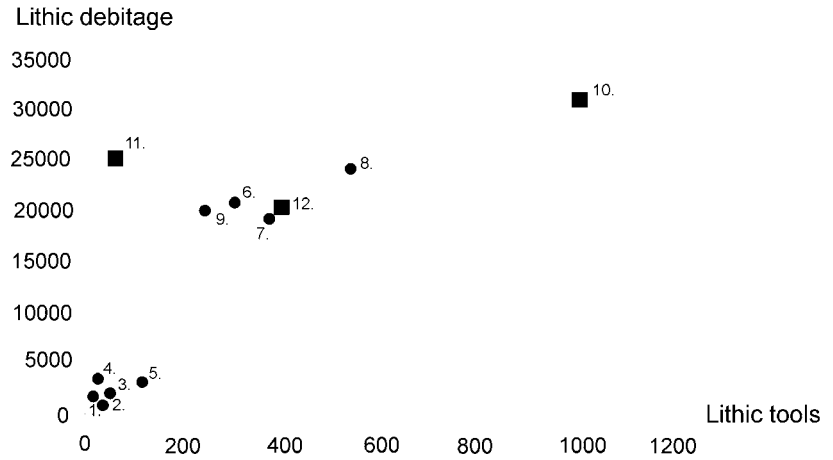
Yet, it should also be stated that there are source-critical aspects to this study. The quality of sites is considerably varied concerning their excavation and recording, which should be further discussed and clarified before certainty

can be addressed. A main problem remains in whether sites have been reused during subsequent periods, *i.e.*, being mixed (for a discussion of the quality of most of the sites, see Berg-Hansen 2018; Petersen 2009; Sørensen *et al.* 2018; Weber *et al.* 2011). Such critical scrutiny is also important considering absolute dating, specifically concerning the context of the dating sample, the dated material (reservoir-effects and own age (Phillipsen 2017)), and the method of radiocarbon dating (AMS dating versus conventional dating).

### The settlement intensity approach

The evidence of an Early Holocene phase of short-term hunting sites leaving depositions of bones from large ungulates in lakes, compared to later, more artefact-rich

Figure 2: Settlement intensity analysis. The number of defined typological lithic tools, *i.e.*, armature points, scrapers, burins, adzes, borers (X-axis), is compared to the total number of the lithic inventory (Y-axis). The criteria for plotted sites are that they: 1) demonstrate a clear and limited concentration of artefacts, 2) have an inventory typical of only one chronological phase. Graphics by the author.



sites, points towards chronological differences in the use of landscapes, settlement size, habitation, and occupation length. Consequently, an analysis of settlement intensity of the period is relevant. In this study, nine sites significant to the Late Palaeolithic-Mesolithic transition are analysed for settlement intensity by comparing the number of defined tools to the number of lithic debitage for each site. Three Late Palaeolithic Bromme culture sites are compared to further discuss the chronological variability. The sites chosen are: Alt Duvenstedt (Clausen 1996), Sølbjerg 1 (Petersen and Johansen 1993), Årup 1 and 2 (Karsten and Nilsson 2006), Nørregård VI (Sørensen and Sternke 2004), Barmosen (Johansson 1990), Ulkestrup I and II (Andersen *et al.* 1982), Eskebjerg (Pedersen 2009), Stoksbjerg Bro (Pedersen and Petersen 2006), Fensmark (Fischer 2012), and Bromme (Fischer and Nielsen 1987) (Fig. 2; Tab. 1).

In order to ideally analyse settlement intensity, sites need to be unmixed, fully excavated, and have a restricted lithic concentration that can be interpreted as representing a single habitation. However, a range of source-critical problems do appear: sites are excavated and reported differently, which makes comparison problematic, *e.g.* regarding excavation method, size of debris, and definitions of tool types described. In the present case, the best and most completely excavated sites are chosen. However, the sites Eskebjerg (Pedersen 2009) and Ulkestrup II (Sørensen 2006) can be interpreted as reoccupied during one phase, the Sølbjerg 1 site was not completely excavated due to modern disturbance, while the Eskebjerg site shows a diffuse spatial distribution that may not have been fully excavated. All other sites represent completely excavated main concentrations and are interpreted as representing a single habitation.

From the analysis, it can be seen that site assemblages dating to the Younger Dryas and the first half of the Preboreal (Alt Duvenstedt 121, Sølbjerg, Årup 1, Årup 2, and Nørregaard VI) cluster with the lowest intensity, having between 20–100 tools and less than 5000 pieces of lithic debris (Fig. 2; Tab. 1). Sites typical of the Maglemosian,

No.	Site name	Lithic tools (n)	Total lithics (n)	Tool %
1	Alt Duvenstedt	21	1837	1.5
2	Sølbjerg 1	38	1200	3.2
3	Årup 1	49	2118	2.3
4	Årup 2	29	3552	0.8
5	Nørregård VI	117	3184	3.6
6	Barmosen 1	305	20659	1.4
7	Ulkestrup I	395	20000	2.0
8	Ulkestrup II	542	24000	2.6
9	Eskebjerg	244	20000	1.2
10	Stoksbjerg Bro	1004	31000	3.2
11	Fensmark	67	25000	0.3
12	Bromme	397	20000	2.0

Table 1: Twelve Palaeolithic and Mesolithic sites are compared for their quantity and percentage of tools versus total lithic assemblages.

dating from the middle Preboreal (Barmosen 1) to Atlantic time (Ulkestrup I and II), have more than 300 tools defined and more than 20.000 pieces of lithic debris. The sites typically have a tool-to-lithic-debitage ratio from 1%–3%, but Nørregård VI has 3.6%, Sølbjerg and Stoksbjerg Bro 3.2%, while Fensmark has only 0.2% and Årup 0.8% (Tab. 1). This variability can be explained, respectively, for the sites with a high tool percentage as specialization for hunting, and for the low percentage, as focused on flintknapping (Löhr 1979; Pedersen 2008). To demonstrate that late Palaeolithic sites from the Bromme culture can be rich in tools and debris, representing high settlement intensity, the sites Fensmark, Bromme, and Stoksbjerg Bro are included. The Bromme site is comparable to late Maglemosian sites in settlement intensity, while the Stoksbjerg Bro site exceeds the Mesolithic sites in tool and debitage quantities, being the most intensively used site in this case study (Fig. 2).

## Qualitative approaches to understanding the *mesolithisation*

Two main typologies defining the Mesolithic will be discussed: armature typology, *i.e.* the shift from tanged point to microlith, and the introduction of the adze.

### The armature points

A change from tanged points to microliths is generally accepted to have appeared in northern Europe at the transition to the Holocene (*e.g.* Jensen 2001, 58). This change is primarily seen within the Ahrensburgian culture. However, there are several problems when trying to define a transition to the Mesolithic with a microlithic armature industry. Already Taute saw that sites defined as belonging to the Ahrensburgian had different forms of microliths included in their inventory, and often in combination with tanged points (Taute 1968). In the Ahrensburgian context, the microliths are often termed Zonhoven points (Bohmers and Wouters 1956). Yet, they typologically represent simple microliths and narrow trapeze-microliths as seen on Nørregård VI and at Oudehaske and Gramsbergen sites (*e.g.* Johansen and Stapert 1997; Sørensen and Sternke 2004), and they are technologically made in the same way by the micro-burin method. The idea that the Mesolithic could be defined by the absence of tanged points also seems problematic. Tanged points are generally not seen in the Federmesser group (but see Riede 2017). Tanged points do, on the other hand, appear in later Holocene periods, *e.g.* in the Neolithic Pitted Ware Culture and at Early Mesolithic sites in Western Sweden and Norway (but see discussion whether these finds actually should be interpreted as Late Palaeolithic (Fuglestad 2007; Schmitt 1999)).

From a technological and functional point of view, microliths and Ahrensburgian tanged points are very similar: they are of similar size and dimensions, both are made from similar blank/blades most often by micro-burin method, and not least, both are hafted in arrows. Microliths must thus effectively function like tanged points did in an Ahrensburgian context. Yet, if the change in armature is not fully explained by function, how should they then be understood? If the armature point is perceived as part of the relation between the hunter and the hunted animal in an animistic hunter-gatherer cosmology, a different interpretation can be reached. It is well described from studies of animist hunter-gatherers of the northern hemisphere that the design of the hunting tool has great symbolic meaning to the hunt as a process: In an animistic hunter's ontology, the animal gives itself to the hunter, but only if hunted the right way and by the right tools (Gulløv and Gilberg 1997; Willerslev 2007). A relational, perhaps even social explanation, to the change in armature point morphology from the Palaeolithic tanged point to the Mesolithic microlith is that, on a symbolic/cosmological level, the Ahrensburgian tanged point was meant for the reindeer in contrast to the

microlithic arrow points that were meant for other mammal game species that arrived during the Early Holocene, *e.g.* elk, aurochs, horse, giant deer (Aaris-Sørensen 2010). This hypothesis can also explain why early Mesolithic hunters in western Sweden and Norway (often termed Hensbacka and Fosna cultures) used tanged points considerably longer in time than their southern Scandinavian neighbours: As the reindeer leaves northern continental Europe and migrates into northern Scandinavian regions, it can be hunted there during the Holocene (Bang-Andersen 2003). In this perspective, the change from tanged points to microliths is perceived as part of a process of enculturation, in which people related to Holocene mammals through specific practices involving their hunting tool types and relating to an animistic cosmology.

### The adze

Socially and technologically, the adze represents a transformative tool due to its ability to shape wooden materials into tools and structures. Potentially, it can also transform a local environment by felling of trees, or when use is intensified, to deforestation.

One can thus argue that the hafted adze constitutes a necessary invention for sustaining a more localized life in a forested environment. Thus, by means of the adze, a hunter-gatherer society could effectively shape their world (Fig. 3). In northern Europe, adzes generally do not appear in assemblages defined as Late Glacial but are common in Holocene Mesolithic assemblages. Adzes are made from both lithic, antler, and bone materials. However, adzes are not a universal criterion for a *mesolithisation* as they appear in Asia in the Upper Palaeolithic (*c.* 30000 BCE in Japan), where they are interpreted as related to boat building and migration to the Asian islands (Bae 2017). It can be concluded that, regarding northern Europe, the adze is (still) a valid criterion for defining the *mesolithisation*, as this tool represents material culture dating to the Early Holocene. Further, it has a significant economic and technological impact, and it therefore potentially carries symbolic meaning in a Mesolithic society.

## Discussion

As demonstrated above, the *mesolithisation* of northern Europe is neither socially nor from a material culture perspective easily archaeologically defined. Studies of lithic blade technology in Ahrensburgian–Early Mesolithic assemblages clearly define a coherent technology of the period, thereby pointing to a coherent social tradition, albeit with local adaptations during the Mesolithic period (Berg-Hansen 2018). The tanged point is produced in the Preboreal, *e.g.* in Norway, and the microlith is part of the Ahrensburgian, meaning that neither armature typology supports a clear transition during the Early Holocene. Bone and antler tools, such as reindeer antler hammers

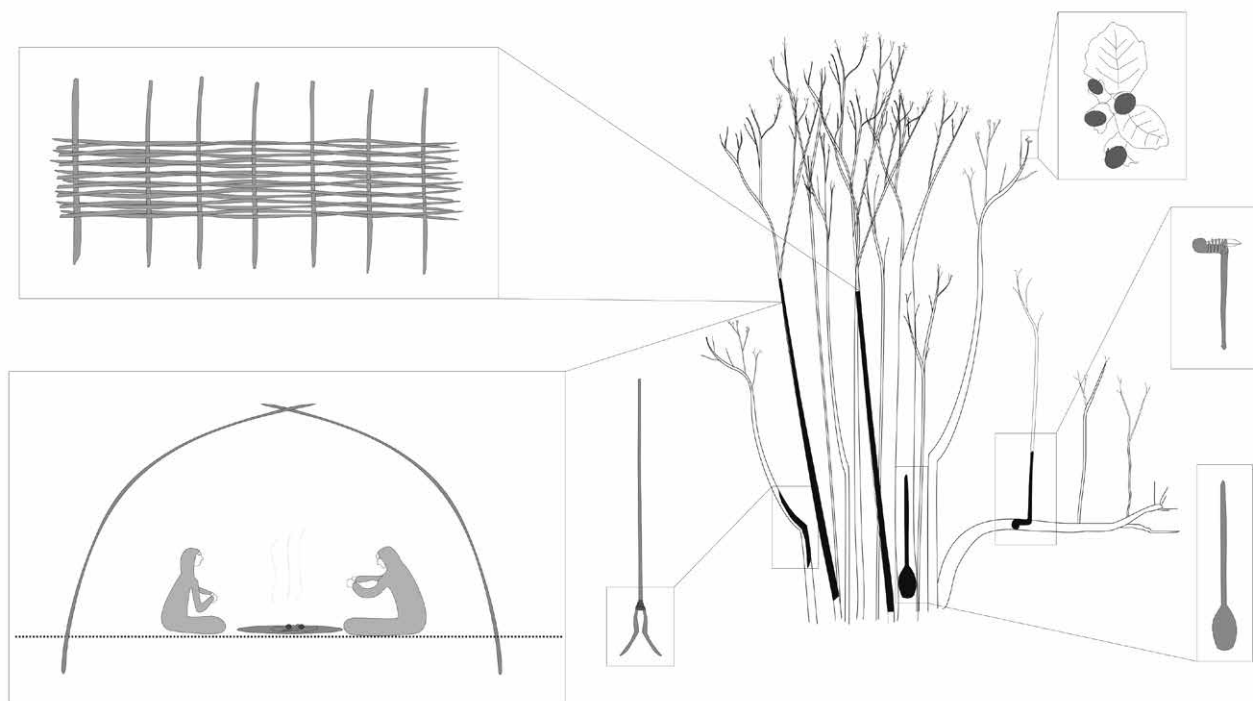


Figure 3: An example of how hazel was used, and how it, in concert with the adze, transformed Mesolithic life. Hazel nuts were systematically gathered and processed for consumption (Holst 2010), while hazel wood stems and rods were worked into a wide variety of purposes such as: dwelling constructions (Andersen *et al.* 1982), shafts, leister prongs (Andersen 2013), paddles (Andersen *et al.* 1982), fish weirs (Koivisto *et al.* 2025) and adze hafts (Andersen 2013). Drawing and design by the author.

and biserial harpoons, that were formerly typologically dated to the Late Glacial period, have recently been AMS dated broadly from the Allerød to the Boreal period (Wild *et al.* 2022). Thus, the former idea of typo-chronological division of bone and antler tools was wrong. In contrast, continuity in social and technological tradition from the Late Palaeolithic to the Mesolithic is now emphasized. Consequently, the hafted adze is the only tool type and artefact technology that can signify change in material culture at the Pleistocene–Holocene transition. In conclusion, the idea of a clear shift in typology and material culture from the Pleistocene to the Holocene cannot be sustained. A clear change did not appear in the settlement intensity analysis at the transition to the Holocene. Very few sites that can be related to habitation are found during the first half of the Preboreal period. The first Mesolithic lakeside habitations of more stationary character, demonstrating that people had an intimate knowledge of landscapes and resources, are seen from the Middle to Late Preboreal period. However, a similar settlement intensity also appears in the Late Palaeolithic Bromme culture during the late Allerød interstadial on Zealand (*e.g.* sites of Bromme and Stoksbjerg Bro).

If we employ Zvelebil's concept of 'enculturation', we can describe the Palaeolithic-Mesolithic transition as a hunter-gatherer society that gradually changed the understanding and conceptions of the world they lived

in. A change in ideology and ontology could happen as people gradually became able to organize an annual life world in a local to regional landscape based on diverse faunal and vegetational species. A Mesolithic society could, following this, be defined as one that lived more stationary in the landscape than a Late Palaeolithic society, had a more local resource exploitation, had more technological possibilities of transforming their world, and had more permanent settlements. In this study, the sites of Barmosen and Ulkestrup I and II are examples of Mesolithic sites that show enhanced enculturation, *i.e.* a wide diversity in economy (animal and vegetational species), technology (boat transport, adze technology, bow technology, dwelling structures, local raw materials, fishing technologies), and high settlement intensity. In contrast, sites like Alt Duvenstedt 121, Sølbjerg 1, Årup 1, Nørregaard VI, and the depositions from Lundby Mose and Potsdam Schlaatz represent short-term inhabited sites, with imported raw material (Alt Duvenstedt 121 and Årup 1), low settlement intensity, and hunting of single species (Lundby Mose 1-4 and 6, Potsdam Schlaatz).

When assessing these characteristics in relation to the definition of the Mesolithic it can be argued that the use of locally procured flint, the use of adzes on the sites probably for transforming wood materials into tools and structures, use of boats and not least the lakeshore habitation sites are features that point to a life world where people were well

acquainted with, and adapted to a specific landscape and a local environment. This stands in clear contrast to Late Glacial sites of the Ahrensburgian culture and sites dated to the first half of the Preboreal that demonstrate short occupations and specialized site use. The Early Preboreal depositions of bones from large ungulates in lakes can be interpreted as part of a process of cosmological negotiation and “making familiar” with a specific place and the landscape (Pedersen and Petersen 2017). In this sense, we might say that despite the absence of intensified habitation sites, there are signs of enculturation appearing within the first part of the Preboreal period.

When discussing the *mesolithisation* of southern Scandinavia and northern Germany, Warren’s idea that it starts with the Hamburgian/Creswellian colonization of Northern Europe during the Bølling interstadial makes sense. It is the first adaptation to the region and, as argued here, the Late Palaeolithic and the Early Mesolithic groups, especially the Ahrensburgian and Maglemosian, are related in terms of material culture and technological tradition. From an environmental adaptation perspective, the Late Glacial Bølling and Preboreal interstadials constitute periods of human adaptation; it is evident that a first microlithisation is seen with the Federmesser group and that settlement intensity increases with the Bromme culture, both dated to the Allerød warming. In this perspective, it should also be addressed that the Preboreal oscillation (Hoek and Bos 2007) represents a cooling that might have played a role in human adaptation in southern Scandinavia and northern Germany. Yet, an idea of adaptation as a natural law must be rejected, as adaptive processes depend on the history and culture of the specific society under investigation (Sørensen 2012).

## Conclusions

From the typological, technological, and chronological analysis conducted here, no clear breaks are seen. This suggests a gradual cultural process in which a social tradition was gradually transformed during the transition to the Holocene. Recent AMS dating of bone and antler tool types supports this conclusion.

The hafted adze, invented during the early Preboreal, is perceived as an important new practice involving a new relation to the landscape, and is thereby a clear sign of an enculturation process. A similar interpretation concerns microliths and Zonhoven points: If these are understood as made for hunting the ‘new’ Holocene mammal species, they must be seen as important parts of an enculturation process. The change in armature style is here suggested to concern the cosmological realm; however, functional aspects of hunting are not ruled out as relevant.

The analysis of settlement intensity demonstrates that there are no clear signs of stationary habitations and intensified local landscape adaptations in the first part of the Preboreal period. It is as though this period is still part of the Ahrensburgian cultural landscape, where only short stays are made at places where particular resources appear. We might thus understand this period as a pioneer situation with different groups of people appearing in concordance, defined as Ahrensburgian, Epi-Ahrensburgian, Long Blade complex, and Maglemosian groups. The period is also enigmatic regarding landscape, fauna, and vegetation. Due to the pioneering vegetation, the Preboreal oscillation, the north-south temperature gradient, and the diverse geology of the region, we must imagine a very regionally diverse landscape with different resources (Aaris-Sørensen 2009; Hamer *et al.* 2019; Krüger and Damrath 2020; Theuerkauf *et al.* 2014). This landscape and cultural situation can be compared to what has been described for the previous Allerød period warming (Mortensen *et al.* 2014). Thus, the Early Preboreal landscape would hold possibilities for various knowledge bases and specialisations, and therefore for different cultural and social groups of hunter-gatherers.

However, during the second half of the Preboreal period we see archaeological evidence of intensified habitation and strategic use of local landscapes and resources. In the same period, we also see the first inhumation graves relating persons and rituals to specific places and landscapes (Eriksen and Andersen 2017) as well as a regionalization of material, technological, and symbolic culture (Berg-Hansen 2018; Toft 2006). Thus, from this period, we can infer that people became familiar with local landscapes and resources, which we might define as an enculturated Mesolithic life, across northern Europe and southern Scandinavia. In conclusion, the *mesolithisation* is defined as a process starting with the Late Palaeolithic and finalizing as a process with fully Mesolithic societies during the second half of the Preboreal period.

This article has, first of all, discussed a range of analytical methods and archaeological materials that hopefully will inspire and arm archaeologists in defining and thinking about the Mesolithic, and not accepting a geological classification for the Mesolithic definition.

## Acknowledgements

The present article is written with inspiration from Berit’s work and interest in the Late Palaeolithic-Mesolithic transition, as chairman of the UISPP Commission for The Final Palaeolithic of Northern Eurasia, and from her work at the ZBSA. This, and from a long and heartfelt friendship.

I would like to thank two reviewers for their passionate and thorough review of an earlier version of this text.

## References

- Aaris-Sørensen, K. 2010. *Diversity and dynamics of the mammalian fauna in Denmark throughout the last glacial-interglacial cycle, 115-0 kyr BP*. Fossils and Strata 57. Chichester, Wiley-Blackwell.
- Andersen, K., Jørgensen, S. and Richter, J. 1982. *Maglemose hytterne ved Ulkestrup Lyng*. Nordiske Fortidsminder Serie B - in quarto 7. København, Kongelige Nordiske Oldskriftselskab.
- Andersen, S. 2013. *Tybrind Vig: submerged mesolithic settlements in Denmark*. Aarhus University press, Århus.
- Bae, C. J. 2017. Late Pleistocene human evolution in eastern Asia: Behavioral perspectives. *Current Anthropology* 58(S17), 514–526.
- Bang-Andersen, S. 2003. Southwest Norway at the Pleistocene/Holocene Transition: Landscape Development, Colonization, Site Types, Settlement Patterns. *Norwegian Archaeological Review* 36(1), 5–25, DOI:10.1080/00293650307293
- Benecke, N., Gramsch, B. and Weisse, R. 2002. Zur Neudatierung des Ur-Fundes von Potsdam-Schlaatz, Brandenburg. *Archäologisches Korrespondenzblatt* 32, 161–168.
- Berg-Hansen, I. 2018. Continuity and change in Late Glacial and Postglacial social networks: knowledge transmission and blade production methods in Ahrensburgian and Early Mesolithic North West Europe. In: Knutsson, K., Knutsson, H., Apel, J. and Glørstad, H. (eds.), *The Early Settlement of Northern Europe: The Technology of Early Settlement in Northern Europe: Transmission of Knowledge and Culture* vol. 2. Sheffield, Equinox Publishing, 63–98.
- Bohmers, A. and Wouters, A. 1956. Statistics and Graphs in the Study of Flint Assemblages. III. A Preliminary Report on the Statistical Analysis of the Mesolithic in Northwestern Europe (pl. II; figs. 6-7). *Palaeohistoria* 5, 27–38.
- Bokelmann, K. 1991. Duvensee, Wohnplatz 9: Ein prä-borealzeitlicher Lagerplatz in Schleswig-Holstein. *Offa* 48, 75–114.
- Childe, V. G. 1956. *Piecing together the past: the interpretation of archaeological data*. London, Routledge and Kegan Paul.
- Clausen I. 1996. Duvenstedt LA 121, Schleswig-Holstein. The occurrence of the Ahrensburgian Culture in soils of the Allerød Interstadial. A preliminary Report. In: Larsson, L. (ed.), *The earliest Settlement of Scandinavia and its relationship with Neighbouring Areas*. *Acta Archaeologica Lundensia* 8(24), 99–110.
- Conneller, C., Milner, N., Taylor, B. and Taylor, M. 2012. Substantial settlement in the European early Mesolithic: New research at Star Carr. *Antiquity* 86(334), 1004–1020.
- Conneller, C., Bayliss, A., Milner, N. and Taylor, B. 2016. The Resettlement of the British Landscape: Towards a chronology of Early Mesolithic lithic assemblage types, *Internet Archaeology* 42. DOI: 10.11141/ia.42.12
- Eriksen, B. V. and Andersen, H. C. H. 2016. Hammelev. An Early Mesolithic cremation grave from Southern Jutland, Denmark. In: Grünberg, J. M., Gramsch, B., Larsson, L., Orschiedt, J. and Meller, H. (eds.), *Mesolithic Burials – Rites, Symbols and Social Organisation of Early Postglacial Communities*. *Mesolithische Bestattungen – Riten, Symbole und soziale Organisation früher postglazialer Gemeinschaften*. Tagungen des Landesmuseums für Vorgeschichte Halle 13. Halle (Saale), Landesamt für Denkmalpflege und Archäologie Sachsen-Anhalt – Landesmuseum für Vorgeschichte, 73–80.
- Fischer, A. 2012. The Fensmark settlement and the almost invisible Late Palaeolithic in Danish field archaeology. *Danish Journal of Archaeology* 1(2), 123–141.
- Fischer, A. and Nielsen, F. O. S. 1987. Senistidens boplads ved Bromme. *Årbøger for Nordisk Oldkyndighed og Historie* 1986, 5–42.
- Fischer, A. and Tauber, H. 1986. New C-14 datings of Late Palaeolithic cultures from Northwestern Europe. *Journal of Danish Archaeology* 5, 7–13.
- Fuglestedt, I. 2007. The Ahrensburgian Galta 3 site in SW Norway. *Acta Archaeologica* 78(2), 87–110.
- Gramsch, B. 2002. Friesack: letzte Jäger und Sammler in Brandenburg. *Jahrbuch des Römisch-Germanischen Zentralmuseums Mainz* 47, 51–96.
- Gulløv, H. C. and Gilberg, R. 1997. The soul of the prey. *Publications of the National Museum, Ethnographical Series: Fifty Years of Arctic Research. Anthropological Studies from Greenland to Siberia* 18, 131–140.
- Hoek, W. Z. and Bos, J. A. 2007. Early Holocene climate oscillations – causes and consequences. *Quaternary Science Reviews* 26(15/16), 1901–1906.
- Holst, D. 2010. Hazelnut economy of early Holocene hunter-gatherers: a case study from Mesolithic Duvensee, northern Germany. *Journal of Archaeological Science* 37(11), 2871–2880.
- Hamer, W. B., Knitter, D., Grimm, S. B., Serbe, B., Eriksen, B. V., Nakoinz, O. and Duttmann, R. 2019. Location modeling of final Palaeolithic sites in northern Germany. *Geosciences* 9(10), 430.
- Hansen, K. M., Petersen, E. B. and Aaris-Sørensen, K. 2004. Filling the gap: Early Preboreal Maglemose elk deposits at Lundby, Sjælland. In: Eriksen, B.V. and Terberger, T. (eds.), *Hunters in a changing world: environment and archaeology of the Pleistocene-Holocene Transition (ca. 11000-9000 BC) in Northern Central Europe*. Internationale Archäologie – Arbeitsgemeinschaft, Symposium, Tagung, Kongress 5. Rahden (Westf.), Verlag Marie Leidorf, 75–84.

- Jensen, J. 2001. *Danmarks Oldtid. Ældre Stenalder*. København, Gyldendal.
- Jessen, C. A., Pedersen, K. B., Christensen, C., Olsen, J., Mortensen, M. F. and Hansen, K. M. 2015. Early Maglemosian culture in the Preboreal landscape: Archaeology and vegetation from the earliest Mesolithic site in Denmark at Lundby Mose, Sjælland. *Quaternary International* 378, 73–87. DOI:10.1016/j.quaint.2014.03.056
- Johansen, K. L. 2006. Settlement and land use at the Mesolithic-Neolithic transition in southern Scandinavia. *Journal of Danish Archaeology* 14, 201–223.
- Johansen, L. and Stapert, D. 1997. Two 'Epi-Ahrensburgian' sites in the northern Netherlands: Oudehaske (Friesland) and Gramsbergen (Overijssel). *Palaeohistoria* 39/40, 1–87.
- Johansson, A. D. 1990. *Barmose-Gruppen. Praeboreale bopladsfund i Sydsjælland*. Aarhus, Aarhus Universitetsforlag.
- Karsten, P. and Nilsson, B. 2006. Life and work during 5.000 years. In: Karsten, P. and Nilsson, B. (eds.), *In the wake of a woman: Stone Age pioneering of northeastern Scania, Sweden, 10,000–5000 BC, the Arup settlements*. Lund, Rigsantikvarieämbetet, 57–172.
- Kleijne, J., Lübke, H., Groß, D., Bokelmann, K. and Meadows, J. 2025. Temporal patterns in Mesolithic activity at Duvensee, Germany. *Quaternary Science Reviews* 353, 109230.
- Koivisto, S., Stafseth, T., Robson, H. K., Philippsen, B., Schmölcke, U., Brinch, M. and Groß, D. (2025). Watling for Fish: The Materials and Construction of Stationary Wooden Fishing Structures in Stone Age Southern Scandinavia ca. 6500–1800 cal BCE. *International Journal of Wood Culture* 1, 1–25.
- Krüger, S. and Damrath, M. 2020. In search of the Bølling-Oscillation: a new high resolution pollen record from the locus classicus Lake Bølling, Denmark. *Vegetation History and Archaeobotany* 29(2), 189–211.
- Löhr, H. 1979. *Der Magdalenien-Fundplatz Alsdorf, Kreis Aachen-Land. Ein Beitrag zur Kenntnis der funktionalen Variabilität jungpaläolithischer Stationen*. Dissertation. Tübingen, University of Tübingen.
- Lubbock, J. 1865. *Pre-historic Times as Illustrated by Ancient Remains and the Manners and Customs of Modern Savages*. London, Williams and Norgate.
- Mortensen, M. F., Henriksen, P. S. and Bennike, O. 2014. Living on the good soil: relationships between soils, vegetation and human settlement during the late Allerød period in Denmark. *Vegetation History and Archaeobotany* 23(3), 195–205.
- Pedersen, K. B. 2008. Site variability and chaîne opératoire. Describing late Palaeolithic settlement intensity. In: Sørensen, M. and Desrosiers, P. (eds.), *Technology in archaeology*. Publications from the National Museum Studies in Archaeology & History 14. Copenhagen, The National Museum of Denmark.
- Pedersen, K. B. 2009. *Stedene og menneskene. Istdidsjægere omkring Knudshoved Odde*, Museerne.dk 3. Vordingborg, Museerne.
- Pedersen, K. B. and Petersen, E. B. 2006. Variability in the late Palaeolithic: the example of Stoksbjerg Bro, Zealand, Denmark. In: Hansen, K. M. and Pedersen, K. B. (eds.), *Across the Western Baltic*. Vordingborg, Sydsjællands Museum, 75–92.
- Pedersen, K. B., and Petersen, E. B. 2017. Bringing home the elk: Preboreal elk deposits from southern Scandinavia. In M. Sørensen and Pedersen, K.B. (eds.), *Problems in Palaeolithic and Mesolithic Research*. Arkæologiske Studier 12. København, University of Copenhagen/ Museum Southeast Denmark, 237–256.
- Petersen, E. B. 1973: A survey of the Late Palaeolithic and Mesolithic of Denmark. I: S.K. Kozłowski (ed): *The mesolithic in Europe*. Warszawa, 77–127.
- Petersen, E. B. 2009. The Human Settlement of Southern Scandinavia 12,500-8,700 calBC. In: Street, M., Barton, R. N. E., and Terberger, T. (eds.), *Humans, environment and chronology of the Late Glacial of the North European Plain*. RGZM-Tagungen 6. Mainz, Römisch-Germanisches Zentralmuseum, 89–130.
- Petersen, P. V. and Johansen, L. 1993. Sølbjerg I – An Ahrensburgian site on a reindeer migration route through eastern Denmark. *Journal of Danish Archaeology* 10(1991), 20–37.
- Philippsen, B. 2017. Problems in radiocarbon dating. In: Sørensen, M. and Pedersen K. B. (eds.), *Problems in Palaeolithic and Mesolithic Research*. Arkæologiske Studier 12. København, University of Copenhagen/ Museum Southeast Denmark, 105–117.
- Price, T. D. and Brown, J. A. 1985 (eds.). *Hunter Gatherers: the Emergence of Cultural Complexity*. New York, Academic Press.
- Price, T. D. 2015. *Ancient Scandinavia: An Archaeological History from the First Humans to the Vikings*. London, Routledge.
- Riede, F. 2017. The 'Bromme problem' – notes on understanding the Federmessergruppen and Bromme culture occupation in southern Scandinavia during the Allerød and early Younger Dryas chronozones. In: Sørensen, M. and Pedersen, K. B. (eds.), *Problems in Palaeolithic and Mesolithic Research*. Arkæologiske Studier 12. København, University of Copenhagen/ Museum Southeast Denmark, 61–85.
- Rowley-Conwy, P. 1996. Why didn't Westropp's 'Mesolithic' catch on in 1872? *Antiquity* 70(270), 940–944.
- Rust, A. 1943. *Die Alt- und mittelsteinzeitlichen Funde von Stellmoor*. Neumünster, Wachholtz Verlag.
- Schmitt, L. 1999. Comparative points and relative thoughts: the relationship between the Ahrensburgian

- and Hensbacka assemblages. *Oxford Journal of Archaeology* 18(4), 327–337.
- Sobotta, J. 1991. Frühmesolithische Wohnplätze aus Draved Moor, Dänemark. *Archäologisches Korrespondenzblatt* 21, 457–467.
- Street, M. 1991. Bedburg-Königshoven: A Pre-Boreal Mesolithic site in the Lower Rhineland, Germany. In: Barton, N., Roberts, A. J. and Roe, D. A. (eds.), *The Late Glacial in north-west Europe: Human adaptation and environmental change at the end of the Pleistocene*. CBA Research Report 77. Oxford, Council for British Archaeology Research Report, 256–270.
- Sørensen, M. 2006. Teknologiske traditioner i Maglemosekulturen. En diakron analyse af Maglemosekulturens flækkeindustri. In: Eriksen, B. V. (ed.), *Stenalderstudier. Tidligt mesolitiske jægere og samlere i Sydsandinavien, Jysk Arkæologisk Selskab*. Højbjerg, Århus Universitetsforlag, 19–76.
- Sørensen, M. 2012. Inuit and climate change in prehistoric eastern Arctic: A perspective from Greenland. In: Hastrup, K. and Olwig, K. (eds.), *Climate Change and Human Mobility: Global Challenges to the Social Sciences*. Cambridge, Cambridge University Press, 35–57.
- Sørensen, M., Lübcke, H. and Groß, D. 2018. The Early Mesolithic in Southern Scandinavia and Northern Germany. In: Milner, N., Conneller, C. and Taylor, B. (eds.), *Star Carr. Volume 1: a persistent place in a changing world*. York, White Rose University Press, 305–361.
- Sørensen, M. and Sternke, F. 2004. Nørregård VI – late glacial hunters in transition. In: Eriksen, B. V. and Terberger, T. (eds.), *Hunters in a changing world: environment and archaeology of the Pleistocene-Holocene Transition (ca. 11000-9000 BC) in Northern Central Europe*. Internationale Archäologie – Arbeitsgemeinschaft, Symposium, Tagung, Kongress 5. Rahden (Westf.), Verlag Marie Leidorf, 85–111.
- Taute, W. 1968. *Die Stielspitzen-Gruppen im nördlichen Mitteleuropa. Ein Beitrag zur Kenntnis der späten Altsteinzeit*. Köln, Fundamenta.
- Terberger, T. and Eriksen, B. V. 2004 (eds.). *Hunters in a changing world: environment and archaeology of the Pleistocene-Holocene Transition (ca. 11000-9000 BC) in Northern Central Europe*. Internationale Archäologie – Arbeitsgemeinschaft, Symposium, Tagung, Kongress 5. Rahden (Westf.), Verlag Marie Leidorf.
- Theuerkauf, M., Bos, J. A. A., Jahns, S., Janke, W., Kuperinen, A., Stebich, M. and Joosten, H. 2014. *Corylus* expansion and persistent openness in the early Holocene vegetation of northern central Europe. *Quaternary Science Reviews* 90, 183–198.
- Thomsen, C. J. 1836. *Ledetraad til nordisk oldkyndighed*. Kjöbenhavn, Kongelige Nordiske Oldskrift-Selskab.
- Toft, P. A. 2006. Hvor går grænsen? Et studium af sociale territorier og ornamentik i Maglemosekulturen. In: Eriksen, B. V. (ed.), *Stenalderstudier. Tidligt mesolitiske jægere og samlere i Sydsandinavien, Jysk Arkæologisk Selskab*. Højbjerg, Århus Universitetsforlag, 101–199.
- Warren, G. 2025. What Is It and Why Should We Care? In: Stutz, L. N., Stjerna, R. P. and Törv, M. (eds.), *The Oxford Handbook of Mesolithic Europe*. Oxford, Oxford University Press, 15–33.
- Weber, M.-J., Grimm, S. B. and Baales, M. 2011. Between warm and cold: Impact of the Younger Dryas on human behavior in Central Europe. *Quaternary International* 242(2), 277–301.
- Westropp, H. M. 1872. *Pre-historic phases, or, introductory essays on pre-historic archaeology*. London, Bell and Daldy.
- Wild, M., Mortensen, M. F., Andreasen, N. H., Borup, P., Casati, C., Eriksen, B. V., Frost, L., Gregersen, K. M., Henriksen, M. B., Kanstrup, M., Olsen, J., Pedersen, K. B., Petersen, P. V., Ramskov, C., Sørensen, L., Sørensen, M. and Wählin, S. 2020. Palaeolithic bone and antler artefacts from Lateglacial and Early Holocene Denmark: technology and dating: Paläolithische Knochen- und Geweihartefakte des Spätglazials und Frühholozäns Dänemarks: Technologie und Datierung. *Quartär* 67, 105–180.
- Willerslev, R. 2007. *Soul hunters: hunting, animism, and personhood among the Siberian Yukaghirs*. University of California Press.
- Worsaae, J. J. A. 1859. Kongelige Danske Videnskabers Selskab. *Oversigt for Marts* 1859, 93–117.
- Zvelebil, M. 2009. The Mesolithic and the 21st Century. In: McCartan, S., Schulting, R. J., Warren, G. M. and Woodman, P. (eds.), *Mesolithic Horizons: Papers Presented at the Seventh International Conference on the Mesolithic in Europe, Belfast 2005* Oxford, Oxbow, xlvii–lviii.

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# Sticks, Stones and Bones

## Recent Early Mesolithic finds from Lolland, Denmark

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Ulrich Schmölcke and Bente Philippsen

### Abstract

Mesolithic sites on Lolland remain elusive, despite the island's reputation for well-preserved prehistoric remains. In this paper we present two new sites identified during the Rødbyhavn–Copenhagen railway expansion, one of which, Kirkenorløbet II, was excavated. The assemblage, though often isolated, contributes valuable insights into local fauna, technology, and chronology, demonstrating that even fragmentary finds can extend our understanding of the period. At the same time, the presented cases highlight the methodological challenges of detecting Mesolithic traces in contract archaeology, where survey techniques and preservation strongly shape what can be recovered. Apart from apparent limitations, our study also shows the potential for progress: by refining predictive models, adapting excavation techniques, and improving training, we can increase our understanding of the Older Stone Ages even if data availability is limited, or sites are excavated under sub-optimal circumstances.

*Keywords: Maglemose, lithic studies, wetland archaeology, archaeozoology, developer-funded archaeology*

### Introduction

The recovery of Mesolithic sites during contract archaeological activities is commonly accidental rather than foreseen. Several examples show that the discovery of *in situ* sites from the older Stone Ages is either due to the involvement of specialists or chance (e.g. Grøn and Sørensen 1995; Price *et al.* 2018; Jensen 2017; Gerken 2013; Mahlstedt 2015, 25–28; Måge 2019; Måge *et al.* 2023). A prominent example is the Early Mesolithic Hammelev grave, which was discovered during the excavation of a large Iron Age farmstead (Eriksen *et al.* 2016). While many sites in southern Scandinavia are known from surface collections, the discovery – and recognition – of intact Mesolithic sites during contract archaeology projects is rarer.

In this contribution we present selected assemblages of Early Mesolithic finds from recent developer-led excavations from Lolland, including the sites Kirkenorløbet II (official site ID: MLF02941), from the Byhavevej site complex (Hansen *et al.* in review), and Nystedvej 14 (official site ID: MLF00147) as well as new <sup>14</sup>C-dates of elk bones from the area. All of these sites, finds and dates present small but significant insights into the Early Mesolithic lifeways on Lolland, where larger settlement complexes, such as the ones known from Zealand and Northern Germany (cf. Sørensen *et al.* 2018), are lacking as of yet.

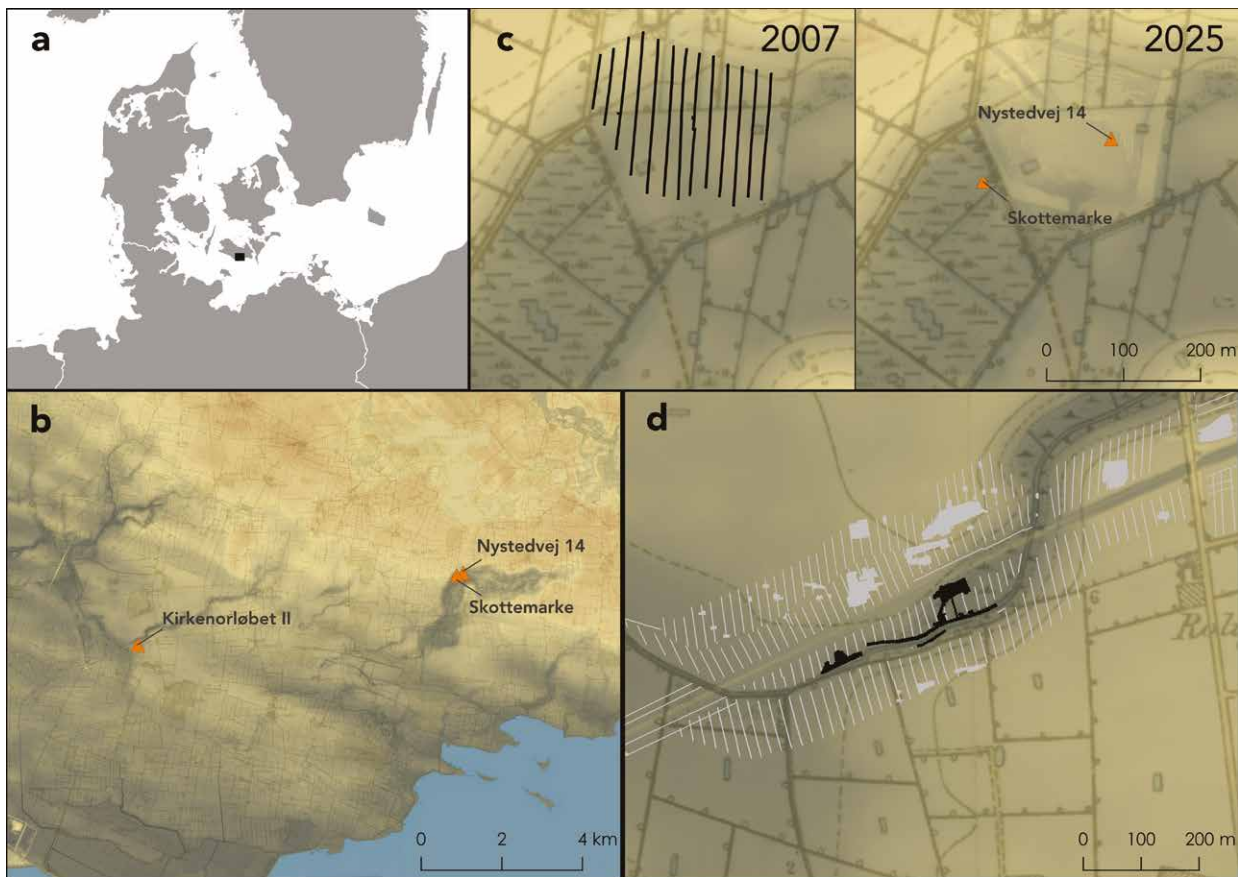


Figure 1: a-b: Location of the sites. c: Excavation trenches (black) and location of the sites Nystedvej 14 and Skottemarke 1. Note the alteration in terrain between 2007 and 2025 due to establishment of a soil dump in the area. d: Excavation areas of the Byhavevej Site Complex (grey) and Kirkenorløbet II (black). Background maps: © EuroGeographics for the administrative boundaries and Klimadatatstyrelsen CC BY 4.0.

Contrary to the large number of Stone Age sites from the Femern Project (Måge 2019; Måge *et al.* 2023), excavations in the context of the hinterland connections mainly comprised periods younger than the Mesolithic. The site Kirkenorløbet II was recovered during excavations of Iron Age settlement structures and activity sites along Kirkenorløbet creek. These settlement structures comprise farmsteads, ritual depositions, and burials at the edge of a former bog as well as several domestic activities, like wells and flax retting pits (cf. Andresen *et al.* 2011) in the wetlands. Here, a concentration of knapped flint and some scattered single finds have been recovered, which date to the Early Mesolithic.

The other site presented here, Nystedvej 14, produced characteristic Early Mesolithic flint artefacts as well as remains of elk antler. It is located at the edge of Bagmose bog, c. 150 metres east of the site Skottemarke. Here, excavations in the 1920s revealed depositions of at least six elk skeletons (Møhl 1980; Sørensen 1980) as well as a concentration of lithic artefacts and fourteen bone points of Duvensee-type in the littoral area of a former waterbody.

It is unclear whether the artefacts and bone assemblages are contemporaneous (Pedersen and Petersen 2017). Due to differing priorities during the initial survey phase, only parts of Nystedvej 14 were excavated. Unfortunately, due to subsequent building activities, the site's full potential can no longer be realised, making only limited data available (Fig. 1).

### Mesolithic finds from Kirkenorløbet II

The site Kirkenorløbet II is located approximately 700 metres northwest of the village of Tågerup on southern Lolland. It is framed by the Iron Age settlements of Byhavevej in the north and the Kirkenorløbet creek in the south. During the occupation in the Stone and Iron Ages, the creek was sustaining a river side wetland.

The site has been subject to modern agricultural activity, which resulted in significant impacts on the soil structure. Peat digging throughout prehistoric and historic times, as well as decades of drainage, have significantly degraded the organic sediments. Thus, there is a smooth transition from topsoil over degraded peat to peat, which

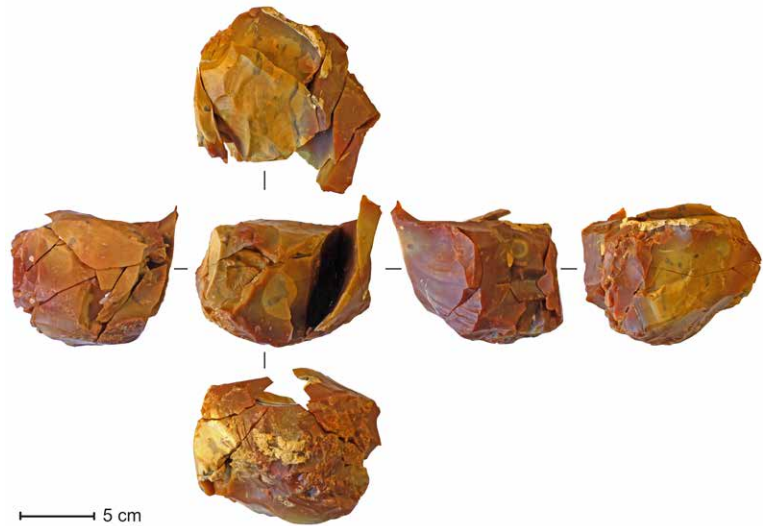


Figure 2: Refit group 1.

is a typical consequence of agriculturally used drained peats (Becker 1945; Boethius *et al.* 2020). The peat was deposited on Late Pleistocene layers of varying thickness, consisting of water-deposited gravel, sand, silt and clay. The presence of Late Glacial gyttja layers in the lower areas of the site furthermore testify to the presence of a low-velocity waterbody during the Pleistocene and Early Holocene.

During the Holocene, the area silted up, resulting in a sedimentary sequence of fine clay gyttja at the base, followed by a coarse detrital gyttja, swamp peat and sphagnum peat in ascending order. Due to the aforementioned peat digging, large areas have been removed and are thus not preserved. Especially towards the railway just north of the site, some of the peat and/or topsoil had been dug up in modern times and replaced with a heavy clay backfill layer containing bricks, stones and (modern) animal bones.

The Stone Age assemblage from Kirkenorløbet II includes both flint artefacts and organic finds. Most finds were recovered in isolated positions, without clear relations to each other, presumably representing multiple episodes of human presence at the site during the Mesolithic. Additionally, one concentration of lithic artefacts has been recorded, which most likely represents a knapping activity. As no diagnostic tools have been found among these finds, they have been analysed from a technological perspective with the objective to obtain more information on processes and a tentative dating. Analyses of the knapping technique and refits provided further information about the targeted blanks and activities at the site.

### Knapping concentration

At the western edge of the excavation trench, approximately 5 metres from the creek, a small fill layer filled with dried peat was recognised early on during investigations. Initially interpreted as a natural depression due to a treefall, a clear concentration of knapped flint was discovered in the

Group:	Find-numbers (X):
1	2, 3, 4, 5, 8, 9, 10, 13, 16, 22, 23, 26, 37, 38, 39, 56, 64, 67, 69, 78
2	18, 21, 48
3	80, 27, 65
4	6, 11
5	7, 20

Table 1. Refit groups and related find numbers.

upper 7-8 cm of the feature. The site is located right on the edge of the former wetland.

The flint from the find concentration is sharp and shows no signs of rearrangement, water rolling or plough damage. All the finds are characterised by a light but very uniform reddish brown bog patina. The assemblage consists predominantly of flakes, blades and a few informal cores. The finds were individually recorded and individually labelled for the refitting process, which was supported by distinct patterns of the patina.

As a result, five refit-groups have been identified within the assemblage (Group 1-5, Tab 1). It is highly likely that all groups and additional non-refitted flakes, are products from the same seriation and nodule, because the flint-type and patina as well as the character of the cortex on the refitted and non-refitted blanks are very similar to each other.

The largest refit group is Group 1, with 20 refits (Fig. 2). The remaining groups (2-5) contain only 2-3 blanks each. Group 1 starts with the only formal core (X3) found in the assemblage, c. 7 × 6 × 4.5 cm in size, which represents the last stage of the production sequence. It is worth noting that within Group 1, the complete seriation shows that the core was reduced quite substantially without producing any intended blanks in the final stages, as all of them are

still present in the material. Instead, most of the targeted, *i.e.* missing, blanks were produced in an earlier stage, when the core was larger and still featured some cortex. Based on the negatives, the targeted blanks seem to have been larger blade-like flakes with varying measurements of *c.* 25–35 mm in width and 50–60 mm in length. Some other missing blanks also seem to represent irregular flakes and cortex flakes. The cortex is smooth and rounded, not chalky, which indicates that a rounded and water-eroded beach flint was used as a starting nodule.

Since formal tools are absent from the assemblage, a typo-chronological classification is not possible. The find of a thin-butted flint axe fragment, *c.* 12 metres northeast of the concentration, is a sign for Early Neolithic activity in the area. However, flints with similar patina cannot be assumed to be contemporaneous, as the patina is formed after deposition in the sediment (*cf.* Groß *et al.* 2021; Hahn 1993, 63–65; Rottländer 2012).

The technological analysis of the blanks indicates that two distinct knapping techniques were used in the production process:

- a direct hard technique, potentially a hammer stone, as seen by the presence of large platforms, often crushed or with distinct conus formations. This technique was most commonly used.
- a direct soft technique, potentially an antler hammer, as seen by more long and narrow platforms, seen on thin flakes. This technique seems to have been less used and seen on only a few blanks.

The nodule has been worked from various directions and very few fragments display any signs of platform preparation. Although the assemblage cannot be reliably dated, the techniques involved, and the presence of other Early Mesolithic activities in the area promote a similar dating (*cf.* Sørensen 2006).

The refit groups show that the different production stages were deposited in different locations: Blanks from the early stages of production are located in the eastern and southeastern part of the find concentration, whereas those from the later stages are found further north. Two less distinct depositions, to the west and south, of later stage-blanks might furthermore indicate a selection process during production. The limited size of the concentration of only 1.3 m<sup>2</sup> limits the possibilities for more detailed spatial analysis. However, as the production stages can be differentiated and show some vague spatial organisation, we conclude that the find concentration represents the remnants of a knapping activity, rather than a dump ground of discarded blanks.

In conclusion, the refits from Kirkenorløbet II provide a small peephole into the flint technology on Lolland during the Stone Age. Flint was gathered from a nearby beach

or eroded riverbank, brought to the site and knapped. The goal of the knapper was to produce larger blade-like flakes, which are no longer present in the assemblage. It is therefore not clear if they were further retouched or used as blanks. The knapping process appears fast and dynamic, represented by a constantly shifting directionality and the lack of a clear core platform. The core was reduced incorporating direct hard and soft techniques, most likely hammer stones and antler hammers. Since these techniques are characteristic of the Early Maglemose culture on Zealand (Sørensen 2006), we tentatively assign the assemblage to the Early Holocene.

## Organic finds

From Kirkenorløbet, three organic finds produced Mesolithic dates (for the more recent assemblages see Hansen *et al.* in review). Two of them were recovered without any connection to other finds or anthropogenic traces and are therefore best characterised as environmental samples.

One jaw fragment of elk (*Alces alces*) or aurochs (*Bos primigenius*) was found at the site dating to the Early Atlantic biozone, as well as a hazelnut shell from the Late Boreal biozone (Tab. 2). Both samples are found without a clear connection to the knapping concentration and might have been naturally deposited.

Similarly isolated, a fragmented arrow shaft was discovered in the detritus gyttja that could be refitted from two longer segments (Fig. 3). The fragmentation is probably due to the excavation technique, using a mechanical excavator, which might have caused some minor relocation (< 1 m). Some fragments, including the notch, were found in the excavator's bucket and up in the soil heaps. It is therefore uncertain how the shaft was deposited and whether the entire arrow was originally present, including the front half and tip. In total, 48 cm of the arrow shaft are preserved, and it is fabricated from pine wood, the typical wood for arrows in the Early Mesolithic (Paulsen 2013).

The shaft has a very well-preserved and finely carved notch, created by a 0.8 cm deep and sharp v-shaped incision. The notch and the proximal 7 cm have a diameter of 0.7 cm, while it increases to 0.9 cm in the middle of the preserved segment and 1 cm at the medial break. This technological feature ('barrel shape') is known from arrow shafts from many different periods from ancient to medieval times and contributes to a more stable flight of the arrow (Paulsen 2013).

Two of the fragments have a total of five small sets of two oblique incisions each, located on the thickest part of the shaft. The lines have a sharp v-shaped cross section and are 0.3–0.5 cm long and spaced 2–3 cm apart. As the distal half of the shaft is missing, it is unclear whether the marks continue further down towards the tip. This ornamentation might have been owner marks, as has been suggested by Engelhardt (1865, 30) for arrow shafts with comparable

Lab ID	Site	Find ID	Species	Description	<sup>14</sup> C age	Calibrated age (cal BCE), 95.4%	Reference
AAR-36766	Kirkenorløbet II	MLF02941 X233	<i>Alces alces/Bos primigenius</i> (?)	Maxillare	9622 ± 40	9790–9450	Hansen <i>et al.</i> in review
Beta-614129	Kirkenorløbet II	MLF02941 X449	<i>Corylus avellana</i>	Nutshell	8860 ± 30	8210–7830	Hansen <i>et al.</i> in review
AAR-36733	Kirkenorløbet II	MLF02941 X600	<i>Pinus sylvestris</i>	Arrow shaft	9237 ± 49	8570–8300	Hansen <i>et al.</i> in review
TRa-21390_1	Nystedvej 14	MLF00147 X525	<i>Alces alces</i>	antler	10025 ± 25	9790–9450	This study
TRa-21390_2	Nystedvej 14	MLF00147 X525	<i>Alces alces</i>	antler	10075 ± 25		This study
AAR-36520	Nystedvej 14	MLF00147 X1271A	<i>Cervus elaphus</i>	mandibula	6829 ± 63	6880–5620	This study
OxA-4864	Skottemarke	A20371	indet.	Bone point, Duvensee-type	9570 ± 100	9240–9650	Fischer 1996
OxA-5528	Skottemarke	A20364	indet.	Bone point, Duvensee-type	9310 ± 90	8770–8300	Fischer 1996
K-2075	Skottemarke	A20364	<i>Alces alces</i>	Bone, indet.	9400 ± 140	9150–8310	Møhl 1980
K-2227	Tåderup (Falster)	ZMK 30/1972	<i>Alces alces</i>	Bone, indet.	7810 ± 120	7037–6460	Ødum 1920, pers. comm. Zoological Museum Copenhagen
No ID	Store Damme, Møn	1025	<i>Bos primigenius</i>	Tibia	9520 ± 85	9200–8630	Noe-Nygaard <i>et al.</i> 2005

Table 2: Directly dated Early Mesolithic finds from Lolland and adjacent islands.

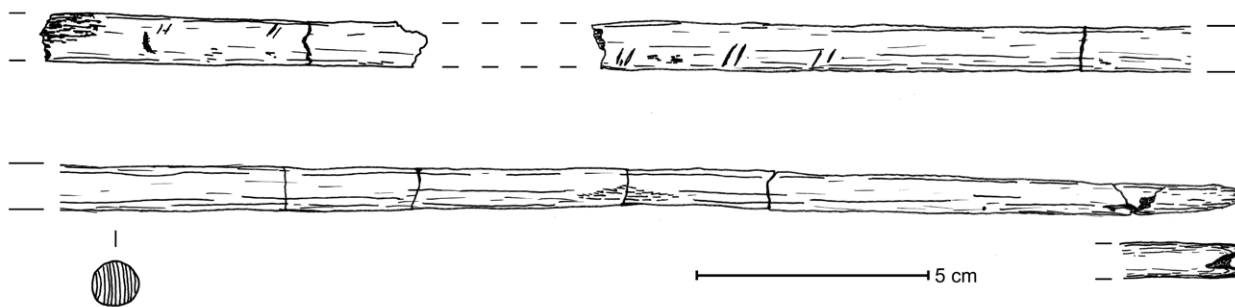


Figure 3: The arrow shaft from Kirkenorløbet. Note that the drawing was done after conservation and is split in the middle for display purposes.

markings from the Late Roman Iron Age site Nydam I. From here, symbols and runes have also been identified on arrow shafts (Malmros 2020, 100).

The arrow shaft is fabricated from Scots pine (*Pinus sylvestris*) with 15–18 year rings preserved. The artefact is directly dated to 8570–8300 cal BCE and can thus be attributed to an Early Maglemose culture context.

### Nystedvej 14

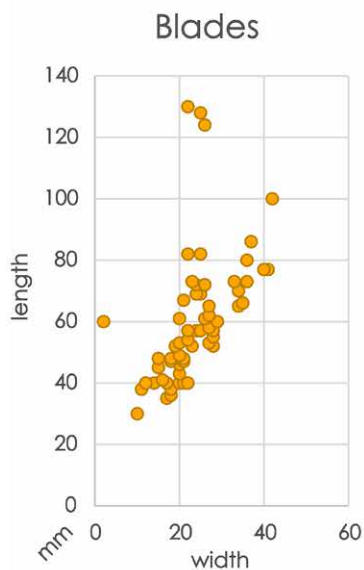
Nystedvej 14 is located on the north side of a large wetland consisting of Bagmose and Vestermose, on the south side of Nystedvej between Skottemarke and Sløsse. The area is a southern extension of the Sønderø-Røgbølle Lake system and was probably formed at the end of the last Ice Age as a minor drainage system of the Fennoscandian ice sheet.

The site is located in the immediate vicinity of the Early Mesolithic site Skottemarke (Møhl 1980; Pedersen and Petersen 2017; Petersen 1991; Sørensen 1980; Sørensen *et al.* 2018) with a primary concentration of finds on a small elevation close to the northern shore of the bog (Fig. 1c). In the wetland parts of the site the subsoil consisted of organic sediments, *i.e.* peat in the upper layers and gyttja in the lower layers. However, the main concentration of finds was deposited on the elevated glacial surface, *i.e.* sandy clay with stones. The excavation has revealed a Mesolithic settlement on a peninsula approximately 150 m northwest of the site Skottemarke. The concentration of finds shows a clear focus of activity on the western part of the island, at the edge of a lake that silted up during the Holocene.

A total of 459 finds were recorded, with the majority being flint artefacts (n=403), but faunal remains are also

classification	n
Core	35
Core axe	1
Scraper	7
Burin	1
Blade	59
Flake	272
Technical flake	4
Debitage	4
Fire-cracked	1
indet.	19
<b>sum</b>	<b>403</b>

Table 3: Flint tools and technical artefacts.



well represented (n=49). As expected, most of the flint tools are flakes and splinters (Tab. 3). One core axe and one unidirectional blade core (Fig. 4) are the most easily datable lithic finds. Both point to a date at the end of the Early Mesolithic, *i.e.* in Maglemose culture phase 3, or technology group 3 according to Sørensen (2006), and thus around the transition from the Boreal to the Early Atlantic biozone.

The blades generally show a typical distribution with a few large specimens, while the majority are between 40 and 75 mm in length. Three blades measure > 100 mm and are thus fairly large (X1253, X1254, X1256). All three were found in the soil heaps so that it is unclear whether they are part of the campsite assemblage.

Several technical flakes from axe and core production were found on the former lake shore of the peninsula, from where also most of the 'domestic tools' like scrapers and axes originate. This area can thus be interpreted as the main activity area of a Mesolithic site. Fire-cracked flint was found almost all over the peninsula, potentially indicating latent or evident hearths outside the excavated area.

During the investigation, an elk antler (*Alces alces*) was found close to the northern edge of the island where the Skottemarke site is located. Several other bones from roe deer (*Capreolus capreolus*) and red deer (*Cervus elaphus*) and several unidentified bones were found after removal of the plough horizon. The bones have not been studied in detail yet. The elk antler is dated to the beginning of the Preboreal biozone with an age of 9790–9450 cal BCE. It is thus the oldest dated elk from Lolland (Fig. 3) and older than the Skottemarke finds (Fig. 5).

Figure 4: Width-Length diagram of blades from Nystedvej 14. Blade core X622. Note the high number of hinge-breaks on almost all negatives.

Both the artefacts and the other faunal assemblages correspond well and can be dated with relative certainty to the developed Early Mesolithic. The elk antler was recovered from deeper gyttja layers in the bog, whereas the remainder of the finds derive from the settlement site and more adjacent areas. These therefore suggest later events. Although the Nystedvej 14 elk antler was found closer to the Skottemarke site, its older age contradicts a direct connection with the activities there. Notably, no cutmarks were recorded on the antler, raising the possibility that it was a natural cast.

Overall, the state of preservation was considerably better in the vicinity of the Skottemarke site than on the peninsula where Nystedvej 14 was situated. The most plausible explanation lies in the difference in elevation: the Nystedvej 14 site is positioned higher in the landscape, which meant that organic material there was less influenced by groundwater. The greater distance to the groundwater table hence resulted in drier conditions and consequently poorer preservation. Nonetheless, it can be assumed that favourable conditions for organic artefacts remained around the banks of the site.

Both Skottemarke and Nystedvej 14 are typical locations for Early Mesolithic settlements, as extensively documented in large parts of Northern Europe (e.g. Groß *et al.* 2019; Larsson and Sjöström 2010; Milner *et al.* 2018; Sjöström 2010; Sørensen *et al.* 2018; Taylor 2025). Surface finds in the wider area of the bog indicate the presence of additional sites, presumably with com-

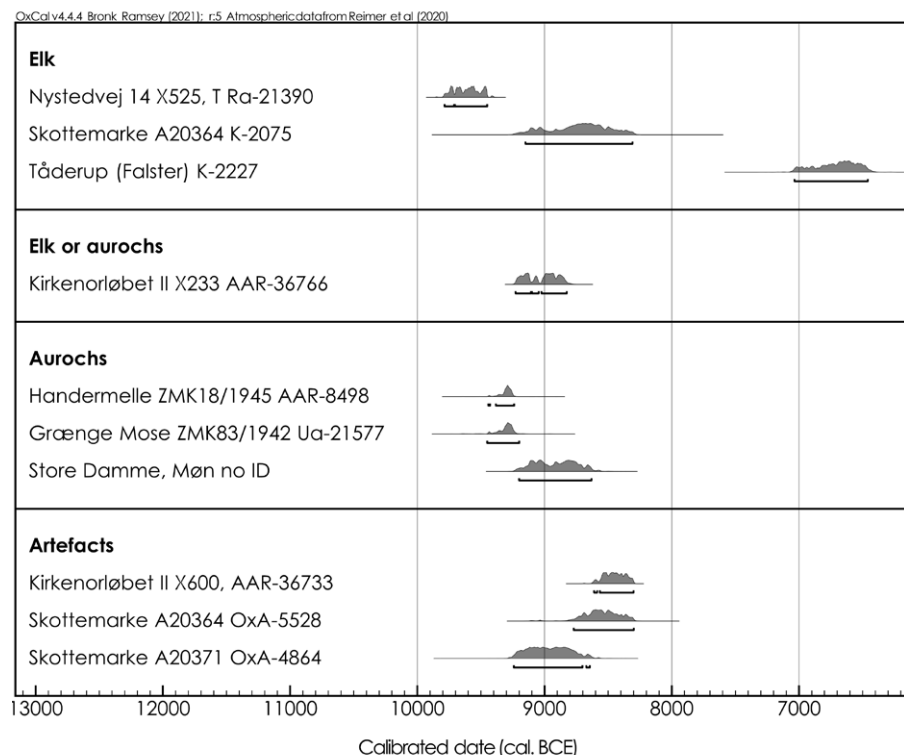
parable preservation conditions. It is worth noting that the building activity has not only destroyed the site Nystedvej 14 but presumably also affected the eastern parts of the settlement area of Skottemarke.

### Discussion

With its former topography and many bays, wetlands and lakes, Stone Age Lolland was characterized by a very diverse and productive ecosystem. Since different migration routes of birds and mammals potentially crossed Lolland already in the Late Glacial, the area was of major interest already in the Late Palaeolithic (e.g. Petersen and Johansen 1996). The Early Mesolithic landscape looked different, but the rising sea-level in the Baltic nonetheless forced southern travels towards the Scandinavian peninsula over Lolland. The area has therefore always been at least of relevance as a transit route.

Lolland has for a long while been known for extensive and well-preserved sites from all periods of the Mesolithic. Early finds like Skottemarke (Møhl 1980; Pedersen and Petersen 2017; Sørensen 1980) or Godsted Mose (Møller Hansen 2001; Petersen 1991) as well as environmental records (Kolstrup and Buchardt 1982) have been vastly expanded by not least results from the Femern project (Groß and Rothstein 2023 for a summary), even though most materials from the latter project post-date the Mesolithic. Even though not large in number, the quality of the sites underlines the potential for good preservation conditions, as well as early exploration of the Older Stone Ages.

Figure 5: Directly dated Mesolithic finds from Lolland and adjacent areas.



## Different local extinction chronologies?

The isolation of the eastern Danish islands in the beginning of the Atlantic biozone (Bailey *et al.* 2020; Bennike *et al.* 2021; Leszczyńska *et al.* 2022) led to a noteworthy impoverishment of the fauna with the local extinction of large and medium sized mammals, like elk and aurochs (Aaris-Sørensen 2009, 47). While the direct and indirect reasons for the local extinctions are not fully resolved yet (see Aaris-Sørensen 2009, 47), the timing of the disappearance can be a little bit better delineated due to new data. Based on current evidence, aurochs and elk had likely become extinct on all the Danish islands by c. 6500 cal BCE, perhaps after a rapid decline over just a few centuries (Magnell 2017), which provides a point of reference for the populations on Lolland.

The directly dated elk and aurochs finds from Lolland almost all date to the Preboreal biozone, when Lolland was still connected to the continent. The youngest elk bone in the assemblage, from Tåderup on the neighbouring island of Falster (Ødum 1920), dates to c. 7040–6460 cal BCE. Magnell (2017) suggests changing biotopes as a potential factor in local elk population extinctions, which might be a potential explanation for the Lolland population as well.

It is noteworthy that the elk remains from Lolland, although few in number, do not date younger than the Early Boreal, around 8300 cal BCE. This corresponds closely with the biozone transition recorded at Nahe palaeolake in central Schleswig-Holstein, only some 100 km to the southwest (Krüger *et al.* 2020). The synchronism suggests that the disappearance of elk in southeast Denmark may have been part of a broader regional pattern of environmental and ecological change, rather than an isolated local development. In this perspective, Lolland provides an important point of comparison for understanding faunal turnover at the transition from the Preboreal to the Boreal biozones, as well as the interplay between climatic shifts, habitat change, and human activity. Further detailed analysis of dated faunal material from Lolland and adjacent areas therefore holds large potential for clarifying the timing and underlying causes of these local extinctions, and for situating the island more firmly within wider Mesolithic trajectories in southern Scandinavia.

## The elusive Stone Age

Lolland is Denmark's fourth-largest island, with a size of c. 1240 km<sup>2</sup>, of which 938 km<sup>2</sup> are under agricultural use – more than 75 %. Around 887 km<sup>2</sup> of this is dedicated to crop production, meaning that these areas are subject to temporary or constant ploughing, which in turn leads to the ongoing disturbance and erosion of *in situ* sites. By contrast, only about 33 km<sup>2</sup> of the island are covered by permanent grasslands, mainly located in

wetland environments, where more stable preservation conditions for archaeological remains may be expected. This uneven distribution of land use has significant consequences for how traces of the Stone Age are encountered and preserved.

Evidence of human presence from the Older Stone Age is particularly difficult to recognise within the framework of Danish standard survey methods, which typically rely on long test trenches aimed at detecting features and mechanical excavations in wetland contexts. While alternative strategies have been applied, such as systematic ploughing surveys (Ethelberg *et al.* 2012), these approaches still face limitations: deeply buried deposits or fragile organic remains are unlikely to be recovered, while shallow features and cultural layers are at constant risk of destruction. The result is a biased archaeological record, where some categories of sites – especially those with good organic preservation – remain almost invisible, while others are systematically eroded before they can be documented.

Recently, Ickerodt *et al.* (2025) have highlighted the urgent need for specialist expertise in wetland archaeology, particularly in the light of ongoing landscape transformations. We would argue that a similar need exists in the sphere of contract archaeology when it comes to the Older Stone Age. Without targeted methodological adaptations – such as coring, remote sensing, or specialist evaluation of wetland contexts – the chances of identifying, preserving, and interpreting the earliest chapters of human presence on Lolland remain limited. Addressing these challenges is crucial if we are to move beyond the fragmentary picture currently available and to integrate Lolland more fully into broader narratives of Stone Age settlement and subsistence in southern Scandinavia.

## Contextualizing context-less finds

The representativity of excavations is always conditioned both by preservation conditions and by the choices made during fieldwork (cf. Groß 2017, 119–123). As a result, the discovery of many finds inevitably contains an element of chance. This becomes especially relevant when working with stray finds or older collections, which usually lack the contextual information that anchors archaeology in its two key dimensions: time and place. Nevertheless, recent studies (*e.g.* Rimkus 2023; Spithoven-Stikkelorum *et al.* 2024) demonstrate how careful analysis of such material can still significantly expand our knowledge of past societies.

The assemblages from Nystedvej 14 and Kirkenørlobet II are not 'stray finds' in the strict sense, but at least the organic artefacts they yielded approach this category in terms of context. The elk antler, the bone, and the arrow shaft must be regarded as isolated finds. Yet,

even as isolated pieces, they provide valuable insights – into local faunal populations on Lolland and into weapon technology of the period. In this sense, they exemplify how single objects, when securely dated and carefully analysed, can illuminate otherwise elusive phases of the Stone Age record.

The case of Kirkenorløbet II in particular highlights the importance of dating individual specimens, as well as the danger of overlooking more subtle archaeological signals when they do not conform to well-known typological markers. Through our analysis of the lithic assemblage, we further demonstrate that type-fossils are not indispensable for assigning lithic inventories to a chronological framework. Instead, this study illustrates the potential of integrating additional lines of evidence – such as raw material studies, technological traits, or contextual association – into archaeological classification. Such approaches provide a means of moving beyond typology alone, and thereby of capturing a more comprehensive and more nuanced picture of the Older Stone Ages (cf. Hussain and Will 2021; Riede *et al.* 2024; Söderlind 2024).

## References

- Aaris-Sørensen, K. 2009. *Diversity and dynamics of the mammalian fauna in Denmark throughout the last glacial-interglacial cycle, 115-0 kyr BP*. Chichester, Wiley-Blackwell.
- Andresen, S. T., and Karg, S. 2011. Retting pits for textile fibre plants at Danish prehistoric sites dated between 800 B.C. and A.D. 1050. *Vegetation History and Archaeobotany* 20(6), 517–526.
- Bailey, G., Andersen, S. H., and Maarleveld, T. J. 2020. Denmark: Mesolithic Coastal Landscapes Submerged. In: Bailey, G. N., Galanidou, N., Peeters, Jöns, H. and Mennenga, M. (eds.), *The Archaeology of Europe's Drowned Landscapes*. Cham, Springer, 39–76. DOI:10.1007/978-3-030-37367-2\_3.
- Becker, C. J. 1945. En 8000-aarig stenalderboplads i Holmegaards Mose. *Fra Nationalmuseets Arbejdsmark* 1945, 61–72.
- Bennike, O., Jensen, J. B., Nørgaard-Pedersen, N., Andresen, K. J., Seidenkrantz, M., Moros, M. and Wagner, B. 2021. When were the straits between the Baltic Sea and the Kattegat inundated by the sea during the Holocene? *Boreas* 50(4), 1079–1094. DOI:10.1111/bor.12525
- Boethius, A., Hollund, H., Linderholm, J., Vanhanen, S., Kjällquist, M., Magnell, O. and Apel, J. 2020. Quantifying archaeo-organic degradation – A multiproxy approach to understand the accelerated deterioration of the ancient organic cultural heritage at the Swedish Mesolithic site Ageröd. *PLoS ONE* 15, e0239588. DOI:10.1371/journal.pone.0239588
- Bronk Ramsey, C. 2009. Bayesian Analysis of Radiocarbon dates. *Radiocarbon* 51, 337–360.
- Engelhardt, C. 1865. *Nydam mosefund, 1859-1863*. Kjöbenhavn, Gad.
- Eriksen, B. V. and Andersen, H. C. H. 2016. Hammelev. An Early Mesolithic cremation grave from Southern Jutland, Denmark. In: Grünberg, J. M., Gramsch, B., Larsson, L., Orschiedt, J. and Meller, H. (eds.), *Mesolithic Burials – Rites, Symbols and Social Organisation of Early Postglacial Communities. Mesolithische Bestattungen – Riten, Symbole und Soziale Organisation früher postglazialer Gemeinschaften*. Tagungen des Landesmuseums für Vorgeschichte Halle 13. Halle (Saale), Landesamt für Denkmalpflege und Archäologie Sachsen-Anhalt – Landesmuseum für Vorgeschichte, 73–80.
- Ethelberg, P., and Andersen, H. C. H. 2012. Motorvej og Naturgas 2007-2012. In: Museum Sønderjylland - Arkæologi Haderslev (ed.), *Med graveske gennem Sønderjylland: arkæologi på naturgas- og motorvejstracé*. Årbog for Museum Sønderjylland 2012. Haderslev, Museum Sønderjylland, 16–24.
- Fischer, A. 1996. At the border of human habitat. The Late Palaeolithic and Early Mesolithic in Scandinavia. In: Larsson, L. (ed.), *The Earliest Settlement of Scandinavia*

## Conclusions

The materials from Nystedvej 14 and Kirkenorløbet II illustrate the challenges of identifying and interpreting Mesolithic activity on Lolland in contract archaeological circumstances, where preservation conditions, survey strategies, and chance all play decisive roles. Concurrently, the case studies demonstrate the considerable potential of combining isolated faunal finds with lithic analyses and direct dating. By moving beyond typology and integrating multiple lines of evidence, we gain a more nuanced picture of local human-environment interactions and landscape use during the Early Holocene. These results reinforce the need for methodological flexibility and specialist expertise in order to capture the elusive traces of the Palaeolithic and Mesolithic in southern Scandinavia.

## Acknowledgements

This paper is part of the project ‘Økonomi og økologi på Lolland-Falster i forhistorisk tid’ (DG & US) supported by Kulturministeriets Forskningsudvalg (KFU) under grant FORMW.2022-0023. DG thanks Klaus Hirsch for valuable discussions on survey techniques. We thank two anonymous reviewers for their helpful comments.

- and its relationship with neighbouring areas. *Acta archaeologica Lundensia*, Series in 8° 24. Stockholm, Almqvist & Wiksell International, 157–176.
- Gerken, K., 2013. Die frühmesolithischen Stationen Bieren 30 und 31, Gde. Stadt Achim, Ldkr. Verden. *Nachrichten aus Niedersachsens Urgeschichte Beiheft* 16, 232–236.
- Grøn, O., and Sørensen, S. A. 1995. Aggemose. An Inland Site from the Early Kongemose Culture on Langeland. *Journal of Danish Archaeology* 11(1992–93), 7–18.
- Groß, D. 2017. *Welt und Umwelt frühmesolithischer Jäger und Sammler. Mensch-Umwelt-Interaktion im Frühholozän in der nordmitteleuropäischen Tiefebene*. Untersuchungen und Materialien zur Steinzeit in Schleswig-Holstein und im Ostseeraum 8. Kiel, Ludwig.
- Groß, D., Berckhan, S., Hauschild, N., Räder, A.-L. and Sohst, A. 2021. Re-evaluating the old excavation from Pinnberg, Germany. In: Borić, D., Antonović, D. and Mihailović, B. (eds.), *Foraging Assemblages*, Serbian Archaeological Society, Belgrade / New York, Serbian Archaeological Society, The Italian Academy for Advanced Studies in America, Columbia University, 312–317.
- Groß, D., Lübke, H., Schmöcke, U. and Zanon, M. 2019. Early Mesolithic activities at ancient Lake Duvensee, Germany. *The Holocene* 29(2), 197–208.
- Groß, D. and Rothstein, M. (eds.) 2023. *Changing Identity in a Changing World. Current Studies on the Stone Age in Northern Europe around 4000 cal BC*. Leiden, Sidestone Press.
- Hahn, J. 1993. *Erkennen und Bestimmen von Stein- und Knochenartefakten. Einführung in die Artefaktmorphologie*. Tübingen, Verlag Archaeologica Venatoria.
- Hansen, M. S. E., Deichmann, P. C. M. and Olsen, J., in review. Byhavevej – sacrality in an Iron Age Landscape on Lolland. *Danish Journal of Archaeology*.
- Hussain, S. T., and Will, M. 2021. Materiality, Agency and Evolution of Lithic Technology: an Integrated Perspective for Palaeolithic Archaeology. *Journal of Archaeological Method and Theory* 28(2), 617–670. DOI: 10.1007/s10816-020-09483-6
- Ickerodt, U., Reuter, T. and Jantzen, D. 2025. Zur Leopoldina-Stellungnahme 'Klima - Wasserhaushalt - Biodiversität: Für eine integrierende Nutzung von Mooren und Auen' – Ein notwendiger Kommentar aus Schleswig-Holstein und Mecklenburg-Vorpommern. *Archäologische Informationen* 48, early view.
- Jensen, L. E. 2017. Archaeological investigations associated with the planned Fehmarnbelt fixed link between Germany and Denmark. In: Pedersen, K. B. and Sørensen, M. (eds.), *Problems in Palaeolithic and Mesolithic Research*. København, University of Copenhagen/Museum Southeast Denmark, 121–135.
- Kolstrup, E. and Buchardt, B. 1982. A pollen analytical investigation supported by an iso-record of a late glacial lake deposit at Grænge (Denmark). *Review of Palaeobotany and Palynology* 36, 205–230.
- Krüger, S., Mortensen, M. F. and Dörfler, W. 2020. Sequence completed – palynological investigations on Lateglacial/Early Holocene environmental changes recorded in sequentially laminated lacustrine sediments of the Nahe palaeolake in Schleswig-Holstein, Germany. *Review of Palaeobotany and Palynology* 280, 104271. DOI: 10.1016/j.revpalbo.2020.104271
- Larsson, L. and Sjöström, A. 2010. Mesolithic research in the bog Rönneholms mosse, southern Sweden. *Mesolithic Miscellany* 21(1), 2–9.
- Leszczyńska, K., Statterger, K., Moskalewicz, D., Jagodziński, R., Kokociński, M., Niedzielski, P., Szczuciński, W., 2022. Controls on coastal flooding in the southern Baltic Sea. *Scientific Reports* 12, 9710. DOI: 10.1038/s41598-022-13860-4
- Magnell, O., 2017. Climate Change at the Holocene Thermal Maximum and Its Impact on Wild Game Populations in South Scandinavia. In: Monks, G. (ed.), *Climate Change and Human Responses. A Zooarchaeological Perspective*. Dordrecht, Springer Netherlands, 123–135. DOI: 10.1007/978-94-024-1106-5\_7
- Mahlstedt, S. 2015. *Das Mesolithikum im westlichen Niedersachsen. Untersuchungen zur materiellen Kultur und zur Landschaftsnutzung*. Frühe Monumentalität und soziale Differenzierung 7. Bonn, Dr. Rudolf Habelt.
- Malmros, C. 2020. The use of wood for weapons and tools: Wooden artefacts from the excavations at Nydam 1984-99. In: Holst, S. and Nielsen, P. O. (eds.), *Excavating Nydam. Archaeology, palaeoecology and preservation The National Museum's research project 1989-99*. Nordiske fortidsminder 33. Copenhagen, The Royal Society of Northern Antiquaries University Press of Southern Denmark, 91–140.
- Milner, N., Conneller, C. and Taylor, B. 2018. *Star Carr. Volume 1: a persistent place in a changing world*. York, White Rose University Press.
- Måge, B. T. 2019. Syltholm VII: En atypisk beliggende Ahrensburglokalitet fra Syd-Lolland. *Geffjon: arkæologi og nyere tid* 4, 176–193.
- Måge, B. T., Groß, D. and Kanstrup, M. 2023. The Femern project: a large-scale excavation of a Stone Age landscape. In: Groß, D. and Rothstein, M. (eds.), *Changing Identity in a Changing World. Current Studies on the Stone Age in Northern Europe around 4000 cal BC*. Leiden, Sidestone Press, 21–32.
- Möhl, U. 1980. Elsdyrskelletterne fra Skottemarke og Favrbø; Skik og brug ved borealtidens

- jagter. *Aarbøger for nordisk oldkyndighed og historie* 1978, 5–32.
- Møller Hansen, K. 2001. Kongemose- og ertebøllekultur i Sydsjælland, på Møn og Lolland-Falster. In: Lass Jensen, O., Sørensen, S. A. and Møller Hansen, K. (eds.), *Danmarks Jægerstenalder - Status og Perspektiver*. Hørsholm, Hørsholm Egns Museum, 39–59.
- Noe-Nygaard, N., Price, T. D. and Hede, S. U. 2005. Diet of aurochs and early cattle in southern Scandinavia: evidence from 15N and 13C stable isotopes. *Journal of Archaeological Science* 32, 855–871. DOI:10.1016/j.jas.2005.01.004
- Ødum, H., 1920. *Et Elsdryrfund fra Taaderup paa Falster*. Danmarks Geologiske Undersøgelse 1.
- Paulsen, H. 2013. From Stone Age hunting bow to medieval weapon of war - Selected examples of bows and arrows in the North. In: Grimm, O. and Schmolcke, U. (eds.), *Hunting in northern Europe until 1500 AD. Old traditions and regional developments, continental sources and continental influences*. Neumünster, Wachholtz, 185–205.
- Pedersen, K. B. and Petersen, E. B. 2017. Bringing Home the Elk: Preboreal Elk Deposits from Southern Scandinavia. In: Sørensen, M. and Pedersen, K. B. (eds.), *Problems in Palaeolithic and Mesolithic research*. København, University of Copenhagen/ Museum Southeast Denmark, 237–256.
- Petersen, P. V. 1991. Palæolitiske og mesolitiske fund fra Lolland-Falster. In: Christoffersen, J. and Poulsen, K. L. (eds.), *Maribo Symposiet. Marts 1990. Landene ved Østersøen - et kulturområde i oldtid og tidlig middelalder*. København, Foreningen af Yngre Forhistorikere Nationalmuseet & Lolland-Falsters Stiftmuseum, 31–33.
- Petersen, P. V. and Johansen, L. 1996. Tracking Late Glacial reindeer hunters in eastern Denmark. In: Larsson, L. (ed.), *The Earliest Settlement of Scandinavia and its relationship with neighbouring areas*. Acta archaeologica Lundensia. Series in 8° 24. Stockholm, Almqvist & Wiksell International, 75–88.
- Price, T. D., Ritchie, K., Gron, K. J., Gebauer, A. B. and Nielsen, J. 2018. Asnæs Havnemark: a late Mesolithic Ertebølle coastal site in western Sjælland, Denmark. *Danish Journal of Archaeology* 7: 255–276. DOI:10.1080/21662282.2018.1551979
- Reimer, P. J., Austin, W. E. N., Bard, E., Bayliss, A., Blackwell, P. G., Bronk Ramsey, C., Butzin, M., Cheng, H., Edwards, R. L., Friedrich, M., Grootes, P. M., Guilderson, T. P., Hajdas, I., Heaton, T. J., Hogg, A. G., Hughen, K. A., Kromer, B., Manning, S. W., Muscheler, R., Palmer, J. G., Pearson, C., van der Plicht, J., Reimer, R. W., Richards, D. A., Scott, E. M., Southon, J. R., Turney, C. S. M., Wacker, L., Adolphi, F., Büntgen, U., Capano, M., Fahrni, S. M., Fogtmann-Schulz, A., Friedrich, R., Köhler, P., Kudsk, S., Miyake, F., Olsen, J., Reinig, F., Sakamoto, M., Sookdeo, A. and Talamo, S. 2020. The IntCal20 Northern Hemisphere Radiocarbon Age Calibration Curve (0–55 cal kBP). *Radiocarbon* 62, 725–757. DOI:10.1017/rdc.2020.41
- Riede, F., Matzig, D. N., Biard, M., Crombé, P., Pablo, J. F.-L. de, Fontana, F., Groß, D., Hess, T., Langlais, M., Mevel, L., Mills, W., Monik, M., Naudinot, N., Posch, C., Rimkus, T., Stefański, D., Vandendriessche, H. and Hussain, S. T. 2024. A quantitative analysis of Final Palaeolithic/earliest Mesolithic cultural taxonomy and evolution in Europe. *PLoS ONE* 19, e0299512. DOI:10.1371/journal.pone.0299512
- Rimkus, T. 2023. Hunter-Gatherer Bone and Antler Implements in Lithuanian Coastal Area: Recent Studies in Chronology, Technology and Decoration Patterns. *Latvijas Universitātes Žurnāls Vēsture* 2022(13/14), 26–47. DOI:10.22364/luzv.13.14.02
- Rottländer, R. C. A. 2012. Entstehung und Verwitterung von Silices. In: Floss, H. (ed.), *Steinartefakte vom Altpaläolithikum bis in die Neuzeit*. Tübingen, Kerns Verlag, 93–99.
- Sjöström, A., 2010. Mesolitiska lämningar i Rönneholms mosse - Arkeologisk förundersökning 2010. Rapporter från Institutionen för arkeologi och antikens historia Lunds universitet 4. Lund, Institutionen för arkeologi och antikens historia.
- Spithoven-Stikkelorum, M., Dekker, J. and Aleo, A. 2024. What points can tell. Artefact biographies of barbed bone and antler points from Mesolithic Doggerland. In: Verbaas, A., Langejans, G., Little, A. and Chan, B. (eds.), *Artefact Biographies from Mesolithic and Neolithic Europe and Beyond. Papers in honour of Professor Annelou van Gijn*. Analecta Praehistorica Leidensia 52. Leiden, Sidestone Press, 141–156. DOI:10.59641/pp090sb
- Söderlind, S., 2024. The Handle Core Concept. Lithic Technology and Knowledge Transmission, ROOTS Studies 6. Leiden, Sidestone Press. DOI:10.59641/x0922aj
- Sørensen, I. 1980. Datering af elsdryrknoglerne fra Skottemarke og Favrbø. *Aarbøger for nordisk oldkyndighed og historie* 1978, 33–43.
- Sørensen, M., 2006. Teknologiske traditioner i Maglemosekulturen. En diakron analyse af Maglemosekulturens flækkeindustri. In: Eriksen, B. V. (ed.), *Stenalderstudier. Tidligt Mesolitiske Jægere Og Samlere i Sydsjælland*. Jysk Arkæologisk Selskab, Højbjerg, 19–75.
- Sørensen, M., Lübke, H. and Groß, D. 2018. The Early Mesolithic in Southern Scandinavia and Northern Germany. In: Milner, N., Conneller, C. and Taylor, B. (eds.) *Star Carr, Volume 1: a persistent place in a changing world*. York, White Rose University Press, 305–329.

Taylor, B. 2025. Wetland Landscapes. In: Stutz, L. N., Peyroteo Stjerna, R. and Törv, M. (eds.), *The Oxford Handbook of Mesolithic Europe*. Oxford, Oxford University Press, 500–512. DOI:10.1093/oxfordhb/9780198853657.013.26

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# The Northwest-German Mesolithic gap and how to fill it

A survey for water-logged Mesolithic sites

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## Abstract

Since 2019 we are conducting a survey project in the northern area between the rivers Ems and Elbe with the aim to detect Mesolithic sites with water-logged preservation conditions. In this study, we provide an overview of the methods and the landscape situations along bogs, pingo scars and wetland edges. While several sites showed a good general setting for preservation conditions, only a small number of sites provided a suitable starting point for further investigations, where traces of activity were found, such as birch bark layers and pit structures.

*Keywords: Landscape reconstruction, peat, pingo scars, birch bark finds, pit structures*

## Point of departure

The Mesolithic in Europe starts with or shortly after the beginning of the Holocene and comes to an end with the beginning of the farming way of life, and thus, the end of foraging as predominant subsistence strategy. In northwestern Germany – referred to as the area along the German North Sea coast between the rivers Elbe and Ems in Lower Saxony – that is the time between 9200 and 3400 cal BCE in absolute dates. The beginning of the Neolithic in the area is proven relatively late with the Funnelbeaker Westgroup (Grimm *et al.* 2020; Müller *et al.* 2010).

As stated elsewhere, well dated and chronologically differentiated subphases of the Mesolithic are missing so far for northwestern Germany such as a differentiated view on subsistence strategies through this period, due to the lack of well-preserved sites (Mahlstedt 2015; Mahlstedt *et al.* 2018; 2022).

Looking at sites with good preservation conditions in the European neighbourhood, like the bog area of Duvensee, Germany, to the east (Groß *et al.* 2018; 2021), or Kerkove Stuw, Belgium (Sergant *et al.* 2016) to the west, we have to state that we need to detect more water-logged sites. Consequently, a research project dedicated to survey for such sites in the coastal area of Lower Saxony was designed and started in 2019. This paper is presenting the general ideas of the project. It provides insights into survey strategies and presents a first overview of the sites in the larger coastal area of Lower Saxony, Germany.



Figure 1: Sites surveyed during the project: 1 Großheide, 2 Utgast, 3 Holtgast, 4 Klosterschoo, 5 Dunum, 6 Utarp, 7 Osteel, 8 Berumerfehn, 9 Upende, 10 Kirchdorf, 11 Holtrop, 12 Wiesedemeer, 13 Wanna, 14 Neuenwalde, 15 Hemmoor, 16 Holter Moor, 17 Wischhafen, 18 Dollern, 19 Bargstedt, 20 Ahlerstedt, 21 Elmer See, 22 Bremervörde, 23 Glinstedt.

Many European Mesolithic sites with outstanding preservation have been found by chance, like the site of Motala in Sweden or Friesack and Rottenburg-Siebenlinden in Germany (Gramsch 2016; Hallgren 2011; Kind 2000; Kind *et al.* 2012). Other newly detected sites were uncovered by surveys in the vicinity of well investigated Mesolithic places as for example in the Federsee area (Jochim 2006) or the Vale of Pickering (Milner *et al.* 2018) as well as for the rediscovery of classic sites as in the area of Maglemose (Pedersen *et al.* 2016).

Except for the well-surveyed area around Lake Dümmer (Heumüller *et al.* 2017; 2022) just north of the midrange mountains, the area of northwestern Germany is lacking well investigated sites as fix points, but many surface sites are available. There, the majority of scattered finds were collected and registered by amateur archaeologists. Despite the challenges posed by surface sites, various collectors and the palimpsest question (for a critical assessment of Mesolithic surface collections see also Mahlstedt 2015, 26–28), these sites need to be seen as point of departure for all further investigations on the Mesolithic in the area.

One of the prerequisites for finding sites with outstanding preservation is thought to be ideally in organic sediments. Conveniently, c. 30% of the northern part of Lower Saxony are covered by peatlands which largely

consist of raised bogs (Große-Brauckmann 1967). Fen development commenced already during the Late Glacial as a consequence of paludification of lower-lying parts of the landscape, *i.e.* in depressions, along streams and lake shores. Fen peat formation continued in the Early Mesolithic but from around 6000 cal BCE an increasingly oceanic climate triggered raised bog growth in the region, as a result of Holocene sea-level rise and the North Sea reaching the forefield of nowadays coastline. Raised bog growth peaked between 4500 and 4000 cal BCE but continued well into the Late Holocene (Gerdes *et al.* 2003). The diachronous onset of peat growth implies that Mesolithic sites were covered at very different times, depending on their position in the landscape. Not every peat covered site is granted to be well preserved. Only if the Mesolithic remains were either dropped in a waterlogged surrounding directly or were overgrown quite rapidly after the place was abandoned and the peat cover or wet soils stayed intact in modern times, chances for organic preservation are favourable. Thus, the dating of peat growth for the different sites tested is an important part of the whole project.

## Methods

Prior to a survey in the field, the heritage database as well as local publications and find notes were studied

intensively for Mesolithic sites as well as geological and soil records of the area. The data were matched in a geographical information system and evaluated for best combinations. It was not always possible to precisely define the type of expected wetland from the maps as the different types overlap, like fens and pingo scars that developed independently and were overgrown by raised bog only in later periods. Thus, a detailed evaluation was subject to the field campaigns.

In total 23 sites with one to six find scatters were investigated between autumn 2019 and spring 2022 (Fig. 1).

The survey strategy ideally started with field walking to confirm the existence of the surface sites and their dimension. In many cases, the field walking part of the survey turned out to be difficult, as most sites are covered by grassland year-round. Thus, we often started directly with coring along transects into the lower and wetter areas in order to detect waterlogged sediments. Corings were conducted with a gouge auger of 2 cm diameter. The sediment was described in the field. The main focus lay on the following aspects: 1) the horizontal distribution of peat, to check where good preservation is to be expected; 2) the depth of the Pleistocene sands below organic soils, to reconstruct the Early Holocene relief; 3) the presence or absence of limnic sediments below peat, for the reconstruction of former water bodies; 4) the preservation and character of sandy soils below organic sediments to detect former surfaces.

A raster coring with a mega-drill (Edelmann-type) of 20 cm diameter followed where former surfaces with little or no erosion were covered by peaty sediments. The sediments were sieved or sorted in the field for finds and datable samples, such as charcoal and organic remains.

In individual cases, samples were taken for pollen, macrofossils and charcoal flitter additionally. Those samples were often the only way to distinguish lacustrine sediments from degraded peat when a distinction was impossible in the field.

At the most promising sites, the investigations were continued by small test trenches in a second campaign to get a better overview of preservation conditions, find compositions and possible anthropogenic structures.

To check the potentials of geomagnetic measurements for the reconstruction of Pleistocene landscape features some sites were also surveyed with a geomagnetic quad with 11 sensors. All anomalies turned out to be of modern origin when drilled up. Neither differences between the sandy rampart and the peaty infill of a pingo nor hidden beds of streamlets in the area of the basal peat could be detected by that way.

Although the geomorphological conditions of the sites were relatively similar, the results are different. The most promising ones are introduced in detail below.

## The pingo-paradox: sites on the shore of former lakes

On the East Frisian sandy upland and along its edges, large numbers of round depressions are visible in the LIDAR data. Most of these depressions seem to originate from periglacial processes as pingo scars. They developed under permafrost conditions, when ice lenses grew beneath the soil surface, fed by ground water, creating large hills – so-called pingos. After the end of the Ice Age the ice melted and left a tight mesh of round ponds or small lakes, still visible in the DEM of western East Frisia (Fig. 2, upper).

They are typically surrounded by a rampart of soil that had slid off the enlarging ice lens. During the Late Glacial and Early Holocene most of these smaller lakes started to silt up through gyttja sedimentation and subsequent fen peat formation, and some were finally overgrown by raised bogs from mid-Holocene times onward. However, similar investigations into Holocene lake development in northwestern Germany (e.g. Freund 1995; Hüser *et al.* 2017; Wolters 2023) have shown that many pingo scars still contained open water bodies during the Early Mesolithic, and some of them even remained small lakes until recent times.

Mesolithic sites in East Frisia can often be found near those (former) lakes, as repeatedly stated in the site record of the heritage management since the early 1980s, before their possible origin as pingo scars was reconstructed (Schwarz 1990).

Only lately, attention was drawn to a large number of round depressions on the Saalian ground moraines in East Frisia and their combination with Mesolithic sites (Heinze *et al.* 2013; Hüser *et al.* 2016; 2017; Mahlstedt *et al.* 2018).

Five sites were selected on the edge of round structures that were already known to contain peat from earlier corings or soil maps. The known find concentrations were located on the inner slope of the rampart, so the contact of finds and waterlogged soils was possible. The finds showed a Mesolithic habitus.

The pingos differ in diameter between 400–500 m up to 2000 m. In case of the larger pingos the rampart is surrounding a relatively flat area with a very shallow slope and a deep and steep depression in the middle. For the smaller pingo scars the situation was a bit different because the slope inside the rampart was steeper in general and the distance between the habitation site on the sandy rampart and the Holocene organic sediments is smaller.

All pingo scars were heavily affected by peat digging and consequent agrarian land-use. At Berumerfehn (Figs. 1 and 2), pollen and macrofossil analyses have shown that the site was a water body until Late Mesolithic times and that during the Early Mesolithic also the shallow littoral zone was open water, creating a lake of nearly 4 ha. Unfortunately, most of these sediments were already degraded by draining and ploughing and the surface

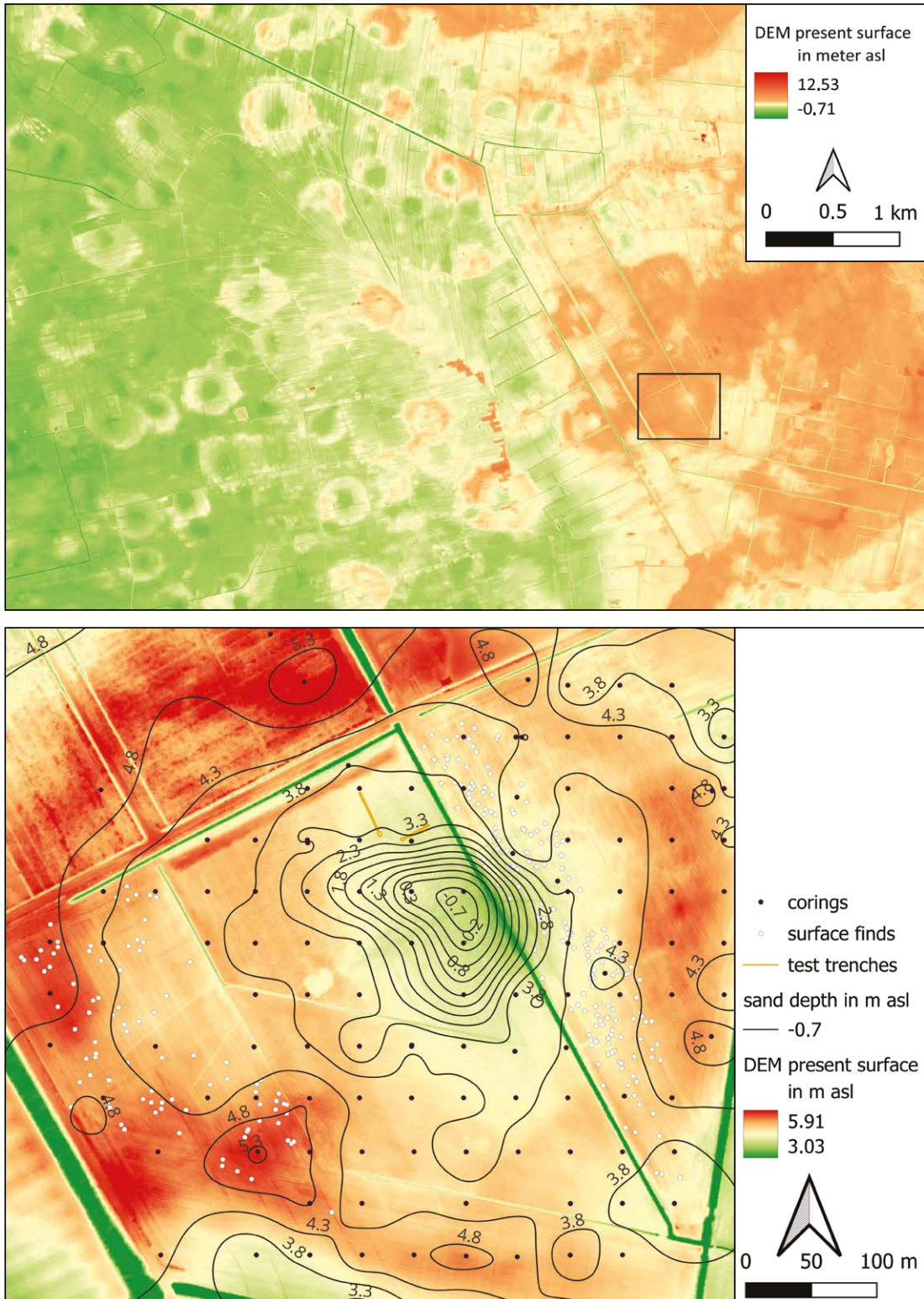


Figure 2: upper: Many of the round structures in the DEM of East Frisia near Berumerfehn (square) are interpreted as pingo scars; lower: the pingo scar of Berumerfehn revealed a much stronger relief in the sandy surface below peat than in the present surface today. The relief of the sandy surface below was interpolated from the results of corings. (Figure: Mahlstedt, NIhK – Illustration based on LiDAR data, resolution 0.25 m. Source: Excerpt from geodata of the Lower Saxony State Office for Geoinformation and Surveying, © 2021).

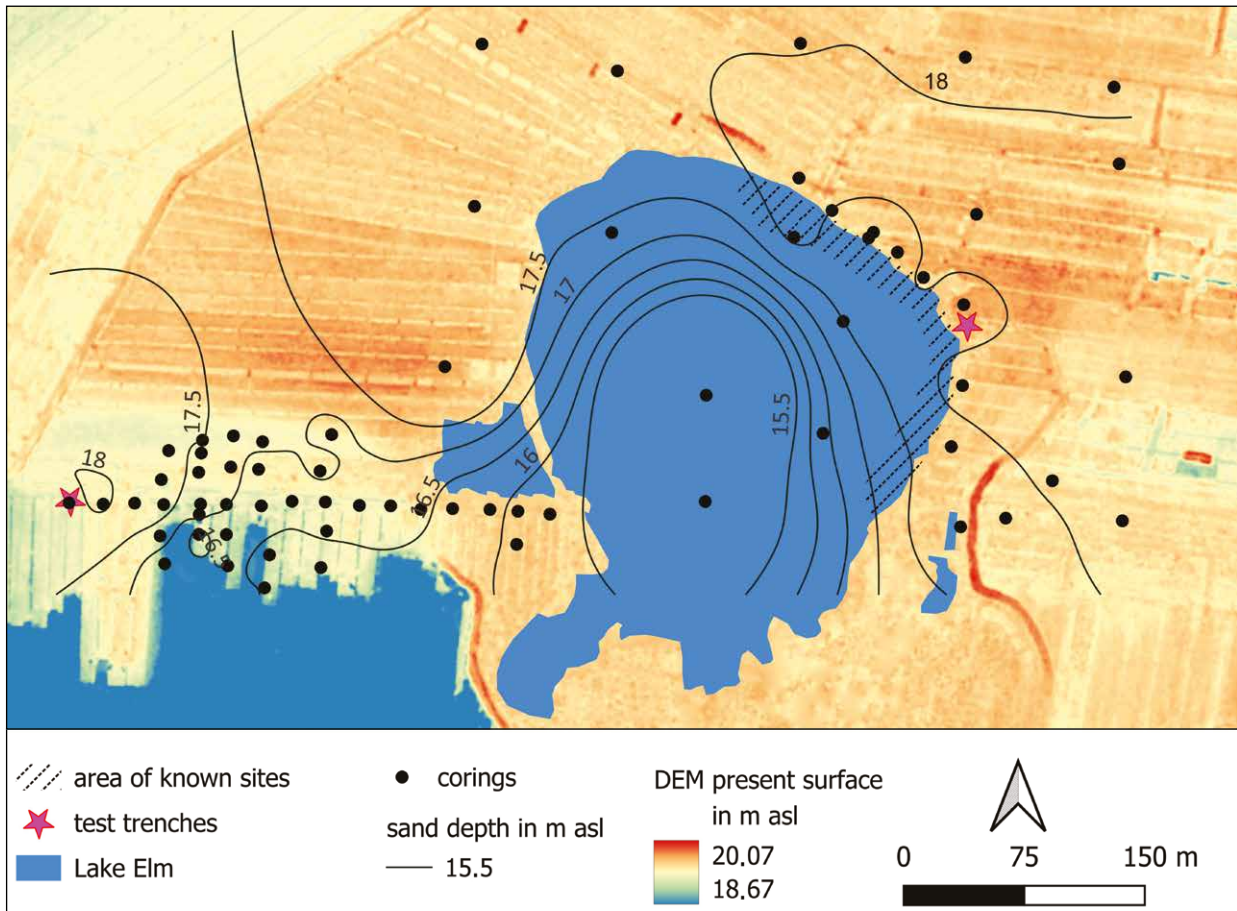


Figure 3: Traces of peat digging are visible in the DEM of the area around Lake Elm. The relief of the sandy surface below was interpolated from the results of corings. (Graphic: Mahlstedt, NIhK – Illustration based on LiDAR data, resolution 0.25 m. Source: Excerpt from geodata of the Lower Saxony State Office for Geoinformation and Surveying, © 2022)

find distribution was influenced by massive modern disturbances. Thus, the organic sediments close to the known surface sites on the ramparts were not preserved *in situ*. Two test trenches on the edge of the steeper part of the pingo depression remained findless. In other pingos the edge of the waterlogged sediments was disturbed by the dumping of gravel and waste in recent times.

Two Mesolithic dates were retrieved from the finds of a slightly burnt hazelnut shell in the deep area of the large pingo scar of Upende (Fig. 1) between 7311–7083 cal BCE (AWI 4938.1.1: 8196 ± 24 BP) and a whole fruit close to a modern gravel infill in Utarp with 5617–5495 cal BCE (AWI 4941.1.1: 6612 ± 21 BP). These dates prove the potential of a good preservation in pingos but, due to the above-mentioned disturbances, no other traces of human Mesolithic activity could be detected.

In summary, pingo scars turned out to be less uniform than expected. The potential for good preservation of organic Mesolithic materials embedded in gyttja or peat inside a pingo scar remains a promising possibility,

although a well-preserved site has not yet been discovered, due to modern draining and infill. For further investigations following the given strategy to select pingos with Mesolithic surface sites on the rampart, smaller features up to 200 m in diameter are expected to provide the highest potential. There, a steep slope in the inner part might have led to a better protection of possible find layers in the immediate vicinity of a known surface scatter on the rampart.

### Under cover: Sites in raised bogs

Large parts of the moraine area of the coastal region have been overgrown by raised bog peat during the Holocene. The very different relief situation in East Frisia and the Elbe-Weser-area led to a different appearance of raised bogs in both parts of the investigation area. While the shallow East Frisian sandy upland was largely covered with peat, the raised bogs in the relief terrain of the Elbe-Weser-area are patchier, as the moraine tops poke out.

While successively being covered by peat, most of the Holocene land surface including Mesolithic sites have

disappeared for thousands of years. In the 17<sup>th</sup> century intensive peat cutting and extraction commenced. The economical urge to drain the 'harvested' areas for agricultural use led to a total change of the landscape and Mesolithic sites were brought to the present-day surface. Many of the known surface sites were detected in former peat digging areas, which unfortunately does not provide a sufficient stratigraphic context. However, in some cases areas of raised bog still exist near known sites. Those that have not yet been subject to peat extraction, inherit a high potential for undisturbed Mesolithic settlement traces beneath the preserved peat layers.

In the Elbe-Weser-area, Lake Elm (Figs. 1 and 3) is situated in a comparable situation in the middle of a vast raised bog (Hohes Moor) in the central moraine area. Being cut into the surrounding peat, it has a steep edge. Although a natural origin of the lake was always suspected, it was not yet clear whether it was a rather young and shallow bog lake or if an older origin could be proven.

Since the 1930s, several Mesolithic flint scatters with microliths and blades as well as the remains of at least one fireplace have been known from the shore of Lake Elm (Mittmann 2016). By the time of recovery, the lake was popular for swimming and as a recreational area. Due to peat extraction in the bog, the water level of the lake was about 1.5 m lower at that time, and a sandy beach stretched out in front of a steep 1.6 m-high cliff formed by an eroded peat bank. The finds and structures were detected on that sandy surface along the northeastern shore of the lake which today is inundated.

A raster of 67 corings on the shore as well as in the lake revealed a depression in the sandy subsoil in the southwestern part of the lake and below the adjacent western rim around 2.5 m and down to 3.7 m below present surface. Along the eastern edge of the present lake the sandy subsoil is found in relatively shallow depth around 1.5 m. Pollen and macro fossil analyses showed that an oligotrophic lake existed since the Allerød Interstadial. Terrestrialisation processes started already during the Younger Dryas and the western part of the lake turned into a fen during the Early Holocene. A pollen diagram ca. 800 m northwest of the lake in the central part of the raised bog complex also shows fen peat development from the Early Holocene onward (Schubert 1933). However, Lake Elm has persisted to the present day as a typical bog lake, with terrestrialisation in the west and erosion forming peat cliffs in the east due to the prevailing westerly winds (Behre 2008).

Thus, it has been proven that the lake existed already during the Mesolithic and was one of the reasons for Holocene hunter-gatherers to stay in the area.

Two test trenches were dug in areas where the sandy subsoil was found in the same absolute height as the known sites, most possibly resembling the height of the former

lake shore (Fig. 3). Unfortunately, no organic perseveration or traces of a former surface below the peat could be identified in the test trenches.

Generally, raised bogs in Lower Saxony were heavily exploited, however, it seems rare that a Mesolithic site was covered by slowly growing raised bogs immediately after it was left. Sites on the edge of a growing fen that eventually turned into a raised bog, seem to have had much better chances of preservation (and recent detection) as will be described in the following.

### **Draining or drowning: Sites near fens and basal peats along the gullies and edges of the sandy uplands**

For Mesolithic times, the areas of basal peat growth along the sandy moraine can be reconstructed as regions with a mixture of marine and limnic influence (Karle *et al.* 2021). As we know from submerged sites in the Baltic Sea, these areas were inhabited by Mesolithic people on a regular basis. Unfortunately, most of those places with lagoon-like brackish waterbodies along the former North Sea coast are covered under thick layers of marine sediments today. Still, some parts of the basal peat layers and fens of suitable age can be expected to be preserved in gullies and alluvial channels of the higher sandy areas that are more easily accessible.

In East Frisia six sites in the vicinity of fen peat in alluvial channels were investigated (Fig. 1: 1–5,7).

The best results for East Frisia were retrieved on the site of Osteel (Figs. 1 and 4), which is situated at the western rim of the Pleistocene sands on a shallow sandy promontory that is stretching into the marshland today. On its northern edge, fen peat is covered by marine clays caused by floods since the 14<sup>th</sup> century CE.

During a development led archaeological survey in the 1990s a pit structure was detected below marine silts and some 20 cm of peat. A charcoal sample from the pit was dated to 6025–4852 cal BCE (Hv-19605: 6560 ± 280 BP; Heun 1994). Approximately 100 m away from this find area, datable charred plant material was found below a cover of marine clay and peat during the recent project. It led to a slightly younger date than the first one between 4684–4464 cal BCE (AWI-5143.1.1: 5720 ± 42 BP).

Further corings, recent topography from digital elevation models as well as geological maps were used to reconstruct the surrounding paleo-environment of the Mesolithic site. Two pingo scars in the vicinity of the site visible in Fig. 4a were found to have been silted up already in the Late Glacial.

In the 5<sup>th</sup> millennium cal BCE, the site was situated in the hinterland of the coast on the southern bank of a small streamlet that was leading westwards. The lower area along the water was covered by a riparian forest that was later drowned and overgrown by fen peat.

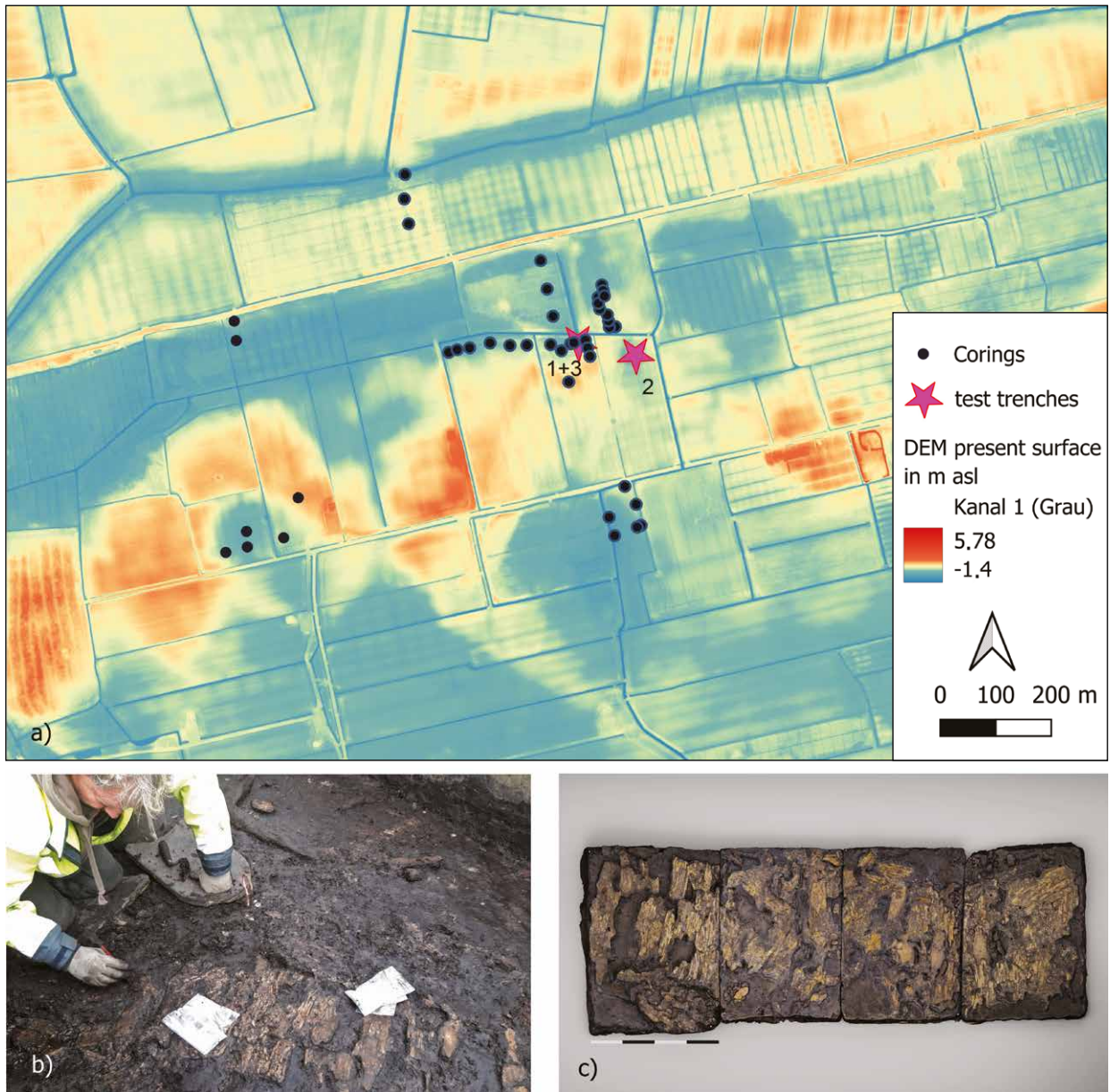


Figure 4: a) The present relief is highly influenced by the marine clay cover, but the slight elevation of the site area (asterisks) is still visible (Graphic: Mahlstedt, NIHK – Illustration based on LiDAR data, resolution 0.25 m. Source: Excerpt from geodata of the Lower Saxony State Office for Geoinformation and Surveying, © 2021). b) The birch bark mats were found below clay and peat on the top of the sandy subsoil and partly retrieved in blocks. c) The blocks were excavated in the NIHK lab and put together digitally (Graphic: Frederiks, NIHK).

The following excavation (Fig. 4a: trench 1 and 3) provided an early medieval find layer at the bottom of the marine clays with a pit and well-preserved ceramics from the 9<sup>th</sup> and 10<sup>th</sup> century CE and some exceptional wooden artifacts (Mahlstedt and Siegmüller 2021) above the older layers.

The peaty layers beneath the marine clays were rich in well preserved twigs, branches and small tree trunks. At the bottom of the peat on the sandy subsoil about the same depth as the radiocarbon sample, three areas with

birch bark layers were found, that date to 4677–4456 cal BCE (AWI 6851.1.1: 5724 ± 26; AWI 6852.1.1: 5700 ± 25). Apart from some charcoal on the bark, burnt parts of the bark itself and a few burned flint remains beneath it, Mesolithic anthropogenic traces were sparse (Mahlstedt *et al.* 2021).

In the deeper wetter parts, the bark was preserved in several layers that covered an area of 1.8 to 0.6 m, large parts were taken in blocks from the site to be excavated and investigated in detail in the laboratory (Fig. 4). All parts of

the bark are spread out on the sandy subsoil. In the wettest and best-preserved parts, there are up to 4 layers of bark on top of each other and laid out in the same manner. The place where the bark mats were spread out on the humid sands was already in a stage of initial waterlogging, as botanical remains and pollen of rushes (*Juncus* sp.) indicate. A detailed publication of the results from Osteel is in preparation.

Together with the slightly older pit structure mentioned above, the multilayered bark finds give the impression of a camp site in an area of repeated use over a longer time span. There are two thinkable scenarios. First, the area was repeatedly of periodic interest for people in a changing environment during the Late Mesolithic, creating a patchy and ephemeral archaeological record. Second, the area was of constant attractivity in a persistent environment of about one millennium and we only touched the edge of a larger activity zone that is best preserved to the west of the birch bark area.

In the Elbe-Weser-area the relief between sandy moraines on the one hand and floodplains, riverbeds and fens on the other is a little more pronounced than in East Frisia. Two very different reliefs should be mentioned here. These are the sites of Neuenwalde and Wolfsbrucher Moor (Fig. 1). The latter is situated in the wider floodplain of the Elbe estuary, where a peat bog has grown on alluvial sediments of sand and marine clays. There, a human jawbone was found in the 1920s during amelioration works. It was expected to be Mesolithic. Saller (1929) reported that it was found on the upper part of the alluvial sediments and had been part of a larger assemblage of human bones that were left at the site after its discovery. Gouge auger coring led to the find of several former surfaces in the upper parts of more than 10 m thick alluvial sediments and partly, directly below the peat. These surfaces can be interpreted as signs of drier periods in an amphibious landscape that could have been used for human inhabitation although no direct indications of human activity could be found. We generally find a situation that is comparable to the lagoonal habitats preferred along the Baltic Sea coast. Also, the preservation condition for bones is a comparable feature that has so far not been found at other sites of the Saalian moraine area in our surveys.

The area of Neuenwalde today is situated between the estuaries of the rivers Elbe and Weser on the northern slope of a sandy moraine (Figs. 1 and 5). It is facing wetlands to the north that are still drained through a glacial channel in easterly direction. There, a fen had started to develop along the slope already in the Late Glacial, and also in the channel from the Early Holocene, around 9986–9453 (AWI-9237.1.2: 10121 ± 55), onward. From the peaty infill in the lowest part of the valley, the fens spread out in the wider floodplain during Mesolithic and Neolithic times, when a raised bog started to grow (Schneekloth 1970).

In an intense survey over several campaigns three find concentrations in a distance of a few hundred meters have been investigated, all of them close to remaining waterlogged soils. Only site Neuenwalde 135 has brought archaeological features so far. From a rescue excavation in the 1960s charcoal concentrations and fire pits as well as stone tools containing a range of microliths, regular and rhombic trapezoids, have been found but never published in detail. In the recent excavations we could detect a fireplace with a stone packing and several blades and blade cores in small test trenches. Charcoal samples from the fireplace were dated to 6256–6434 cal BCE (AWI-8117.1.1: 7505 ± 27 BP). Further down the slope two larger pit structures were documented in an area that was already situated in wet soils during its use. Due to datings from a charcoal concentration and organic bulk samples they are associated with an activity zone from the 5<sup>th</sup> millennium BCE (AWI -8118.1.1: 5625 ± 25 BP, 4542–4355 cal BCE; AWI 13471.1.1: 5843 ± 24 BP, 4788–4654 cal BCE; AWI 13472.1.1: 6014 ± 24 BP, 4992–4835 cal BCE). This first insight already shows that the Neuenwalde area offers best opportunities to access well-preserved dryland parts of the sites as well as waterlogged find layers from very Early to Late Holocene phases. Together with the presence of a large amount of Mesolithic surface finds as proof for the intense use of the area by Holocene hunter-gatherers, there is a very high potential for waterlogged Mesolithic sites to be expected.

### Putting the mosaic together

Within the framework of the ongoing project, it has been possible to identify regions in the area between the Ems and Elbe rivers where Mesolithic wetland sites have been preserved. In contrast to previously known surface sites or isolated pit finds without landscape context or regional embedding, the Osteel and Neuenwalde microregions offer good preservation conditions for Mesolithic finds, both on higher-lying sandy areas and, in particular, in the wetland soils of the adjacent bogs. Pedological and palynological investigations confirm increasing waterlogging and a corresponding development in the landscape during this period, with marked boundary shifts between dry and wet zones. In both zones traces of repeated and prolonged occupation can be assumed, suggested by *e.g.* pit structures as well as charcoal concentrations and – particularly in Osteel – also by plant remains that represent human activity in the wetland areas. These are neither easy to decipher nor to recognize in another setting, as, for example, a rescue excavation. This emphasizes that our knowledge about “ghost sites” (Grøn and Peeters 2021) or off-site situations (Foley 1981) that obviously belong to larger and or repeated settlement activities has to grow, to further comprehend the complexity of Mesolithic land use in the area.

In many other cases the survey for waterlogged sites in northwestern Germany showed a wide variety

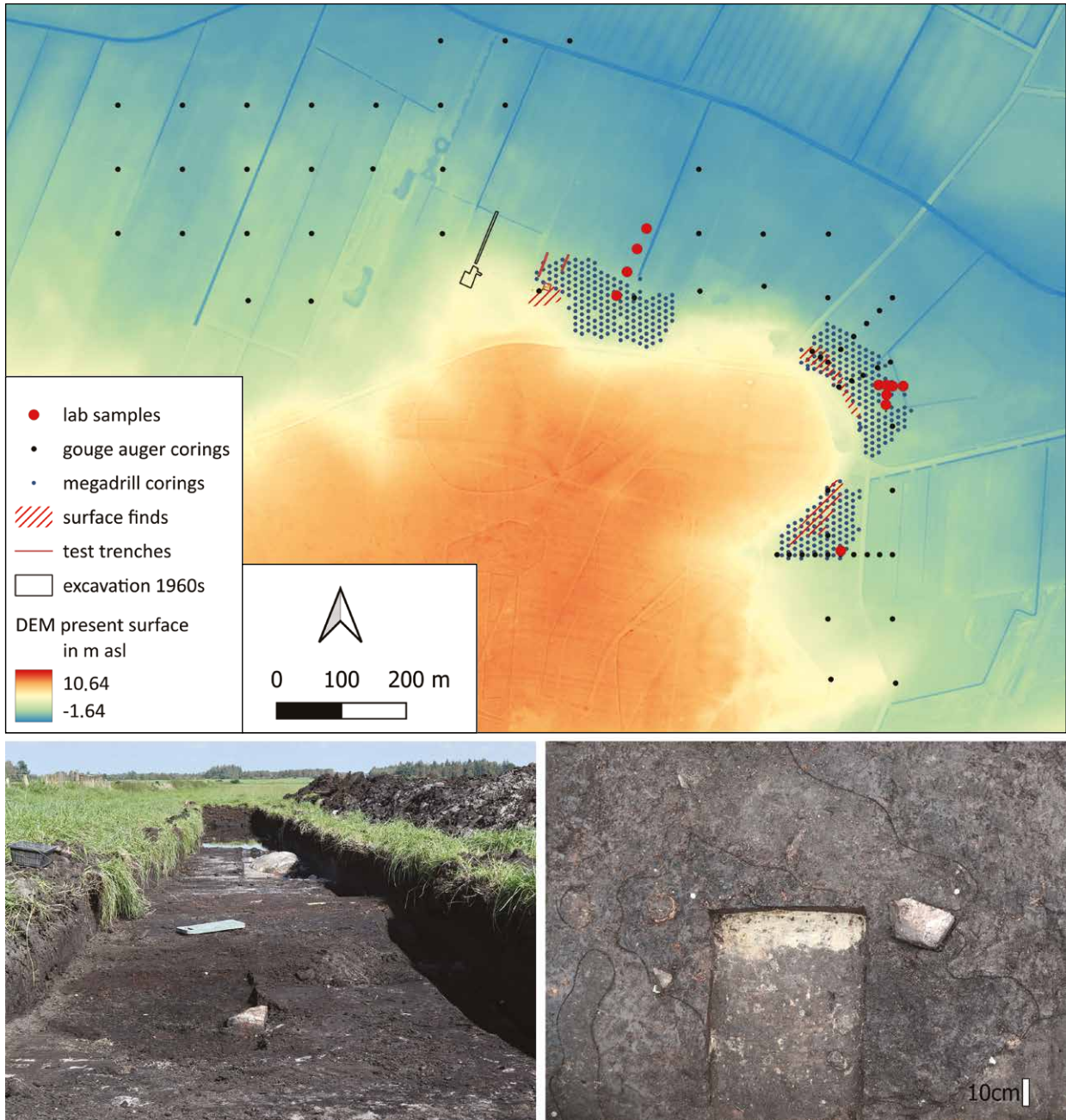


Figure 5: a) The area of Neuenwalde with three surface sites was investigated intensely. b, c) A shallow pit structure was indicated by a charcoal concentration below around 40 cm of peat cover.

of geomorphological, depositional and conservational circumstances.

The idea of the rich pingo scar landscape in the western part of East Frisia as a small lake district in the dense Holocene woods remains a promising picture, but our investigations showed that we cannot expect every pingo scar to have been a place of open water. Some scars silted up as early as the Late Pleistocene, like the pingos near Osteel. Others are so wide that known surface sites and

preserved wetland remains are situated some 100 meters apart as at Berumerfehn.

An unexpected result is the fact that fen and carr peat growth along streams and their slopes can happen as early as the Late Pleistocene, depending on local paludification processes and high groundwater levels independent of sea-level rise, as in Neuenwalde. This widens the possibilities of waterlogged preservations for Mesolithic and possibly also Late Pleistocene sites

in areas that have not been in the focus of Mesolithic prospection so far.

Peat covers turned out to be frequently disturbed by different activities like peat extraction, drainage work and agricultural use of different intensities. Additionally, very poor preservation conditions in the sandy subsoil of Saalian moraines of northwestern Germany are caused by periglacial processes during the last Ice Age. Leaching and a resulting lack of carbonates left these soils in an acidic state that caused podsolization and prevented the preservation of bones. This is the largest difference to the well-preserved wetland sites in southern Scandinavia and the coastal region of the Benelux countries. Exceptions can be found in the German northwest around larger lakes, such as Dümmer and Zwischenahner Meer, as proven by rich bone and antler finds (Deichmüller 1974; Heumüller *et al.* 2022; Mahlstedt *et al.* 2018). Better preservation of bone finds has also been proven along the coast and river outlets due to the marine

## References

- Behre, K.-E. 2008. *Landschaftsgeschichte Norddeutschlands: Umwelt und Siedlung von der Steinzeit bis zur Gegenwart*. Neumünster, Wachholtz.
- Deichmüller, J. 1974. Eine Geweihaxt mit Flintbohrer aus der Siedlung Hüde I am Dümmer, Kr. Grafschaft Diepholz. *Archäologisches Korrespondenzblatt* 4, 197–199.
- Foley, R. 1981. Off-site archaeology: An alternative approach for the short-sited. In: Hodder, I., Isaac, G. L. and Hammond, N. (eds.), *Pattern of the Past: Studies in Honour of David Clarke*. Cambridge, Cambridge University Press, 157–183.
- Freund, H. 1995. Pollenanalytische Untersuchungen zur Vegetations- und Siedlungsentwicklung im Moor am Upstalsboom, Ldkr. Aurich (Ostfriesland, Niedersachsen). *Probleme der Küstenforschung im südlichen Nordseegebiet* 23, 117–152.
- Gerdes, G., Petzelberger, B. E. M., Scholz-Böttcher, B. M., and Streif, H. 2003. The record of climatic change in the geological archives of shallow marine, coastal, and adjacent lowland areas of Northern Germany. *Quaternary International* 22, 101–124.
- Gramsch, B. 2016. Friesack 4 – eine Feuchtbodenstation des Mesolithikums in Norddeutschland. In: Benecke, N., Gramsch, B. and Jahns, S. (eds.), *Subsistenz und Umwelt der Feuchtbodenstation Friesack 4 im Havelland. Ergebnisse der naturwissenschaftlichen Untersuchungen*. Arbeitsberichte zur Bodendenkmalpflege in Brandenburg 29. Wünsdorf, Brandenburgisches Landesamt für Denkmalpflege und Archäologisches Landesmuseum, 9–24.
- Grimm, S. B., Groß, D., Gerken, K. and Weber, M.-J. 2020. On the onset of the Early Mesolithic on the North German Plain. In: Zander, A. and Gehlen, B. (eds.), *From the Early Preboreal to the Subboreal Period - Current Mesolithic Research in Europe. Studies in Honour of Bernhard Gramsch on his 85th Birthday*. Edition Mesolithikum 5. Kerpen-Loogh, Welt und Erde, 15–37.
- Grøn, O. and Peeters, H. 2021. Mesolithic 'ghost' sites and related Stone Age problems with lithics. In: Borić, D., Antonović, D. and Mihailović, B. (eds.), *Foraging Assemblages*. Belgrade/New York, Serbian Archaeological Society, The Italian Academy for Advanced Studies in America, Columbia University, 233–239.
- Groß, D., Henke, I. S., Lübke, H., Meadows, J. and Schmölcke, U. 2021. Duvensee WP 10 – an Early Mesolithic Site at Ancient Lake Duvensee, Germany. *Journal of Wetland Archaeology* 21, 1–20. DOI:10.1080/14732971.2021.1973778
- Groß, D., Lübke, H., Schmölcke, U. and Zanon, M. 2018. Early Mesolithic activities at ancient Lake Duvensee, northern Germany. *The Holocene* 29(2), 197–208. DOI:10.1177/0959683618810390
- Große-Brauckmann, G. 1967. Die Moore in der Bundesrepublik Deutschland. *Natur und Landschaft* 42(9), 195–199.
- Hallgren, F. 2011. Mesolithic Skull Depositions at Kanaljorden, Motala, Sweden. *Current Swedish Archaeology* 19(1), 244–246.
- Heinze, A., Hoek, W. and Tammen, M. 2013. Pingo-Landschaft in Ostfriesland. *Siedlungs- und Küstenforschung im südlichen Nordseegebiet* 36, 49–52.
- Heumüller, M., Briel, M., Klimscha, F., Kotula, A., Leuschner, H. H., Schoon, R. and Zerl, T. 2022.

- Wetland settlements and a wooden trackway: Swifterbant sites in the Dümmer basin. In: Klimscha, F., Heumüller, M., Peeters, H., Raemackers, D. and Terberger, T. (eds.), *Stone Age borderland experience: Neolithic and Late Mesolithic parallel societies in the North European plain*. Materialhefte zur Ur- und Frühgeschichte Niedersachsens 60. Rahden/Westfalen, Verlag Marie Leidorf, 25–45.
- Heumüller, M., Briel, M., Schoon, R. and Zerl, T. 2017. Die Fundstelle Hunte 3 am Dümmer, Ldkr. Vechta: ein neuer Fundplatz der Swifterbant-Kultur? *Nachrichten aus Niedersachsens Urgeschichte* 86, 11–33.
- Heun, S. 1994. Osteel, Gde. Osteel Fst. Nr. 2409/5:6. *Nachrichten aus Niedersachsens Urgeschichte* 63, 205–206.
- Hüser, A., Wolters, S., Larocque-Tobler, I., Mahlstedt, S. and Enters, D. 2017. Von Sedimenten, Zuckmücken, Pollen und kleinen Steinen. Suchen und Finden des Mesolithikums an Pingo-Ruinen. *Archäologie in Niedersachsen* 20, 92–96.
- Jochim, M. 2006. Settlement Variability in the Early Mesolithic of Southwestern Germany. In: Kind, C.-J. (ed.), *After the ice age*. Stuttgart, Theiss, 175–180.
- Karle, M., Bungenstock, F. and Wehrmann, A. 2021. Holocene coastal landscape development in response to rising sea level in the Central Wadden Sea coastal region. *Netherlands Journal of Geosciences* 100, e12.
- Kind, C.-J. (ed.). 2000. *Siebenlinden 2: Ein mesolithischer Lagerplatz bei Rottenburg am Neckar, Kreis Tübingen*. Stuttgart, Theiss.
- Kind, C.-J., Niederhöfer, J. and Wahl, J. 2012. *Das Mesolithikum in der Talaue des Neckars*. Stuttgart, Theiss.
- Mahlstedt, S. 2015. *Das Mesolithikum im westlichen Niedersachsen: Untersuchungen zur materiellen Kultur und zur Landschaftsnutzung*. Frühe Monumentalität und soziale Differenzierung 7. Bonn, Dr. Rudolf Habelt.
- Mahlstedt, S., Hüser, A. and Kegler, J. F. 2018. Mesolithic Settlement sites on the East Frisian Peninsula. Landscape history and development with regard to pingo scars as preferred settlement sites. *Quartär* 65, 115–127.
- Mahlstedt, S., Karle, M. and Kegler, J. F. 2022. Foraging in a changing landscape - the Late Mesolithic in the coastal area of Lower Saxony. In: Klimscha, F., Heumüller, M., Peeters, H., Raemackers, D. and Terberger, T. (eds.), *Stone Age borderland experience: Neolithic and Late Mesolithic parallel societies in the North European plain*. Materialhefte zur Ur- und Frühgeschichte Niedersachsens 60. Rahden/Westfalen, Marie Leidorf, 185–194.
- Mahlstedt, S. and Siegmüller, A. 2021. Ein feuchter Erdkeller am Ufersaum – frühmittelalterliche Funde und Befunde aus Osteel. *Archäologie in Niedersachsen* 24, 71–74.
- Mahlstedt, S., Siegmüller, A. and Wolters, S. 2021. Die mesolithischen Birkenrindenfunde von Osteel, Lkr. Aurich. *Siedlungs- und Küstenforschung im südlichen Nordseegebiet* 44, 9–24.
- Milner, N., Conneller, C. and Taylor, B. (eds.) 2018. *Star Carr Volume 1: A persistent place in a changing world*. York, White Rose University Press.
- Mittmann, M. 2016. ... man nennt diese Stätten auch Flintplätze : zur Sammlung, Erforschung und Vermittlung mesolithischer Funde im Bachmann-Museum Bremervörde. In: Gerken, K., Groß, D. and Hesse, S. (eds.), *Neue Forschungen zum Mesolithikum*. Archäologische Berichte des Landkreises Rotenburg (Wümme) 20. Oldenburg, Isensee, 221–238.
- Müller, J., Brozio, J.P., Demnick, D., Dibbern, H., Fritsch, B., Furholt, M., Hage, F., Hinz, M., Lorenz, L., Mischka, D. and Rinne, C. 2010. Periodisierung der Trichterbecher-Gesellschaften. Ein Arbeitsentwurf. *Journal of Neolithic Archaeology* 12, 1–6.
- Pedersen, K. B., Mortensen, M. F. and Sørensen, M. 2016. Tilbage til Holmegård Mose. *Geffjon* 1, 11–34.
- Saller, K. 1929. Der Unterkiefer aus dem Wolfsbrucher Moor (Kreis Freiburg a.d. Elbe, Reg.-Bez. Stade). *Stader Archiv Neue Folge* 19, 3–14.
- Schneekloth, H. 1970. Das Ahlen-Falkenberger Moor. Eine moorgeologische Studie mit Beiträgen zur Altersfrage des Schwarz-/Weißtorfkontaktes und zur Stratigraphie des Küstenholozäns. *Geologisches Jahrbuch* 89, 63–96.
- Schubert, E. 1933. Zur Geschichte der Moore, Marschen und Wälder NW-Deutschlands II: Das Gebiet an der Oste und Niederelbe. *Mitteilungen der Provinzialstelle für Naturdenkmalpflege Hannover* 4, 1–148.
- Schwarz, W. 1990. *Besiedlung Ostfrieslands in ur- und frühgeschichtlicher Zeit*. Aurich, Verlag Ostfriesische Landschaft.
- Sergant, J., Vandendriessche, H., Noens, G., Cruz, F., Allemeersch, L., Aluwé, K., Jacobs, J., Wuyts, F., Windey, S., Rozek, J., Depaape, I., Herremans, D., Laloo, P. and Crombé, P. 2016. Opgraving van een mesolithische wetlandsite te Kerkhove ‘Stuw’ (Avelgem, West-Vlaanderen, BE). Eerste resultaten. *Notae Praehistorica* 36, 47–57.
- Wolters, S. 2023. Der Pingo von Esens-Norddorf – eine vegetationsgeschichtliche Voruntersuchung. *Nachrichten des Marschenrates* 60, 69–75.

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# Hunter-Gatherers in the Sorge River Valley (Rendsburg-Eckernförde district)

A Mesolithic Settlement Hotspot  
in the 7<sup>th</sup> millennium BCE in  
northern Schleswig-Holstein

Sönke Hartz, Ingo Clausen and Fynn Rohweder

## Abstract

The 30 km long Sorge River is, after the Treene River, the second largest tributary of the Eider River, which forms the largest river system in the southern part of Cimbrian Peninsula. In its upper and middle reaches in the districts of Owschlag and Alt Duvenstedt the Sorge River forms wide valleys and narrow passages, where Late Palaeolithic and Late Mesolithic sites are located along the banks. While the Late Palaeolithic sites are mostly buried under coversands, the Late Mesolithic ones are located on sandy hilltops, dunes and peninsulas that extend prominently into the valley (Clausen 1994; Clausen and Hartz 1988). The Mesolithic assemblages do not represent single occupations, however, the majority of the settlement sites date to the early Atlantic period and belong to the Late Mesolithic Trapeze-Phase, *i.e.* the Southern Scandinavian Kongemose Culture (6700–5500 cal BCE). Flakes, macro- and micro blades and cores predominate the flint assemblages. Among the modified pieces, blade tools and microliths are the most numerous, while axes and other larger implements and borers are rather rare.

This paper presents a selection of two flint assemblages with focus on artefact composition, tool and blade technology, and discusses its functional and chronological context. Combined with other chronologically significant assemblages, the Sorge sites represent an important contribution to the superregional lithic technological development, the Late Mesolithic settlement system and the regional cultural history of northern Schleswig-Holstein.

**Keywords:** *Surface sites, Late Mesolithic, Kongemose Culture, macro and micro blade technology, Schleswig-Holstein*

## Introduction and history of discovery

The large bogs and vast lowlands of Schleswig-Holstein's waterways are excellent archives for researching Stone Age cultural and natural landscapes. Specifically, the area around the upper and middle Sorge valley (Rendsburg-Eckernförde district) seems to have been highly attractive for Mesolithic inland hunter-gatherer societies, here referred to as a 'settlement hotspot'. However, the earliest evidence of hunter-gatherer settlements in the area dates to the Allerød period and the Younger Dryas and is accredited to Late Palaeolithic hunter-gatherer groups related to Federmesser/Bromme and Ahrensburg Culture (Clausen and Hartz 1988; Clausen 1995; 1996; Reuter 2023). From the middle of the 6<sup>th</sup> millennium onwards, the formation of the present-day Baltic Sea and the change in subsistence to marine resources led hunter-gatherer groups to shift their main activities from the inland to the Baltic Sea coast. For this reason, only minor Ertebølle-activities are expected in the Sorge valley.

Due to the numerous Mesolithic surface assemblages in this micro-region, it is possible to gain insights into the function of the inland sites based on artefact composition and the distribution of the sites. The geomorphological conditions of the river valley with its sandy banks offered ideal conditions for mobile hunter-gatherers to hunt and fish. The Mesolithic sites appear like a string of pearls commencing in the vicinity of the Lake Owschlag and then following the rivers Seeaue, Mühlenau, Stente and Sorge (Fig. 1). Already in the 1990s c. 40 sites with Mesolithic artefacts were identified in this area (Clausen 1994). However, since 1940 the Sorge valley has been of keen interest to amateur archaeologists who collected surface finds here for more than 80 years now. These people have continuously observed the sites in this area, visited them regularly and have submitted the artefacts for recording, making scientific research possible.

In 1970, Stone Age researcher Klaus Bokelmann investigated the sites Owschlag LA 183 and LA 150 as part of the archaeological field survey (Bokelmann 1971). Subsequently, archaeological fieldwork was carried out in the 1980s by one of the authors (I. C.) in preparation for the construction of an oil pipeline. Small-scale test pits and boreholes resulted in the findings of partially preserved settlement features along the river valley and thus confirmed the area's potential for Late Mesolithic research (Clausen 1994). At the same time, systematic field surveys were carried out by members of the 'Prehistory and Early History Working Group' (Arbeitsgemeinschaft für Vor- und Frühgeschichte des Kreises Eckernförde) in the Rendsburg-Eckernförde district. From their discoveries, a large flint collection from the site Alt Duvenstedt LA 74 was subsequently published showing its potential for Mesolithic research in Schleswig-Holstein (Hartz 1985).

Recently, a structural shift in agriculture has affected the survey possibilities in certain parts of the Sorge valley.

Sites that were previously exposed by ploughing are now covered by grassland, which make archaeological surveys nearly impossible. However, since 2022 the upper and middle Sorge valley has been regularly visited by one of the authors (F. R.) in an effort to further explore and expand the Mesolithic settlement patterns of this river landscape.

This resulted in the finding of various Mesolithic flint assemblages, of which the ones from Owschlag LA 186 and Owschlag LA 192 are presented here. The assemblages are assigned to specific cultural horizons based on their typological and technological composition. It is striking that no organic remains have been found, which contrasts with Mesolithic find spots in the Holstein region in the upper Trave valley and the upper Alster valley as well as in the Schleswig region in the Kreuzau valley or the Satrupholm peatbog (Fig. 5). It is unclear whether this is due to poor preservation conditions or whether individual Stone Age objects were overlooked when draining works had been carried out. To approach an absolute chronological classification of the assemblages, <sup>14</sup>C-dated and stratified layers with organic preservation are of crucial importance. Unfortunately, these materials are missing from Mesolithic contexts in the Sorge valley (Clausen 1994).

## Landscape history of the upper and middle Sorge valley

About eight kilometres north of Rendsburg the Sorge river, flowing east to west, leaves the Weichselian push moraines of Schleswig-Holstein (Fig. 1). There, the river enters a grassland area that is initially about 500 metres wide, before crossing the sandy outwash plain with many twists and turns in an east-west direction, now in a much narrower valley basin. This section, known as the middle Sorge river course, reaches its western end after about 13 kilometres, where the river flows into the wide lowlands of the former Lake Börm. Archaeological surveys revealed that narrow ridges of fine sand near the Sorge river were settled in prehistory, mainly by Mesolithic communities (Clausen 1994). It remains unclear if dense human occupation also continued west of Sorgwohld village. Due to reforestation around 120 years ago these extensive areas are inaccessible for archaeological surveys today.

During the Weichselian glaciation, the Sorge valley was formed as an east-west drainage channel crossing the alluvial sand plain, called 'Geest'. Heavily eroded end moraine remnants and boulder fields in the eastern part of the river valley mark the former course of a maximum glacier advance (Fockbek glacier advance, Clausen and Hartz 1988). This advanced over eastern parts of what is now the Sorge valley and released its meltwater in the vicinity of the current Schleswig-Rendsburg railway line (Fig. 1). This initially shaped the subsequent course of the river. With the retreat of the glacier front (Borgstedt

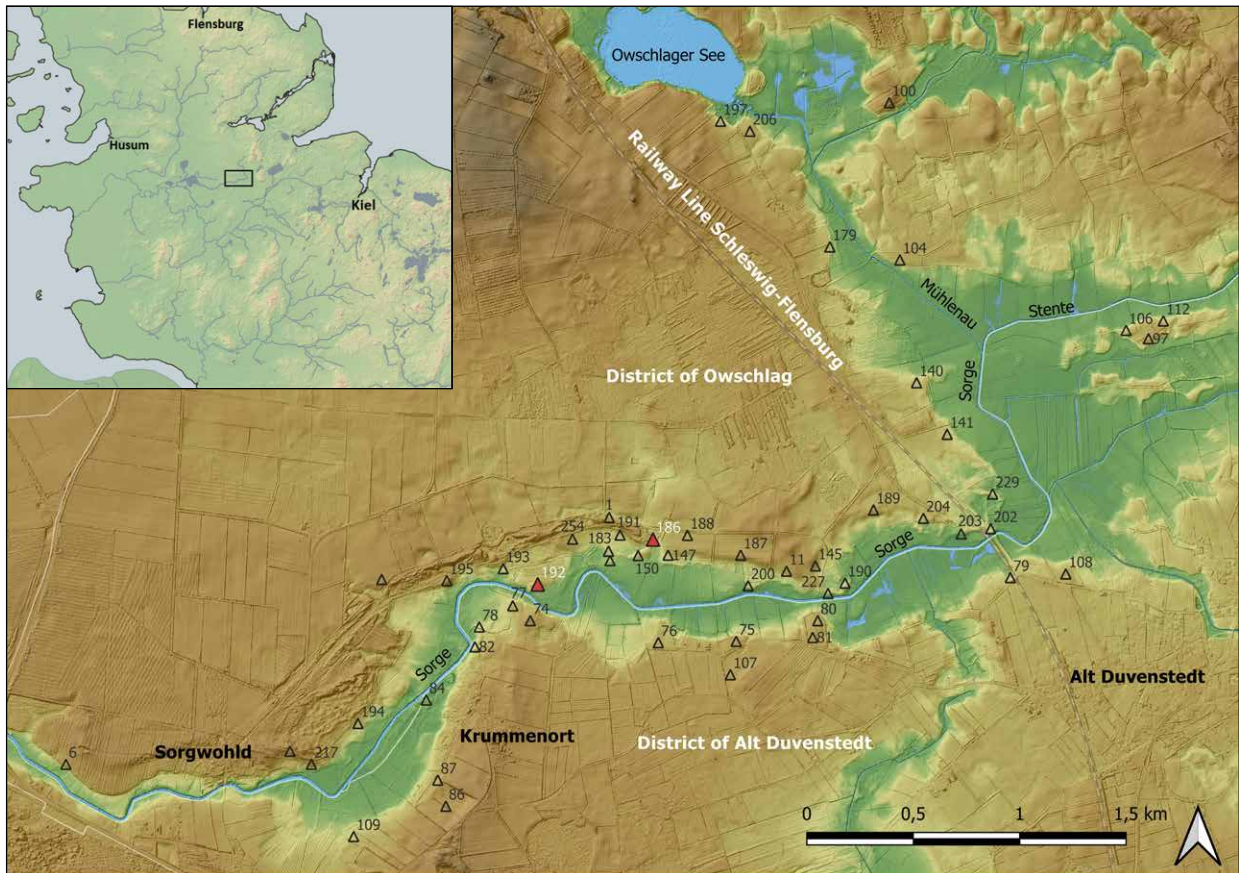


Figure 1: Lidar map with overview of Late Mesolithic sites in the Sorge valley (Rendsburg-Eckernförde district). The sites Owschlag LA 186 and Owschlag LA 192 are highlighted in red.

glacier advance), the eastern areas of the Sorge valley were exposed. The transport of loose mineral soil associated with the melting of the ice and its subsequent deposition in front of the inland glacier created the alluvial sand plains. The sand was altered by periglacial processes and exposed to strong wind erosion, which resulted in the establishment of aeolian sand and dunes that formed on both sides of the Sorge valley. During the Younger Dryas period, aeolian sands in this area covered a palaeo-soil of Usselo type containing archaeological sites from the Late Palaeolithic period (Kaiser and Clausen 2005). Additional soil surveys and their geological analysis also confirm extensive sand drifts during the Holocene even in modern times (Kaiser *et al.* 1989). The use and anthropogenic character of the middle Sorge valley and neighbouring bogs are determined by river straightening, drainage, peat extraction and ploughing until the 1970s. Today, the inland dunes between the villages Sorgwohld and Alt Duvenstedt and further west are among the most remarkable and important drifting sand landscapes of the glacial meltwater plain in Schleswig-Holstein. Large parts of it are now protected by law.

### Archaeological sites on the Sorge valley in the districts of Owschlag and Alt Duvenstedt

Between Lake Owschlag and the village of Sorgwohld, a total of 51 sites with Late Mesolithic artefacts are known in the Sorge valley (Fig. 1). Of these, 33 are located in the district of Owschlag and 18 in the district of Alt Duvenstedt. All assemblages are palimpsests. Some materials contain Late Palaeolithic diagnostic tool forms such as scrapers of Wehlen-type from Owschlag LA 186 and three backed (Federmesser) points from Owschlag LA 192. In addition, some assemblages include Neolithic finds, such as large round scrapers, bifacially retouched tools, axe rejuvenation flakes with polished facets and a fragment of a flint dagger.

The Mesolithic artefacts were made from homogeneous, glossy-grey Senon flint (from Baltic glacial deposits). Most of the raw material originated from the adjacent moraine area to the east and was transported from there to the sites. The finds look relatively fresh, with sharp edges, although some are showing surface remains of rust from contact with ploughs. The patina colour varies from light grey to blue-grey to various white-blue shades. Flint artefacts

Tool types	Owschlag LA 186 $\Sigma$ 100	Owschlag LA 192 $\Sigma$ 131
Microliths (incl. trapezes, rhombic points)	38/38%	52/36%
Transverse arrowheads	26/26%	10/7%
Core/flake axes	4/4%	11/8%
Core tools ( <i>Dreikanter</i> )	1/1%	/
Scrapers	20/20%	25/19%
Burins	3/3%	14/11%
Borers	1/1%	1/1%
Retouched flakes/blades	7/7%	18/14%
<b>Unretouched artefacts</b>	<b><math>\Sigma</math> 584</b>	<b><math>\Sigma</math> 1030</b>
Flakes >1cm <sup>2</sup>	300/51%	370/36%
Macro blades (incl. fragments)	147/25%	345/34%
Micro blades (incl. fragments)	22/4%	146/14%
Cores	15/3%	22/2%
Handle cores	/	2/<1%
Burin spalls	2/1%	6/1%
Microburins	/	3/<1%

Table 1: Owschlag LA 186 and LA192. Late Mesolithic assemblages from the Sorge valley. Number and percentage of artefact types.

from lower-lying areas also have a brownish-reddish bog patina. Two flint assemblages from Owschlag LA 186 and LA 192 are presented in more detail below. They are representatives of the rich Late Mesolithic settlement material from the Sorge valley.

The Owschlag LA 186 site (Fig. 1, red triangle) was discovered in the 1970s by Peter Worch from Bordesholm. He surveyed the site regularly and collected surface finds from the farmed fields until the end of the 1980s. The site is located on a hilltop north of the Sorge river at an elevation of approximately 5.5 metres above sea level. The hill is probably part of a crescent-shaped sand dune, and the surface finds were concentrated at its north-eastern end. Today the site is overgrown with dense bushes and trees and is bordered to the west by an artificial drainage ditch. The exact extent of the find distribution is unknown but based on the topography, it is unlikely that it extended over more than 5,000–6,000 m<sup>2</sup>. The assemblage consists of a total of 684 artefacts, of which 100 (17%) are formal tools.

The second site, Owschlag LA 192 (Fig. 1: red triangle), is located on a hilltop on light, very fine-grained aeolian sand. It was systematically surveyed by Peter Worch between 1970 and 1980. The site's elevation of c. 6 m above sea level seems modest but it nonetheless stands out prominently from the surrounding lowland. The finds were found scattered over an area of maximum 10,000 m<sup>2</sup>. In this part of the Sorge, the river valley is only 50 metres wide, which offers a narrow passage that is easy to cross. Only c. 200 metres downstream, the river turns south and the valley widens up to 250 metres. Since the 1980s, the area has been used as permanent pasture but recent

surveys at the site still reveal numerous patinated artefacts in molehills. Several other collectors surveyed the site at the same time as Worch, but unfortunately those materials have disappeared. The existing assemblage consists of a total of 1131 artefacts (Tab. 1), of which 131 (13%) are formal tools.

### Analysis of the artefact assemblages and tool spectrums

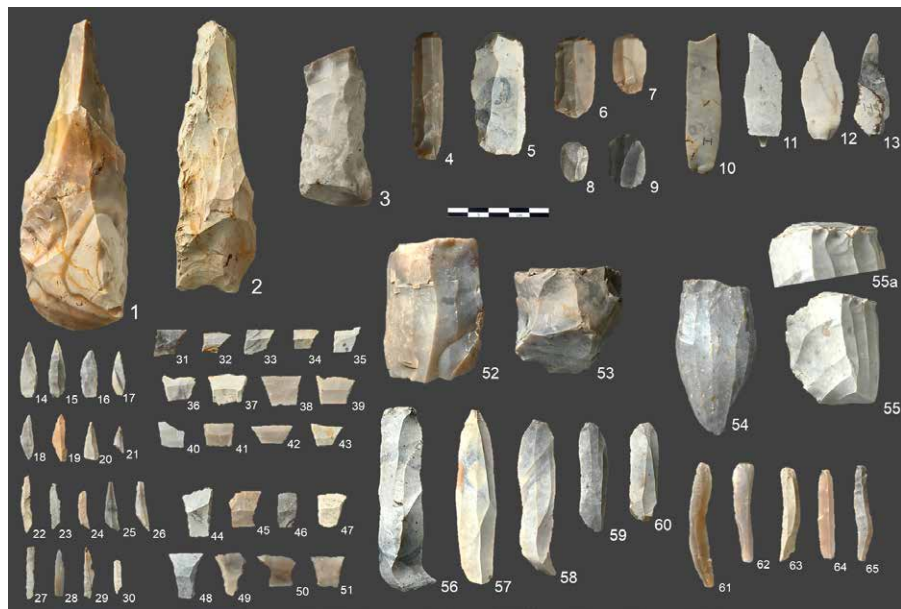
Owschlag LA 186 and Owschlag LA 192 were surveyed over several years by an experienced amateur archaeologist specialising in Stone Age flints, with a special interest in Mesolithic finds. However, when evaluating the assemblage and tool spectrums of surface finds, the question arises as to the representativeness of certain artefact groups. We assume that flakes and microflakes (preparation products) are underrepresented in absolute terms due to subjective preferences and their low attractiveness to collectors (Hinz 2014). In contrast, blades, cores, diagnostic waste products and, in particular, formal tools are the focus of collecting activities and are likely to be represented in the two find assemblages with representative frequencies.

The two Sorge assemblages are characterised by a number of common features. Firstly, it is striking that both microliths and blade tools dominate the tool classes. Scrapers (Figs. 2: 4–7; 3: 4–9) are particularly prominent among the blade tools, accounting for about 20% of the total tool number. The microliths include simple points (Fig. 3: 14–17), small backed knives (Fig. 3: 27–30), geometric types such as triangles (Figs. 2: 14–16; 3: 18–26) and symmetrical trapezes (Fig. 3: 36–43), as well as asymmetrical rhombic

Figure 2: Owschlag LA 186.  
 Flint artefacts. 1–3 Axes.  
 4–7 Scrapers. 8–10 Burins.  
 11–23 Microliths.  
 24–30 Transverse arrowheads.  
 31–35 Cores. 36–41 Macro  
 blades. 42–47 Micro blades.



Figure 3: Owschlag LA 192. Flint  
 artefacts. 1–3 Axes. 4–9 Scrapers.  
 10–13 Burins. 14–43 Microliths.  
 44–51 Transverse arrowheads.  
 52–55 Cores. 56–60 Macro  
 blades. 61–65 Micro blades.



(oblique) points (Figs. 2: 17–22; 3: 31–35). Symmetrical trapezes, rhombic points and small backed knives made from micro blades also occur at both sites. Trapezes and rhombic points were produced from thin and very slightly curved macro blades. The triangles consist of narrow, scalene and a few long, isosceles types. Transverse arrowheads occur in significant numbers although, according to Gehlen (2012), they should not be counted as microliths.

Previous publications on finds from the Sorge valley have already pointed out the low presence of large tools

(Bokelmann 1971; Clausen 1994; Hartz 1985). In addition, core axes dominate over flake axes at the two sites presented here. The relatively large core axes with a length exceeding 12 cm (Figs. 2: 1–2; 3: 1–2) are mostly roughly bifacially retouched. They have an irregular to triangular cross-section and a working edge created by a lateral stroke. With their partly flat ventral side they resemble flake axes, but they lack the trapezoidal shape and the characteristic ventral-dorsal edge retouching. Axes account for less than 10% of the total tool assemblage and the simple core tools (*Dreikanter*) are even rarer. The borers show a



Figure 4: 1 Owschlag site 55 (no LA-No). 2–3 Owschlag LA 140. 4 Alt Duvenstedt LA 75. 1–2 Microblade cores made from small circular nodules by a simple blow. 3 Exhausted microblade core made from flint debris with a prepared vertical ridge. 4 Long conical macroblade core.

very similar low percentage, indicating that they were not a part of the standard tool repertoire of hunter-gatherer groups in the Sorge valley. The burins were mainly made from solid, regular blades (Figs. 2: 8–10; 3: 10–13) and the only types represented are angle burins on a break and dihedral burins. However, in terms of blade technology, all burins clearly belong to the Mesolithic tool tradition and are no older admixtures.

Based on the number of blades, including the proximal fragments, it is possible to draw conclusions about lithic production methods. Blade production followed two concepts, each of which served the serial production of regular, largely parallel-sided products. The macro blade spectrum is characterised by prismatic, slightly curved specimens measuring between 4.0 and 8.5 cm in length and 1.3 and 2.0 cm in width (Figs. 2: 36–41; 3: 56–60). Most of these blades and larger fragments show a high degree of regularity and lateral parallelism. The butts are always unfaceted with no traces of impact cones. They are usually oval or slightly triangular in shape and carefully reduced or abraded, with only a few being ridge-shaped or broken. A distinct lip is formed on the ventral face between the diffuse bulb and the butt. After evaluating all diagnostic attributes and based on the lithic concepts for the southern Scandinavian Maglemose and Kongemose Cultures (David and Sørensen 2016; Sørensen 2006; 2012),

we assume that indirect soft percussion (punch technique) was applied used to produce the Sorge macro blades. The products also served as blanks for formal blade tools such as scrapers and burins.

Large complete macro blade cores are very rare, not only at the Sorge sites, but also at the settlements of the Kongemose Culture in southern Scandinavia (Fischer 1987). A unique example is an 11 cm long, conical core from the site Alt Duvenstedt LA 75 with a circular platform and elaborately prepared platform edge (Fig. 4: 4). It displays a series of regular blade removals. The assemblages from Owschlag LA 186 and Owschlag LA 192 contain predominantly single or multi-fronted cores with smooth or coarsely faceted platforms (Figs. 2: 31–32; 3: 52–53). The preparation of the platforms is so rough that it is not reflected on the blade butts. In rare cases, bidirectional cores with two opposing platforms and blade negatives also occur (Fig. 2: 33).

There is yet another interesting feature within the core assemblages, which also appears on other sites in the Sorge valley. These are small cores with only one platform, from which micro blades with a width of up to 8 mm and a length of 20 to 30 mm were removed. These cores were produced from one of two starting nodules. The first option was a flint nodule, only slightly larger than a golf ball, which was cut off with a simple blow (Fig. 4: 1–2). The micro blades

were then removed from the cut-off, which served as a platform. The second option for the starting nodule was small fragments of flint debris or frost flakes (Figs. 2: 33–35; 4: 3), from which blades were produced according to the same principle. A vertical ridge can be seen several times on the back of these cores (as highlighted in Fig. 4: 3). This ridge was possibly deliberately retouched in order to fix the core in a V-shaped holding or similar clamping device for removing the blades by pressure technique in a controlled manner (Sørensen 2006).

In addition, some of the small cores display fine cracks at the base of the core. This could further indicate that the core was supported distally and placed on a hard surface during blade removals. Those small core types, made from frost flakes or flint debris, have been observed several times at the Sorge sites, as well as in the Bordesholm LA 11 assemblage (unpublished) and in Late Mesolithic assemblages in northern Lower Saxony (Gerken 2001 and pers. comm.).

Micro blades (lamellae) are found in varying numbers at Owschlag LA 186 and Owschlag LA 192. However, some of these are not actual blades, but rather incidental byproducts from the platform rejuvenation of macro blade cores. These pieces are relatively broad at the proximal end, usually having only one central ridge and a pointed terminal end (Fig. 2: 46–47). In contrast, the complete lamellae from handle cores are longer than platform rejuvenation products, furthermore they are parallel, mostly straight or only slightly curved at the distal end (Figs. 2: 42–45; 3: 61–65). A single or two parallel ridges are usually formed on the dorsal face. The butts of the micro blades are often irregular in shape, with some also having a punctiform or lens-like appearance. This suggests a specialisation in striking technique, in which the micro blades were removed by pressure technique (David and Sørensen 2016; Sørensen 2012). Several specimens have larger parts of the cortex or a chalky surface remaining. It seems that flintknappers used flint nodules of up to fist-size as a starting point. The low occurrence of handle cores in Table 1 indicated that this concept was scarcely used at the Sorge sites.

### **Relative chronology of the finds from the Sorge valley**

In the late Boreal and early Atlantic periods, the hunter-fisher societies of the late Maglemose Culture (c. 7500–6700 cal BCE) and Kongemose Culture (c. 6700–5500 cal BCE) were widespread on the Cimbrian Peninsula and in northern Mecklenburg-Western Pomerania. In contrast to Denmark and southern Sweden (Astrup 2018; Dencker and Dokkedal 2004; Fischer 1987; Larsson 2017), no submerged coastal sites from the Kongemose period are currently known in northern Germany. Due to the limited data, the general term *Trapezemesolithic* has also

been proposed for this period on the southern Cimbrian Peninsula (Hartz 2009), based on the characteristics of the trapezes and their variants, the rhombic points. Triangles and other microliths gradually lost importance in this area until they finally disappeared in the Terminal Mesolithic around 5500/5600 cal BCE.

In terms of the relative chronology of the Sorge assemblages, microliths and blade technology are the most informative. The exception is simple points, which, like blade tools, are not chronologically significant due to their long duration during the Mesolithic. Large tools like axes and simple core tools (*Dreikanter*) exist only in small numbers and are not significant in terms of their informative value. They can therefore be disregarded for the following discussion. Typical Late Mesolithic microliths occur both at Owschlag LA 186 and at Owschlag LA 192, including symmetrical trapezes, asymmetrical rhombic points, small backed knives, scalene triangles and slender lancet points (Gerken 2001; Hartz 2009; Lübke 2000). The asymmetrical rhombic points in both assemblages are probably indicators of a terminal phase of the Late Mesolithic in Schleswig-Holstein (Hartz 2009).

In north-eastern Jutland, eastern Denmark and southern Sweden, the Kongemose Culture is characterised by an advanced macro blade technology compared to the late Maglemose Culture. The blades become longer and wider on average (Sørensen 2012; Terberger 2006). Among the organic tools, this technological advance is represented by long and strongly curved punches (Sørensen 1996). On average, micro blades of this period are shorter than in the late Maglemose Culture. They were produced using pressure technique from elongated single fronted handle cores, or occasionally on thick flake blanks (Callahan 1985; David and Sørensen 2016; Petersen 1984; 1993; Söderlind 2024; Sørensen 2012). In Schleswig-Holstein, an elaborate blade technology with very long (>10 cm) and regular macro blades has been detected only at a few excavated sites, such as Seedorf LA 296, Satrup LA 2 and Rude LA 2, where they are always associated with finds of trapezes (Bokelmann 1999; Briel and Hartz 2020; Feulner 2010).

The most impressive finds from the Kongemose period come from the sites Stoltenberg LA 10 (Plön district) (Bokelmann 1999; Lage 2014) as well as from Owschlag LA 186 and LA 192, where a wide range of trapezes and macro- and micro blades have been found. Possibly, the access of high-quality raw materials played a major role in the production of long prismatic macro blades.

Based on both the microliths and the dual blade concept, the two assemblages discussed here can be attributed to the Late Mesolithic *Trapezemesolithic* in Schleswig-Holstein. However, due to a lack of absolute data, it is only possible to date them relatively to the first half of the Atlantic period between 6700 and 5500 cal BCE. However, this chronological uncertainty can be narrowed down with

Seedorf LA 296	Sample-no.	material	dates BP	dates cal BCE (2-sigma range)
punch	KIA-273	antler	7380 ± 120	6360–6100
wood	KI-3930	charcoal	7360 ± 65	6320–6120
ornamented axe	KIA-266	antler	7220 ± 40	6150–6030
axe	KIA-267	antler	7190 ± 70	6150–5990
animal bone (deer)	KIA-4479	bone	7150 ± 75	6080–5920
axe	KIA-263	antler	7130 ± 50	6040–5920
point	KIA-274	bone	7070 ± 60	5990–5870
ornamented axe	KIA-264	antler	7020 ± 120	6000–5780
axe	KIA-265	antler	6960 ± 40	5880–5780
animal bone (aurochs)	OxA-4480	bone	6925 ± 70	5880–5740
harpoon head (deer)	KIA-272	antler	6880 ± 40	5800–5720
ornamented bone (wild boar)	OxA-6583	bone	6735 ± 65	5700–5580

Table 2: Seedorf LA 296, Segeberg district. Radiocarbon data from charcoal, animal bones and bone and antler tools from the early (*Trapezemesolithic*) settlement phase. The calibration was conducted with the program Calpal ([www.calpal.de](http://www.calpal.de)) and the calibration curve INTCAL98 (Stuiver *et al.* 1998).

the help of data and comparisons with the two <sup>14</sup>C-dated sites Seedorf LA 296 (Segeberg district) (Bokelmann 1999) and Jäckelberg-Huk (Poel-Neuburg 45) (Lübke 2005). These two find assemblages are also characterised by core axes, long and slender blade tools (scrapers, burins), various small and broad trapezes and a few triangles. There are also similarities in lithic blade technology from the Sorge assemblages, for example, in the presence of long prismatic macro blades and the occurrence of micro blade cores and complementary pieces. The <sup>14</sup>C dates from the two sites fall roughly within the period 6400–5600 cal BCE (Lübke 2005 and Table 2), thus narrowing down the period of Late Mesolithic settlements in the Sorge valley.

The Sorge sites should be understood alongside various other find spots and (surface) collections from Schleswig-Holstein, like the sites Stoltenberg LA 10 (Plön district), Dreggers LA 6, Nahe LA 1/2, Wakendorf II LA 2 and LA 27, Pronstorf site V, Wensin LA 32 (all Segeberg district) and Bordesholm LA 11 (Rendsburg-Eckernförde district) (Hartz 2009). It cannot be ruled out that the asymmetrical rhombic points and the transverse arrowheads from Owschlag LA 186 and Owschlag LA 192 represent influences from the very late *Trapezemesolithic* or early Terminal Mesolithic period around 5500 cal BCE. In fact, in eastern Schleswig-Holstein, regular transverse arrowheads are already part of the standard repertoire on coastal aceramic Ertebølle sites (Goldhammer and Hartz 2013). The charcoal date of 5960 ± 80 BP (KI-2351, 5215–4546 cal BCE) from a hearth at the Owschlag LA 200 site (Clausen 1994) suggests that the occupation in the Sorge valley was not completed in the middle Atlantic period.

## Regional context and function of the Sorge sites

The wetlands of the Sorge valley belong to a group of Late Mesolithic settlement hotspots in Schleswig-Holstein. These are located both in river valleys and on large open lakes or bogs (Fig. 5). A high settlement density can be observed for example, on the upper Alster valley (Groß and Hartz 2013; Péntek and Faragó 2021), on the middle Trave valley (Groß and Lübke 2019; Hadenfeldt 1936), at Dosenmoor peatbog (Hartz and Goldhammer 2015) and inside Kreuzau valley (Hartz and Harten 2024). In the Late Mesolithic period, the Satrupholm peatbog and Bondenau valley in the historical landscape of Angeln (Briel and Hartz 2020; Feulner 2010; Schwabedissen 1957/58), the ‘Altes Moor’ or Boksee peatbog (Läufer 1934; Thon 1937; Tillmann 1986) and the upper Trave valley (Bokelmann 1999) were also densely populated. In addition, there are notable sites at Lake Selent and Schwentine valley at Lake Warder and along the courses of the Schwartau, Stecknitz and Bille valleys.

What could have made the Sorge lowlands so attractive to Late Mesolithic hunter-gatherer groups? The raw material situation can be ruled out, because high quality flint was not available on the river terraces formed by wind-blown and alluvial sands. Those flints had to be imported to the sites from the adjacent moraine areas in the east. Based on the presence of finds, it seems likely that not all domestic activities were carried out at most Sorge sites at that time. The very low occurrence of axes and borers, as well as the limited range of microlithic points, suggest a specialised



Figure 5: Distribution of Late Mesolithic settlement Hotspots Schleswig-Holstein. The Hotspot in the Sorge valley is highlighted in orange.

spectrum of activity. Apparently, axes were not needed in large quantities for cutting trees for stable huts or for the manufacture of dugout canoes. The number of points at most sites is not particularly high compared to other Late Mesolithic settlement hotspots (e.g. upper Alster valley, Lake Warder, Lake Selent, Dosenmoor peatbog). From this, one could conclude that big game hunting in the forest was not a priority. We propose that the focus of the local activities was on acquiring aquatic food resources as well as hunting waterfowl and fur-bearing animals, such as beavers, near the water, as has been suggested for hunter-gatherer groups of the Late Palaeolithic, based on animal bone remains (Clausen 1996). The river could be deliberately blocked at its natural narrow points using fishing systems such as nets and weirs, as suggested by the rows of poles on the upper Alster valley near Naherfurt (Kayhude LA 8, Segeberg district) (Clausen 2008).

At some Sorge sites, the finds cover an area of over 40,000 m<sup>2</sup>. However, given this size, they should probably not be interpreted as the remains of permanent base camps. It is more likely that the river valley was a commonly used activity area as part of a larger territory. It is conceivable that the artefact patterns are an expression of temporary, seasonal campsites that reflect a variety of functions. An example of this is the ephemeral hazelnut roasting stations in the Duvensee peatbog (Bokelmann

*et al.* 1981; Groß *et al.* 2018; Holst 2010). However, when aspects of food procurement are discussed, only very little evidence can be found in flint assemblages, especially from surface collection sites. However, the extremely high density of sites and finds in the Sorge river valley may have specific reasons that cannot be found solely in the topography or the fast transport routes on the watercourse. Further insights and a more distinct picture of the life of the Late Mesolithic communities can only be gained if information about organic tools and food remains is also available. More archaeological and scientific research is needed, and strongly encouraged, to further our understanding of the high-potential, and densely populated, lowland areas of the upper and middle Sorge valley.

### Acknowledgements

The authors would like to thank Ringo Kloöß (Archaeological State Service Schleswig) and the family members of Peter Worch (Bordesholm) and Klaus Joachim Sievers (Rickert) for practical assistance and the access to the find materials and documents. Furthermore, we express our gratitude to two anonymous reviewers for their critical and inspiring comments and suggestions which are highly appreciated. The corrections to our English version have certainly improved the text.

## References

- Astrup, P. M. 2018. *Sea-level change in Mesolithic southern Scandinavia: long- and short-term effects on society and the environment*. Jysk Arkæologisk Selskabs Skrifter 106. Aarhus, Aarhus University Press.
- Bokelmann, K. 1971. Zwei mesolithische Fundplätze im Kr. Rendsburg-Eckernförde. *Offa* 28, 88.
- Bokelmann K., Averdick F.-R., Willkomm H. 1981. Duvensee, Wohnplatz 8 – Neue Aspekte zur Sammelwirtschaft im frühen Mesolithikum. *Offa* 38, 21–40.
- Bokelmann, K. 1999. Zum Beginn des Spätmesolithikums in Südsandinavien. *Geweihtaxt, Dreieck und Trapez*, 6100 cal. BC. *Offa* 56, 183–192.
- Briel, M. and Hartz, S. 2020. Hunters and Fishermen at the ‚Satrupholmer Moor‘: a Late Mesolithic stratified site in Northern Germany. In: Zander, A., Gehlen, B., and Schön, W. (eds.), *From the Early Preboreal to the Subboreal period – Current Mesolithic research in Europe, Studies in Honour of Bernhard Gramsch*. Kerpen-Loogh, Welt und Erde, 131–149.
- Callahan, E. 1985. Experiments with Danish Mesolithic Microblade Technology. *Journal of Danish Archaeology* 4, 23–39.
- Clausen, I. and Hartz, S. 1988. Fundplätze des Spätglazials am Sorgetal bei Alt Duvenstedt, Kreis Rendsburg-Eckernförde. *Offa* 45, 17–41.
- Clausen, I. 1994. Alt Duvenstedt und Owschlag, Kr. Rendsburg-Eckernförde. Zwei mesolithische Wohnplätze, LA 78 und 200. *Zehnter Arbeitsbericht des Landesamtes für Vor- u. Frühgeschichte Schleswig-Holstein 1988-1993*. *Offa* 51, 192–202.
- Clausen, I. 1995. Alt-Duvenstedt, Kreis Rendsburg-Eckernförde, LA 121. Ein Ahrensburger Kulturvorkommen im alleröd-zeitlichen Boden. *Archäologische Nachrichten aus Schleswig-Holstein* 6, 103–126.
- Clausen, I., 1996. Alt Duvenstedt LA 121, Schleswig-Holstein. Occurrence of the Ahrensburgian culture in soils of the Alleröd Interstadial: A preliminary report. In: Larsson, L. (ed.), *The earliest settlement of Scandinavia and its relationship with neighbouring areas*. Acta Archaeologica Lundensia 24. Lund, Almqvist & Wiksell International, 99–110.
- Clausen, I. 2008. Von späten Jägern und frühen Bauern... Binnenländische Ertebøllekultur bei Kayhude, Kreis Segeberg. *Archäologische Nachrichten aus Schleswig-Holstein* 14, 14–16.
- David, E. and Sørensen, M. 2016. First insights into the Identification of Bone and Antler Tools used in the Indirekt Percussion and Pressure Techniques during the Early Postglacial. *Quaternary International* 423, 123–142.
- Dencker, J. and Dokkedal, L. 2004. Marinarkæologiske forundersøgelser ved Amager Strandpark. *NMU j. nr. 2322 og Italiensvej NMU j. nr. 2323*. Roskilde, Vikingeskibsmuseet.
- Feulner, F. 2010. Die spätmesolithischen und früheolithischen Fundplätze im Satrupholmer Moor, Kreis Schleswig-Flensburg. Rekonstruktion einer Siedlungskammer. Dissertation. Kiel, Christian-Albrechts-Universität zu Kiel.
- Fischer, A. 1987. Stenalderbopladsen på Argusgrunden. Fortidsminder og kulturhistorie, *Antikvariske studier* 8, 11–58.
- Gehlen, B. 2012. Mesolithische Silexwerkzeuge in Mitteleuropa. In: Floss, H. (ed.), *Steinartefakte. Vom Altpaläolithikum bis in die Neuzeit*. Tübingen Publications in Prehistory. Tübingen, Kerns Verlag, 581–598.
- Gerken, K. 2001. *Studien zur jung- und spätpaläolithischen sowie mesolithischen Besiedlung im Gebiet zwischen Wümme und Oste*. Archäologische Berichte des Landkreises Rotenburg (Wümme) 9. Oldenburg, Issensee Verlag.
- Goldhammer, J. and Hartz, S. 2013. Versunkene Steinzeit – Endmesolithische Funde aus der Ostsee vor der Steilküste von Stohl. *Jahrbuch der Heimatgemeinschaft Eckernförde* 71, 1–12.
- Groß, D. and Hartz, S. 2013. Kleine Steine ganz groß, mittelsteinzeitliche Siedlungsspuren auf dem „Germanenacker“ an der Oberalster bei Wakendorf II. *Archäologische Nachrichten aus Schleswig-Holstein* 19, 20–24.
- Groß, D., Lübke, H., Schmölcke U. and Zanon, M. 2018. Early Mesolithic activities at ancient Lake Duvensee, northern Germany. *The Holocene* 29(2), 197–208.
- Groß, D. and Lübke, H. 2019. Das obere und mittlere Travetal – Eine mesolithische Fundlandschaft in Holstein. Norddeutschland. In: Baales, M. and Pasda, C. (eds.), *All der holden Hügel ist keiner mir fremd... Festschrift zum 65. Geburtstag von Claus-Joachim Kind*. Universitätsforschungen zur prähistorischen Archäologie 327. Bonn, Dr. Rudolf Habelt, 485–499.
- Hadenfeldt, M. 1936. Unbekannte Travefunde. *Die Heimat – Monatsschrift des Vereins zur Pflege der Natur- und Landeskunde in Nordelbingen* 46, 294–300.
- Hartz, S. 1985. Kongemosekultur in Schleswig-Holstein? *Offa* 42, 35–56.
- Hartz, S. 2009. Towards a new Chronology of the Late Mesolithic in Schleswig-Holstein. In: Crombé, P. H., van Strydonck, M., Sergeant, J., Boudin, M. and Bats, M. (eds.), *Chronology and Evolution within the Mesolithic of North-West Europe. Proceedings of an International Meeting, Brussels, May 30th-June 1st. 2007*. Newcastle upon Tyne, Cambridge Scholars Publishing, 395–415.
- Hartz, S. and Goldhammer, J. 2015. Steinzeit im Moor. Das Dosenmoor bei Einfeld, ein Hochmoor und seine

- Besiedlungsgeschichte. *Archäologische Nachrichten aus Schleswig-Holstein* 21, 26–31.
- Hartz, S. and Harten, L. 2024. Die Kreuzau - ein Siedlungshotspot des Mesolithikums im Norden Schleswig-Holsteins. *Archäologische Nachrichten aus Schleswig-Holstein* 30, 6–11.
- Hinz, M. 2014. *Neolithische Siedlungsstrukturen im südöstlichen Schleswig-Holstein*. Frühe Monumentalität und soziale Differenzierung 3. Bonn, Dr. Rudolf Habelt.
- Dynamik in Landschaft und Besiedlung*. Frühe Monumentalität und soziale Differenzierung 3. Bonn, Dr. Rudolf Habelt.
- Holst, D. 2010. Hazelnut economy of early Holocene Hunter-Gatherers: A case study from Mesolithic Duvensee, Northern Germany. *Journal of Archaeological Science* 37(11), 2871–2880.
- Kaiser, K., Walther, M. and Mühmel-Horn, H.-P. 1989. Spätglaziale und holozäne Dünen im Rendsburger Staatsforst beiderseits des mittleren Sorgetales zwischen Tetenhäusen/Fährden und Krummenort (Schleswig-Holstein). *Meyniana* 41, 97–152.
- Kaiser, K. and Clausen, I. 2005. Palaeopedology and stratigraphy of the late palaeolithic Alt Duvenstedt site, Schleswig-Holstein (Northwest Germany). *Archäologisches Korrespondenzblatt* 35(4), 447–466.
- Larsson, L. 2017. Submarine Settlement in the Öresund, Western Scania, Southernmost Sweden. In: Bailey, G. N. and Sakellariou, D. (eds.), *Under the Sea: Archaeology and Palaeolandscapes of the Continental Shelf*. Coastal Research Library 20. Cham, Springer, 165–175.
- Lage, W. 2014. *Fahrens Vor- und Frühgeschichte. Chronik der Gemeinde Fahren*. Unpublished manuscript.
- Läufer, A. 1934. Steinzeitsiedlung „Boksee“. *Die Heimat* 44, 9–13.
- Lübke, H. 2000. *Die steinzeitlichen Fundplätze Bebensee LA 26 und LA 76, Kreis Segeberg. Die Steinartefakte. Technologisch ergologische Studien zum Nordischen Frühneolithikum*. Untersuchungen und Materialien zur Steinzeit in Schleswig-Holstein 3. Neumünster, Wachholtz-Verlag.
- Lübke, H. 2005. Spät- und endmesolithische Küstensiedlungsplätze in der Wismarbucht. Neue Grabungsergebnisse zur Chronologie und Siedlungsweise. *Bodendenkmalpflege in Mecklenburg-Vorpommern* 52, 2004 (2005), 83–110.
- Péntek, A. and Faragó, N. 2020. Chipped stone assemblages from Schleswig-Holstein (North Germany) in the collection of the Institute of Archaeological Sciences – ELTE Eötvös Loránd University Bence. *Dissertationes Archaeologicae ex Instituto Archaeologico Universitatis de Rolando Eötvös nominatae Ser. 3*, 8, 21–47.
- Petersen, P. V. 1984. Chronological and Regional Variation in the Late Mesolithic of Eastern Denmark. *Journal of Danish Archaeology* 3, 7–18.
- Petersen, P. V. 1993. *Flint fra Danmarks Oldtid*. København, Høst.
- Reuter, T. 2023. *The Social Significance of Technology in Hunter-Gatherer Communities: An Exploration of Lithic Manufacturing during the Lateglacial in Northern Europe*. Dissertation. Kiel, Christian-Albrechts-Universität zu Kiel.
- Schwabedissen, H. 1957/58. Die Ausgrabungen im Satruper Moor. *Offa* 16, 5–28.
- Stuiver, M., Reimer, P. J., Bard, E., Beck, J. W., Burr, G. S., Hughen, K. A., Kromer, B., McCormac, G., van der Plicht, J. and Spurk, M. 1998. INTCAL98, Radiocarbon Age Calibration, 24,000-0 cal. BC. *Radiocarbon* 40(3), 1041–1083.
- Söderlind, S. 2024. *The Handle Core Concept. Lithic Technology and Knowledge Transmission in Mesolithic Northern Europe*. Roots Studies 6. Leiden, Sidestone Press.
- Sørensen, M. 2006. Rethinking the lithic blade definition: towards a dynamic understanding. In: J. Apel and K. Knutsson (eds.), *Skilled Production and Social Reproduction. Aspects of Traditional Stone-Tool Technologies. Proceedings of a Symposium in Uppsala, August 20-24, 2003*. SAU Stone Studies 2. Uppsala, Societas Archaeologica Upsaliensis, 277–296.
- Sørensen, M. 2012. The Arrival and Development of Pressure Blade Technology in Southern Scandinavia. In: Desrosiers, P. M. (ed.), *The Emergence of Pressure Blade Making: From Origin to Modern Experimentation*. New York, Springer, 237–259.
- Sørensen, S. A. 1996. *Kongemosekulturen i Sydskandinavien*. Nordiske Fortidsminder Serie B 27, 2017. Jægerpris, Egnsmuseum Færggården.
- Terberger, T. 2006. The Mesolithic Hunter-Fisher-Gatherers on the Northern German Plain. In: Hansen, K. M. and Pedersen, K. B. (eds.), *Across the western Baltic*. Vordingborg, Sydsjællands Museum, 111–184.
- Thon, C. 1937. Die Umgebung des „Alten Moorsees“ im Spiegel der Vorgeschichte. *Die Heimat* 47, 264–270.
- Tillmann, A. 1986. *Boksee 1A (Schleswig-Holstein): Ein mesolithischer Fundplatz an der Wende Boreal/ Atlantikum*. BAR International Series 280. Oxford, BAR Publishing.

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# Engravings, decorations and feathers

Aesthetics at two sites in  
a Late Mesolithic perspective

Lars Larsson

## Abstract

The two sites Skateholm I and Skateholm II in southernmost Sweden, dated to a late part of the Mesolithic (5200–4900 cal BCE), include graves as well as occupation layers. On both sites, ornamented objects have been found, made mainly of bone and antler. These objects are presented, along with finds that may relate in one way or another to a broadened perspective regarding ornamentation. This includes not only engravings on objects but also finds that can provide information on decoration with animal parts, ranging from large antlers to small fragments of feathers.

*Keywords: Southern Sweden, Late Mesolithic, decorated objects, grave finds, settlement finds*

## Introduction

The intention is to present objects and phenomena relating to ornamentation and decoration, which constitute an aspect of the Late Mesolithic society that has left its traces at the two sites Skateholm I and Skateholm II, southernmost Sweden. Remains of ornamentation or decoration have been found both in graves and at the settlements. Here, the terms *ornamentation* and *decoration* refer to a wide insight into various aesthetics as well as symbolic expressions.

The sites Skateholm I and Skateholm II date to a late part of the Mesolithic, 5200–4900 cal BCE (Larsson 1988; 1989; 2016). On both sites, there are graves as well as settlement remains. Skateholm II, which – despite the designation – is the older of the two sites, lies on a long, narrow elevation that was a small island at the time of settlement. Skateholm I, located about 200 m to the west, lies on the southern slope of a larger elevation that was likewise an island in the lagoon – a waterbody that was growing larger through shore displacement. This change in the shoreline was the reason why one of the settlements was abandoned for relocation to the higher one. Skateholm II, with 22 graves, has a smaller settlement area compared to Skateholm I, where 65 graves have been found, along with an occupation layer about three times larger. Considering the difference in the extent of the sites, one would expect significantly fewer finds of objects provided with ornaments on the smaller site, especially as the number of excavated areas is significantly smaller on Skateholm II compared to Skateholm I. This is true with regard to the number of finds in the occupation layer, but not with regard to the finds in the graves. To distinguish between the graves of the two sites, those of Skateholm I are numbered with Arabic numerals and those of Skateholm II with Roman numerals.



Figure 1: A. Harpoon from grave IV with ornamentation on the narrow sides of the barbs; B. Bone needle from grave X with a head resembling an animal head; C. Bone point from grave XII with groups of short strokes; D. Fragment of a slotted dagger from grave IV with ornamentation in the form of short strokes at right angles to the edges. Drawings by Eva Koch, scale 1:1.

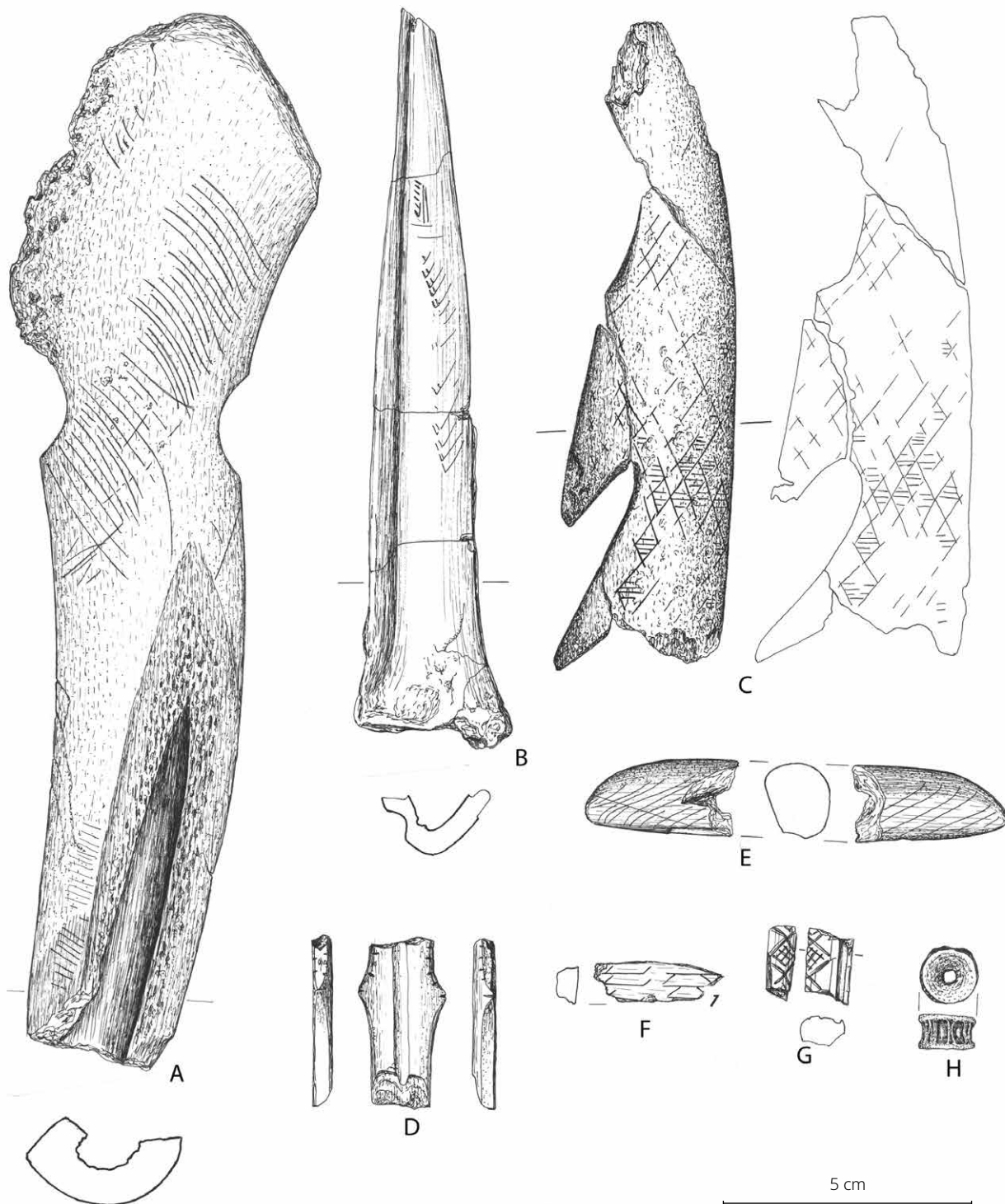


Figure 2: A. Antler axe from grave 22 with parallel lines and crosshatching; B. Bone point with groups of F-shaped engravings; C. Fragment of a harpoon with crosshatching; D. Fragmented bone object from grave II with series of short incisions and plastic ornamentation; E. small bone fragment with parallel strokes; F-G: small bone fragments with ornamentation; H. Fish vertebra with perforation. B-C, E-H from the occupation layers at Skateholm I. Drawings by Eva Koch, scale 1:1.

## Finds in the graves

From the graves within Skateholm II, there are four with ornamented objects. Grave IV includes two decorated pieces. One is a harpoon with a length of about 30 cm, probably made of deer antler. The object is slightly damaged due to the influence of moles. Ornamentation is present on the flattened narrow sides of the barbs (Fig. 1A) and take the form of intersecting diagonal lines. Short lines have also been incised along both edges higher up on the narrow sides. No ornamentation occurs on the broad sides of the barbs.

The second item is a 12 cm long fragment of a slotted dagger. Due to the destruction caused by mole-digging, only a portion of the lower part of the handle and the top part of the blade is preserved. Ornamentation in the form of a row of short strokes at right angles to the edges is visible on one side (Fig. 1D).

Double grave XII, with two small children placed in a sitting position, includes a bone point fashioned from a tubular bone (Fig. 1C). The entire surface has been the subject of careful smoothing after the initial shaping. The shaping has given the point an almost triangular cross-section. The object is somewhat fragmentary. Its original length was about 23 cm. Decoration is visible in the form of groups of short strokes along the ridge formed by grinding. Altogether, eleven strokes can be discerned, in four separated groups.

During the excavation of grave II, that of a male placed in a sitting position, a smaller bone object was found that had somehow been fixed to the forehead of the buried person (Fig. 2D). This object, with a length of 3.5 cm, is symmetrically shaped, with well-polished lateral faces. Both ends, however, display distinct fractures. The degree of patination shows that the fractures occurred prior to deposition in the grave. Each of the lateral faces has a small projection, both of these being placed approximately halfway along the length of the object. The edges on both sides of each lateral face are furnished with a series of short incisions, starting from the tip of each projection and continuing up to the fractured end. The object is fashioned from a large tubular bone, whose convex interior may still be discerned on one side. This is the only object that exhibits both incised and plastic ornamentation. This is evidently a fragment of a larger object, but its original shape is unclear. It might have been a kind of bone knife, where the ledge marks the area between the handle and the blade. The fact that it was found on the forehead indicates that the object had a special significance for the buried person, even in a fragmentary state. This object is the only one found on the forehead.

The largest object provided with ornamentation is a hammer, 35 cm in length, made of a shed red deer antler, which was found with a dog burial, grave XXI (Fig. 3). Decoration is present both on the head and on the handle.

This takes two forms, each in its own section – one on the head and the other on the handle. The ornamentation on the handle consists of two rows of short strokes. These are arranged at right angles to the ridge on one side, whereas the upper row on the opposite side is somewhat oblique. These two rows almost conjoin towards the end of the handle. The decorated area on the head section features long, forcefully incised lines, which form rhombuses of varying sizes. These lines can be difficult to follow in their entire length, due to the weathered condition of the surface. Extremely weak traces of fine lines occur within certain parts of the rhombic figures.

Double grave X was intended for two men, one person lying in a supine position and one in a sitting position. The latter had a broad bone needle, almost 14 cm in length, that lay across the skull. Considering its placement, the object has been perceived as a form of hair decoration. The main section is obliquely angled and also has a perforation (Fig. 1B). This design may have had a practical function, but it also has similarities to an animal's head, where the perforation corresponds to the position of the eye (Larsson 2017).

From the graves within Skateholm I, there are few ornamented objects of bone and antler in proportion to the number of burials. Grave 22, that of a man, yielded an antler shaft-hole axe, 23 cm in length, found inserted under the left upper arm (Fig. 2B). A section below the shaft hole has been provided with ornamentation in the form of parallel lines, curved at the top, which run diagonally in relation to the long axis of the object. The surface of the opposite side is more degraded. However, there are a few traces indicating a similar form of engraving. Further down, in connection with the design of the edge, a number of short parallel lines can be distinguished. On the opposite side there is an area of crosshatching.

The difference in the number of decorated objects in graves between Skateholm II and Skateholm I can be related to a trend observed in Western Denmark, where the number of decorated objects decreased towards the end of the Mesolithic (Andersen 2023a).

The decoration includes not only tools and utensils but also personal ornaments. Women as well as men were provided with tooth beads from red deer, wild boar, elk, aurochs, porpoise and wolf. Several of the buried individuals have been given some form of tooth bead decoration. The women have several beads in one or two rows around the hip. This likewise occurs with buried males, but they also have tooth beads across and around their heads and on other parts of the body (Larsson 2024a; 2024b).

Roe deer do not appear in the form of tooth beads, but in two graves the hooves of this hunted animal were found attached to the person's trunk. In another grave, a marten skull was found, as well as vertebrae of porpoises, attached to the elbow on either side.



Figure 3: Antler hammer from dog grave XXI with various forms of ornamentation. Drawing by Eva Koch.

### Finds in the occupation layer

No ornamented objects were found in the occupation layer of Skateholm II, which could be due to the small extent of the excavation area. From the occupation layer of Skateholm I, there are some bone and antler objects with ornamentation. An object of particular interest is a 13 cm long fragment of a harpoon (Fig. 2C). That it previously had a completely different function is shown by the fact that significant parts

of the surface are provided with ornamentation consisting of cross-cutting lines that formed rhombic fields. These have been filled with parallel rows of transverse lines. This ornamentation is interrupted by the reshaping of the object into a harpoon. It is therefore a part of another object. Considering the shape and ornamentation, it might have been an antler axe or more probably a longer section of antler with shaft holes (Płonka 2003). The latter form of object is



Figure 4: A. Tubular bone with a range of ornaments; B. Fragment of a tubular bone with a perforation and crosshatching; C. Fragment of an antler with a perforation and crosshatching; D. Fragment of a grindstone with ornaments; E-F. Perforated amber pieces; G-H. Pottery of Ertebølle type with imprints. Drawings by Eva Koch.

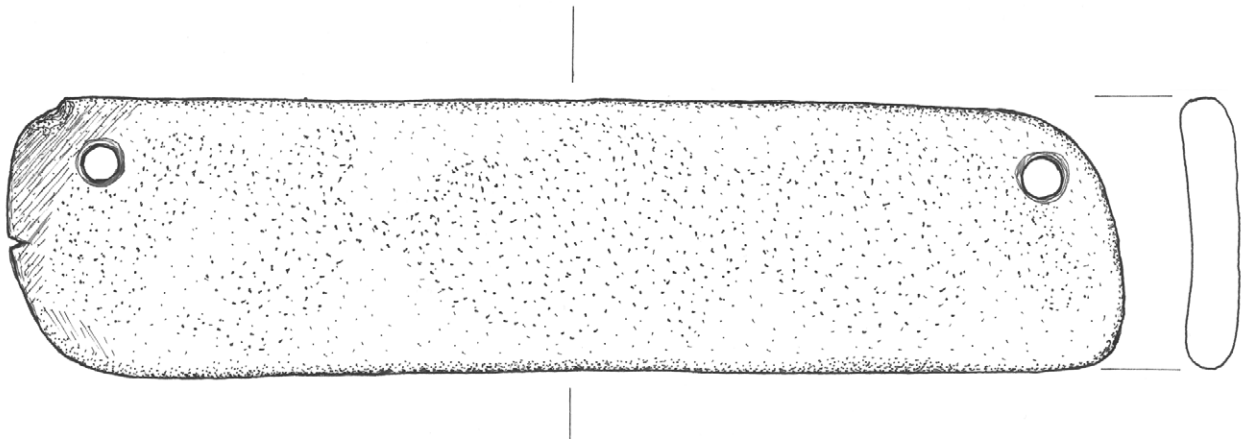


Figure 5: Slate plate found as a neck ornament in Grave XXII. Drawing by Eva Koch.

of unknown function, but considering the long and rather uneven design, these pieces were probably used in ritual acts.

The ornamentation has partially disappeared, and because the surface is poorly preserved, it is not possible to determine whether the ornamentation has been obliterated due to the poor degree of preservation, wear and tear from heavy handling, or deliberate scraping or polishing.

This kind of transformation of an object has been perceived as deliberate destruction of a significant item, a form of killing (Brinch Petersen 2021) or a reduction of the object's importance. On an object from the Late Mesolithic settlement Strandvägen, by Lake Vättern, ornaments have been removed and replaced with new ones (Larsson and Molin 2024).

There is a fragmentary object consisting of a 13.8 cm long tubular bone, which is covered in engravings (Fig. 4A). In the centre, the object has been provided with a 0.8 cm diameter hole. The ornamentation has been centred on one side of the hole, with a rhombus-like figure filled with lines centring on the hole, as well as rows of slashes. On one side of the rhombus there are rows of long, slightly slanted lines directly linked to the geometric motif, that probably also consisted of slashes. On the opposite side of the hole, two rows of oblique lines form a design reminiscent of a herringbone pattern.

It is clear that the object was larger, and that the ornamentation was more extensive. Although the object has a perforation, it is too small for a shaft that would withstand strenuous activity. It may be included in the group of commonly occurring objects with small holes and extensive ornamentation (Płonka 2003).

An antler piece and a bone have been provided with both drill holes and engravings (Fig. 4B–C). In both cases, the ornamentation consists of cross-cutting lines. The function is unclear – possibly a form of pendant.

A bone needle, 15 cm long, has been provided with a series of F-shaped carvings that end in longitudinal lines and strokes in the direction of the tip (Fig. 2B).

There are three small fragments, 1.5 cm, 2.5 cm and 3.5 cm in length, that derive from objects with well-

executed carvings (Fig. 2E–G). One displays rows of four-sided motifs, another has rows of scribbled triangles, while the largest fragment shows parallel lines.

Objects may have more than one kind of pattern, and in some cases, they overlap, indicating that the object was continuously used for some time and that carving over previous ornamentation did not reduce the item's importance (Larsson and Molin 2024). It may be the case that new carvings actually increased the importance of an object when it passed between different tribes and remained in use over a longer period.

The fact that objects made of mineral materials were also provided with ornamentation is exemplified by a grindstone fragment of sandstone (Fig. 4D). The motif is unclear, but it has a long, narrow section partly filled with slashes that ends with a rhombus. Possibly, this could be part of a zoomorphic or anthropomorphic depiction.

In contrast to the finds from other Late Mesolithic settlements (Karsten and Knarrström 2003), there are few carvings on flint surfaces. One explanation may be that the main kind of flint in use, obtained from the immediate surroundings, does not have a well-preserved crust due to the eroded, uneven surface. Other flint, such as Senonian flint, with an even and white-coloured crust, was also used, but only in relatively small amounts, and most of this material was acquired from outside, generally in the form of blades, with few surfaces where the crust was preserved.

In grave XXII, that of a woman in a seated position, a square slate plate, 14 cm in length, was found as a neck ornament (Fig. 5). Documentation with various kinds of film as well as oblique light has not revealed traces of colour or carvings, such as occur on other pendants of minerogenic material (Milner *et al.* 2016). But the possibility that the slab was originally painted cannot be completely excluded.

From a couple of graves there are pendants of amber. Grave 46 is the grave of a woman, which was severely damaged by a later grave cut. Four pendants of amber, with a length of 2.2 cm up to 3.5 cm, along with teeth from red deer, were found next to the woman's neck. A child buried with an elderly man in grave 41 has been provided

with five amber pendants, 1.6 to 6 cm in length. The surface of the amber is heavily eroded, which made it impossible to determine whether they were originally provided with ornamentation, which is common on well-preserved amber pendants (Brinch Petersen 2023b; Petersen 1998). From the occupation layer at Skateholm I there are several finds of amber, including a couple of perforated pieces (Fig. 2E–F), which were used as beads. In addition to beads of teeth and amber, there are also finds of pike vertebrae that have been perforated for use as ornaments (Fig. 2H).

During the final part of the settlement's use, when burial on the site was no longer practiced, ceramics were also introduced: so-called Ertebølle pottery, taking the form of wide-mouthed vessels with pointed bottoms. Only fragments have been found, but all of these seem to indicate that the entire surfaces were provided with decoration. Ornaments are oval and round impressions in horizontal or vertical rows (Fig. 4G–H). This is consistent with further Ertebølle ceramics found in Scania, with various kinds of impressions covering almost all of the surface (Stilborg and Bergenstråhle 2000).

At Skateholm, wooden objects such as paddles are absent as the refuse layers outside the settlements have been washed away from both sites due to the rising sea level. However, their occurrence on sites with good preservation (Andersen 2014; Skriver *et al.* 2017) shows that they were widespread. The large patterns that appear on these may have played an important role in the contact between different coastal settlements. The markings on paddles could permit recognition at a distance, before disembarkation, and thus prevent confrontations.

### Ochre, feathers, hair and antlers

A large number of graves, about half in the case of Skateholm II, were provided with red ochre. It is uncertain to what extent the red ochre was applied to the body at the time of burial, or whether the deceased or the clothes were dyed before the burial. In some graves, red ochre staining also occurs under the deceased, in which cases this dyeing may have been applied as a colour variation of parts of the costume.

A new perspective on the decoration worn by the buried persons emerges from a detailed analysis of the soil samples taken at different places in direct contact with the skeletons. In these samples, fragments of feathers and hair were found (Kirkinen *et al.* 2026). One such example is the seated man in grave XV. He had been provided with 22 tooth beads of red deer placed on top of the skull from ear to ear. The skull was also stained with red ochre. Analysis of the soil next to the skull shows that the head ornament also contained feathers from hawk/eagle (Accipitridae), owl (Strigiformes), goose (Anserinae) and duck (Anatidae). Hair from bat (Rhinolophidae), hare (Lagomorpha) and marten (Mustelidae) has also been identified. One may wonder

what such headgear could have looked like! Remains of birds from the Accipitridae family (hawks and eagles), recovered in seven graves, have been detected especially in the skull and neck area, but in a small number of graves also in association with the hands. A woodpecker feather fragment was detected in double grave 41, associated with the young child.

When it comes to other aspects of a decorative appearance, one can imagine that there was considerable variety in people's dress. The skeletal material from the settlement layer can provide an indication (Jonsson 1988). Finds of hair from various animals found in samples from the graves offer a further source of evidence. A sample from the heel of the woman buried in grave 58 (Kirkinen *et al.* 2026) provides an interesting example of multicoloured costume. A white winter hair from a weasel and a brown hair from a feline indicate that the shoes consisted of skins of different colours, deriving from different animals.

Ethnographic material illustrates how different skins and furs may be combined in costume, where, in addition to the practical, symbolic and gender aspects, the aesthetic perspective has also been taken into account (Barnes 1994; Eicher and Roach-Higgins 1992; Schmidt 2011).

Four graves, all within Skateholm II, have red deer antlers. With one exception, these are shed antlers. None has been provided with ornamentation. Their placement under, behind and in front of the buried individual, in one instance a dog, indicates that they had a special symbolic function.

### Decorations and society

Most of the carvings are relatively shallow. Even if they were originally filled with a dark resinous material, their contrast with the lighter bone or antler surface can hardly have been visible from more than a few metres. The creation of the carved motifs was evidently prompted by a requirement or desire to execute a certain pattern on the object, rather than an aesthetic need for the engraving. The engravings themselves might have had symbolic value. The fact that a certain pattern appeared on an object was of greater importance than its visibility.

Comparison with other sites and the frequency of engraved objects on these sites does not show a clear pattern. Larger settlements have indeed produced larger numbers of objects than smaller settlements. Nevertheless, there seem to be some differences in this respect, which may largely be related to the preservation environment, but may also indicate special circumstances. For example, the settlement at Strandvägen in Motala, on the eastern shore of Lake Vänern, has an unusually large number of decorated objects in the form of various tools (Larsson and Molin 2017; 2023). The fact that most of them were found in the bottom layer outside of the shore zone, where they have been untouched since the settlement

period, about 7500 years ago, shows the importance of the environment for ensuring preservation. At Skateholm, the refuse layers outside the settlements have been washed away from both sites due to the rising sea level. However, there are sites with a favourable environment for preservation beyond the shoreline which have not produced a corresponding number of decorated objects (Karsten and Knarrström 2003; Larsson 1982). It may thus be the case that certain places had a special function within a larger social perspective, leading to the accumulation of a larger number of objects. The number of decorated objects at Skateholm I seems comparable to that of other larger Late Mesolithic sites.

### **Ornaments for personal use or for the whole community**

The variety of engravings ranges from full coverage, as with the antler hammer in the grave of a dog, to just a few parallel and intersecting lines. There could have been considerable variation in the meaning of the carvings. A few simple lines may constitute a mark by the owner intended to recall the object's use while the more extensive designs probably had a completely different purpose.

There are differences in the ornamentation of different kinds of objects. One explanation may be that some objects were individually owned or used, while others had a communal function with a deep symbolic role. The ornamented objects from the graves, which could have had a personal connection, display only limited ornamentation. One such example is the slotted dagger in Grave IV. Although only a fragment remains, the ornamentation on the knife blade consisted of only a few lines. From the settlement of Skateholm I there is a fragmentary blade for a slotted dagger. No ornamentation was found on this.

The slotted dagger found in grave HB:4 at Dragsholm/Bøgebakken, which was robbed before the grave was properly examined, is claimed to lack ornamentation (Andersen 1998). Likewise lacking ornamentation is a slotted dagger found in Grave 5 on the burial ground at Nederst in Jutland (Kannegaard Nielsen 2016).

Contrasting with these finds are the numerous slotted daggers that do not have a relation to graves. Many of these are provided with rich ornamentation, some decorated on both sides of the blade (Larsson 2005; Voss 1961).

A surprisingly large number of richly decorated antler and bone objects have been found in wetlands without direct contact to settlements. This suggests that a significant majority of the richly decorated objects were deliberately buried in the wetland, intentionally incorporated into the surroundings (Phillips *et al.* 2002).

Objects not relating to an individual, which were used in rites involving part or all of the community, seem to have been provided with abundant ornamentation. The antler hammer in dog grave XXI is one such example. This

must have been one of the objects that, with its all-over ornamentation, probably had a special societal function. The fact that it was deposited with a dog may indicate that it was the hammer that was the central object in the grave, while the dog was placed here as protector of the hammer.

Danish objects of a similar kind have likewise been provided with rich decoration (Petersen 1998). A suggested function of these items is that they were used for beating drums (Petersen 2016). The size of the piece suggests a powerful drum. In an experiment, a hollowed-out log, in this case a logboat, was struck with a newly made antler tool of similar form, producing a very loud sound.

When richly decorated objects lost their function, they would either be converted into objects with another function, as described above regarding the harpoon, or else, they would generally be deposited in wetlands outside the settlement.

Although there are several examples of ornamented bone and antler objects, the find situation significantly limits the range of evidence. Due to shoreline displacement, the discards from both sites have been completely washed away. In such layers, objects of different types may have been present. This is exemplified by the various finds in the zone beyond the beach at the Late Mesolithic site of Strandvägen in Motala, southern central Sweden (Larsson and Molin 2024). Some items appear together as deliberate deposits of defunct items. This may have been a frequently used treatment of whole or fragmentary objects, partly to avoid allowing them to contaminate the settlement area, but at the same time turning them into a medium for contact with another world.

That rodent marks appear on richly decorated objects in fragmentary condition, for example in deposits at Ageröd I:HC, from the late Early Mesolithic (Larsson 2023), and likewise on the Late Mesolithic settlement of Strandvägen at Motala (Larsson and Molin 2024), shows that after depositing the pieces immediately outside the settlement, the people did not bother to check the deposit site. At low water, these objects could become vulnerable to damage by animals. The objects may have been perceived as separated from any form of function or magic and thus of no future significance to the settlers.

In addition to food waste, the material found among discards also includes remains of the production of bone and antler tools. Some are of such size that they seem to have been deliberately excluded for future use (Gummeson *et al.* 2019). Another explanation may be that in the production of objects that were intended to have a special function within the ritual sphere, it was important that the remaining parts of the bone or antler are deposited in the water outside the settlement and no longer used.

It is possible to identify a certain parallel with flint objects having a special function. In Rönneholms mosse, central Scania, several accumulations of flint blades were

found. Next to a small settlement, there were 108 blades from four different cores (Larsson and Sjöström 2011). When a core was re-assembled, it became clear that one blade was missing. This blade was probably given a special function, while the others, as waste products also having a special value, were deposited. It is particularly interesting to note that at this specific site in Rönneholm bog there were no traces of blade production. The blades were produced at another site but deposited in a special environment – the wetland.

The fact that there are geographically specific patterns indicates that they had a meaning that can be linked to different groups within southern Scandinavia (Andersen 2023b). A chronological factor is also present, with the introduction and subsequent disappearance of certain patterns and the way of carving them. The small number of zoomorphic and anthropomorphic representations suggests that the patterns cannot be directly linked to the real world but rather were an abstraction of it (Brinch Petersen 2023a). For example, patterns with dimples are similar to the backs of deer calves, while zigzag motifs have similarities to the pattern on the viper's back (Petersen 2016; 2021). Others interpret certain intricate patterns as projections of nets and thus linked to fishing (Płonka 2021).

## Summary

The finds from the Skateholm complex provide a basis for the study of objects with some kind of aesthetic element from both graves and occupation layers. An interesting pattern emerges: decorated bone and antler objects

occur in graves at Skateholm II, while in the case of the somewhat younger Skateholm I they mainly appear in the occupation layer. Although there are critical ambiguities, this may suggest that this form of ornamentation acquires a different status over time, where decorated objects of a personal nature decrease as grave gifts.

It seems that the decorated objects that ended up in the graves had a restricted, probably more personal character. Few items provided with abundant ornamentation occur in the settlement area. The fact that most of the richly decorated bone and antler objects are found in refuse layers or without direct contact to settlements indicates that these objects had an important role for the whole community, and that most were deposited in such a manner as to remove them from contact with everyday activities. They were to gradually become integrated into their surroundings.

An important aspect, when it comes to different forms of ornamentation in a broader perspective, is that many of the forms of expression are hidden from us. Only in connection with new analytical results, such as the examination of fragments from feathers and hair, will reveal new perspectives on aesthetic and probably also symbolic features.

## Acknowledgements/ personal note

Dear Berit, before your departure, you should be honoured with a decoration. Maybe not with something resembling the one for the man in grave XV, but rather with a wreath of flowers. With your release from the shackles of administration, I wish you may henceforth have the time to devote yourself to archaeological research.

## References

- Andersen, S. H. 1998. En mønstret pragtøkse fra ældre Ertebølletid. *Kuml* 1997/98, 9–28.
- Andersen, S. H. 2014. *Tybrind Vig: Submerged Mesolithic settlements in Denmark*. Jutland Archaeological Society publications 77. Aarhus, Jutland Archaeological Society.
- Andersen, S. H. 2023a. Ertebølle Art. In: Grünberg, J. M., Gramsch, B., Brinch Petersen, E., Plonka, T., Meller, H. (eds.), *Mesolithic Art - Abstraction, Decoration, Messages / Mesolithische Kunst - Abstraktion, Dekoration, Botschaften*. Tagungen des Landesmuseums für Vorgeschichte Halle 26. Halle (Saale), Landesamt für Denkmalpflege und Archäologie Sachsen-Anhalt – Landesmuseum für Vorgeschichte, 119–143.
- Andersen, S. H. 2023b. Ertebøllekunstens teknik og kronologi. Nye fund fra den jyske Ertebøllekultur. *Kuml* 2023, 41–80.
- Barnes, R. 1994. *Dress and Gender: Making and Meaning in Cultural Contexts*. Oxford, Berg.
- Brinch Petersen, E. 2021. Final destruction and ultimate humiliation of an enemy during the Mesolithic of southern Scandinavia. In: Boric, D., Antonovic, D. and Mihailovic, B. (eds.), *Foraging Assemblages*. Belgrade and New York, Serbian Archaeological Society, 619–621.
- Brinch Petersen, E. 2023a. Lots of dots – a Late Mesolithic art style with human figures. In: Grünberg, J. M., Gramsch, B., Brinch Petersen, E., Plonka, T., Meller, H. (eds.), *Mesolithic Art - Abstraction, Decoration, Messages / Mesolithische Kunst - Abstraktion, Dekoration, Botschaften*. Tagungen des Landesmuseums für Vorgeschichte Halle 26. Halle (Saale), Landesamt für Denkmalpflege und Archäologie Sachsen-Anhalt – Landesmuseum für Vorgeschichte, 179–189.
- Brinch Petersen, E. 2023b. Working with geometrics – decorated amber pendants from the Danish Maglemosean (9600–6500 cal. BC). In: Grünberg, J. M., Gramsch, B., Brinch Petersen, E., Plonka, T. and Meller, H. (eds.), *Mesolithic Art - Abstraction, Decoration, Messages / Mesolithische Kunst - Abstraktion, Dekoration, Botschaften*. Tagungen des Landesmuseums für Vorgeschichte Halle 26. Halle (Saale), Landesamt für Denkmalpflege und Archäologie Sachsen-Anhalt – Landesmuseum für Vorgeschichte, 91–109.
- Eicher, J. B. and Roach-Higgins, M. E. 1992. Definition and Classification of Dress: Implications for Analysis of Gender Roles. In: Barnes, R. and Eicher, J. B. (eds.), *Dress and Gender: Making and Meaning in Cultural Contexts*. Oxford, Berg, 8–28.
- Gummesson, S., Molin, F. and Sjöström, A. 2019. The Spatial Organization of Bone Crafting During the Middle and Late Mesolithic at Ringsjöholm and Strandvägen in Sweden. *Journal of Field Archaeology* 44(3), 165–179.
- Jonsson, L. 1988. The vertebrae Faunal Remains from the Late Atlantic Settlement Skateholm in Scania, South Sweden. In: Larsson, L. (ed.), *The Skateholm project I. Man and environment*. Regiae Societatis Humaniorum Litterarum Lundensis LXXIX. Lund, Almqvist & Wiksell International, 56–88.
- Kannegaard Nielsen, E. 2016. Late Mesolithic ochre graves at Nederst, Denmark: ochre rituals and customs of personal adornment. In: Grünberg, J. M., Gramsch, B., Larsson, L., Orschiedt, J. and Meller, H. (eds.), *Mesolithic burials – Rites, Symbols and Social Organisation of Early Postglacial Communities*. Tagungen des Landesmuseums für Vorgeschichte Halle 13. Halle (Saale), Landesamt für Denkmalpflege und Archäologie Sachsen-Anhalt – Landesmuseum für Vorgeschichte, 81–94.
- Karsen, P. and Knarrström, B. 2003. *The Tågerup excavations*. Skånska spår– arkeologi längs Väst kustbanan. Stockholm, Riksantikvarieämbetet.
- Kirkinen, T., Larsson, L. and Mannermaa, K., 2026. Waterbirds, mustelids and bast fibres – evidence of soft organic materials in the Late Mesolithic Skateholm I and II cemeteries, Sweden. *Archaeological and Anthropological Sciences* 18, 56. <https://doi.org/10.1007/s12520-026-02415-7>
- Larsson, L. 1982. *Segebro. En tidigatlantisk boplats vid Sege ås mynning*. Malmöfynd 4. Malmö, Malmö Museum.
- Larsson, L. 1988. The Skateholm Project. Late Mesolithic Settlement at a South Swedish Lagoon. In: Larsson, L. (ed.), *The Skateholm Project. I. Man and environment*. Regiae Societatis Humaniorum Litterarum Lundensis LXXIX. Lund, Almqvist & Wiksell International, 9–19.
- Larsson, L. 1989. Late Mesolithic Settlements and Cemeteries at Skateholm, Southern Sweden. In: Bonsall, C. (ed.) *The Mesolithic in Europe. Papers presented at the third international symposium Edinburgh 1985*. Edinburgh, John Donald Publisher, 367–378.
- Larsson, L. 2005. Regional or interregional? A slotted bone dagger from Offerdal, Jämtland. In: Engelmark, R., Larsson, T.B. and Rathje, L. (eds.), *en lång historia... Festskrift till Evert Baudou på 80-årsdagen*. Archaeology and Environment 19. Umeå, Umeå universitet Institutionen för arkeologi och samiska studier, 261–273.
- Larsson, L. 2016. Some aspects of mortuary practices at the Late Mesolithic cemeteries at Skateholm, southernmost Sweden. In: Grünberg, J. M., Gramsch, B., Larsson, L., Orschiedt, J. and Meller, H. (eds.), *Mesolithic burials – Rites, Symbols and Social Organisation of Early Postglacial Communities*. Tagungen des Landesmuseums für Vorgeschichte Halle 13. Halle (Saale), Landesamt für Denkmalpflege und Archäologie Sachsen-Anhalt – Landesmuseum für Vorgeschichte, 175–184.

- Larsson, L. 2017. Animals and animal depictions in the early Holocene of Northern Europe. Based on an antler adze with deer depictions. In: Brieske, V., Dickers, A. and Rind, M. M. (eds.), *Tiere und Tierdarstellungen in der Archäologie*. Beiträge zum Kolloquium in Gedenken an Torsten Capelle, 30–31 Oktober 2015 in Herne. Veröffentlichungen der Altertumskommission für Westfalen, Landschaftsverband Westfalen-Lippe Band 22. Münster, Aschendorff Verlag, 63–73.
- Larsson, L. 2023. Spirals, bands and deer. Hafted and richly decorated antler objects from Scania, southern Sweden. In: Grünberg, J., Gramsch, B., Brinch Petersen, E., Płonka, T. and Meller, H. (eds.), *Mesolithic Art - Abstraction, Decoration, Messages / Mesolithische Kunst - Abstraktion, Dekoration, Botschaften*. Tagungen des Landesmuseums für Vorgeschichte Halle 26. Halle (Saale), Landesamt für Denkmalpflege und Archäologie Sachsen-Anhalt – Landesmuseum für Vorgeschichte, 191–204.
- Larsson, L. 2024a. Embellished Clothing in the Mesolithic Based on Finds from Two Cemeteries in Sweden. In: Mannering, U., Nosch, M-L. and Drawsen, A. (eds.), *The Common Thread: Collected Essays in Honour of Eva Andersson Strand*. Turnhout, Brepols Publishers, 239–246.
- Larsson, L. 2024b. Tooth Beads in Two Hunter-Fisher-Gatherer Societies of Northern Europe. *Beads. Journal of the Society of Bead Research* 36, 36–47.
- Larsson, L. and Sjöström, A. 2011. Bog sites and wetland settlement during the Mesolithic Research from a bog in central Scania, Southern Sweden. *Archäologisches Korrespondenzblatt* 2011(4), 457–472.
- Larsson, L. and Molin, F. 2017. Symbols in the Late Mesolithic. Ornaments on bone and antler from Strandvägen, Motala, in Central Sweden. In: Märgärit, M. and Boroneanț, A. (eds.), *From Hunter-Gatherers to Farmers. Human adaptations at the end of the Pleistocene and the first part of the Holocene. Papers in Honour of Clive Bonsall*. Targoviște, Cetatea de Scaun, 397–408.
- Larsson, L. and Molin, F. 2023. Island of rich decorations – the uneven impact of preservation on the interpretation of long-distance connections. In: Grünberg, J., Gramsch, B., Brinch Petersen, E., Płonka, T. and Meller, H. (eds.), *Mesolithic Art - Abstraction, Decoration, Messages / Mesolithische Kunst - Abstraktion, Dekoration, Botschaften*. Tagungen des Landesmuseums für Vorgeschichte Halle 26. Halle (Saale), Landesamt für Denkmalpflege und Archäologie Sachsen-Anhalt – Landesmuseum für Vorgeschichte, 205–217.
- Larsson, L. and Molin, F. 2024. The biography of a fragment. A late Mesolithic antler object from the Strandvägen site, south Central Sweden. *Oxford Journal of Archaeology* 44(4), 40–56.
- Milner, N., Bamforth, M., Beale, G., Carty, J.C., Chatzipanagis, K., Croft, S., Conneller, C., Elliot, B., Fitton, L. C., Knight, B., Kröger, R., Little, A., Needham, A., Robson, H. K., Rowley, C. C. A. and Taylor, B. 2016. A unique engraved shale pendant from the site of Star Carr: the oldest Mesolithic art in Britain. *Internet Archaeology* 40. DOI: 10.11141/ia.40.8
- Petersen, P. V. 1998. Rav, hjortetak og mesolitisk magi. Danefæ fra jægerstenalderen. *Nationalmuseets Arbejdsmark* 1998, 87–100.
- Petersen, P. V. 2016. Protective patterns in Mesolithic art. In: Boric, D., Antonovic, D. and Mihailovic, B. (eds.), *Foraging Assemblages*. Belgrade and New York, Serbian Archaeological Society, 602–609.
- Petersen, P. V. 2021. Zigzag lines and other protective patterns in Palaeolithic and Mesolithic art. *Quaternary International* 573, 66–74.
- Phillips, C., Johns, D. and Allen, H. 2002. Why did Maori bury artefacts in the wetland of precontact Aotearoa/New Zealand? *Journal of Wetland Archaeology* 2(1), 39–60.
- Płonka, T. 2003. *The Portable Art of Mesolithic Europe*. Wrocław, Wydawnictwo Uniwersytetu Wrocławskiego.
- Płonka, T. 2021. Net patterns in Mesolithic art north-western Europe. Boric, D., Antonovic, D. and Mihailovic, B. (eds.), *Foraging Assemblages*. Belgrade and New York, Serbian Archaeological Society, 595–601.
- Schmidt, L. 2011. Reindeer Skin Clothing and Sámi Identity. *Acta Borealia* 28(1), 5–23.
- Skriver, C., Borup, P. and Astrup, P. M. 2017. Hjarnø Sund: An eroding Mesolithic site and the tale of two paddles. In: Bailey, G. N., Harff, J. and Sakellariou, D. (eds.), *Under the Sea: Archaeology and Palaeolandscapes of the Continental Shelf*. Coastal Research Library 20. Cham, Springer, 131–143.
- Stilborg, O. and Bergenstråhle, I. 2000. Traditions in transition: A comparative study of the patterns of Ertebølle lithic and pottery changes in the Late Mesolithic Ceramic Phase at Skateholm I, III and Soldatorpet in Scania, Sweden. *Lund Archaeological Review* 6, 23–41.
- Voss, O. 1961. Danske flintægddolke. *Aarbøger for nordisk Oldkyndighed og Historie* 1960, 153–167.

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# The fire between life and death

## Mesolithic cremation at Hammelev as a ritual transformation

Mari Törv

### Abstract

Recent research has revealed that Mesolithic mortuary practices in Europe were far more diverse than traditionally recognized, with cremation emerging as a deliberate and structured form of body treatment. The Hammelev cremation burial in Southern Jutland, Denmark, dated to the 9<sup>th</sup> millennium BCE, provides a rare Scandinavian example, featuring a single individual cremated with red ochre, associated stone tools, and burnt animal remains. Using van Gennep's tripartite model of rites of passage – separation, liminality, and incorporation – this study interprets the ritual sequence, highlighting how fire transformed the deceased from life to death and facilitated integration into a broader cosmological and social framework. Comparative analysis with other Scandinavian and European Mesolithic cremations reveals variability in burning intensity, grave architecture, and associated materials, emphasizing that cremation was an established, regionally embedded practice. This approach underscores the symbolic and transformative dimensions of Mesolithic cremation, situating it within the wider spectrum of hunter-gatherer mortuary behaviour.

*Keywords: Cremation, burial practices, rites of passage, Scandinavia*

### Introduction

The traditional view of Stone Age hunter-gatherer burial practices is shifting profoundly. The long-held narrative, which was dominated by inhumation cemeteries (e.g. Albrethsen and Brinch Petersen 1977; Bugajska and Gumiński 2016; Grünberg 2016; Gumiński and Bugajska 2016; Larsson 2016; Zagorskis 1987), is giving way to a new understanding that acknowledges the diverse and elaborate ways the dead were handled in the deep past (e.g. Bugajska 2015; Gray Jones 2011; 2025; Nilsson Stutz 2025; Schulting 2015; Törv 2018; Wallduck and Bello 2015). These include the deliberate fragmentation of human remains (e.g. Gray Jones 2011; 2025), guided natural mummification (Peyroteo Stjerna *et al.* 2022), using the remains of foragers as pendants (Mannermaa *et al.* 2022) and the cremation of bodies (e.g. Brinch Petersen and Meiklejohn 2003; Eriksen and Andersen 2016; Gray Jones 2017; Jensen 2016), reflecting a nuanced and varied approach to death and the dead in Mesolithic contexts. Despite this paradigmatic shift in the interpretation of prehistoric mortuary practices, cremation continues to occupy a marginal position in scholarly discourses. As Nilsson Stutz (2025, 917) notes regarding the mortuary traditions of foragers in the circum-Baltic region – and as is equally evident across Mesolithic Europe more

broadly – “Cremation burial has never truly shaped our understanding of mortuary practice.” Of the 280 known burial sites across Europe (Grünberg 2024), cremation appears only sporadically or with limited regularity (Gray Jones 2017; Nilsson Stutz 2025, 915). Nevertheless, its geographical distribution is extensive, ranging from the northern regions of Europe (e.g. Gray Jones 2017; Wehlin 2021) to the Mediterranean coast (Cullen 1995). It is now possible to conclude that cremation constituted one of the recognised methods for transforming the human body in Mesolithic Europe. Although cremations are more challenging to study and interpret in the archaeological record – especially considering the Third Scientific Revolution in archaeology, which prioritises biomolecular and quantitative data (e.g. Kristiansen 2014) – their cultural significance should not be overlooked due to our current limitations in analysing them. The fragmented and commingled nature of cremated human remains has posed difficulties, but these challenges are being actively addressed by research groups worldwide. Without engaging with and exploring these practices, our understanding of hunter-gatherer mortuary behaviour remains incomplete. Moreover, what is considered the norm – typically inhumation – may be overrepresented, leaving alternative practices like cremation underexplored and undervalued. As Gray Jones (2017) demonstrates, this was an established and regionally embedded practice.

Berit V. Eriksen has contributed significantly to the study of an Early Mesolithic cremation burial discovered at Hammelev, Southern Jutland, Denmark (Eriksen and Andersen 2016). The burial, dating to the 9<sup>th</sup> millennium BCE, was uncovered unexpectedly during the excavation of a Late Roman Iron Age settlement (200–375 CE), lifted as a block, and is currently exhibited at a local museum (Eriksen and Andersen 2016, 73). The grave was identified by diffuse discoloration in sandy soil, with a small heap of cremated human remains covered in red ochre and accompanied by stone tools. Nearby traces of Maglemose-period activity further confirmed its cultural context (Eriksen and Andersen 2016, 75–76).

In this article, I undertake an intellectual exercise: an attempt to interpret the remarkable Hammelev cremation grave from Denmark through the lens of Arnold van Gennep’s tripartite model of rites of passage (1960, initially published in 1909). My goal is not to produce a quantitative or data-driven analysis, but to investigate how fire, death, and ritual intersected in Mesolithic mortuary practices as transformative processes. His model offers a useful interpretive framework for cremation burials, as it moves beyond the mechanics of disposal to explore ritual complexity, symbolism, and social meaning. Its universality and clarity make it widely applicable across cultures and time periods, and it forms the theoretical foundation for later theoretical developments (e.g. Hertz 2009; Turner 1996).

Moreover, previous studies in Fennoscandian cremations have successfully employed this model to interpret funerary sequences as structured social transitions (e.g. Larsson 2003; Wickholm and Raninen 2006). This approach allows me to situate the Hammelev find – studied by my PhD supervisor, Berit – within a broader symbolic and cosmological framework of Mesolithic forager societies. Van Gennep’s model of ritual transformation consists of three phases: i) *separation*, ii) *liminality*, and iii) *incorporation* which help me think through how cremation might have functioned as a transformative process. In the *separation* phase, the individual departs from the social world; during *liminality*, they exist in a transitional state between life and death; and in *incorporation*, they are reintegrated into a new social or cosmological order. I see cremation not simply as a method of bodily disposal, but as a ritual act that facilitates movement across these thresholds – from life to death, from presence to absence, and from individual to ancestor. Through this theoretical lens, I seek to offer one possible reading of the Hammelev cremation.

### **Hammelev in the context of other Mesolithic cremations in Scandinavia**

The cremation grave at Hammelev, Southern Jutland, dated to the 9<sup>th</sup> millennium BCE and associated with the Maglemose Culture, represents one of the earliest known cremation burials in Scandinavia. The burial was located within a multi-layered settlement site that was initially excavated as a Late Roman Iron Age (200–375 CE) settlement but later revealed to be situated within the Maglemose-period occupation layer (Eriksen and Andersen 2016, 73–76). It was identified by diffuse discoloration in sandy soil, measuring approximately 0.6 × 1.1 meters in area and 0.7 meters in depth. The cremated remains of a single individual, most likely female, formed a compact heap (c. 51 × 27 cm), covered with red ochre and accompanied by stone tools (Eriksen and Andersen 2016, 75). Most of the identifiable bones belonged to the upper part of the body, including fragments of the cranium and limb bones. Notably, the cremated remains also included bones from a wild cat, most likely a single individual, represented by a left radius and right ulna (Eriksen and Andersen 2016, 76).

The grave goods comprised unburnt flint tools – a small core axe and 16 small flint blades and flakes – as well as a single bone pin, which, like the human bones, had been exposed to fire (Eriksen and Andersen 2016, 76–77). Analysis indicates that the bones were carefully retrieved from the pyre, cleaned, and then buried. The cremation temperature likely exceeded 800°C, and osteological evidence suggests that the body was cremated while still fleshed (Eriksen and Andersen 2016, 78). Based on the compact arrangement and preservation of the remains, it is likely that the bones were deposited in a container, although the material has not survived.

Although the Hammelev cremation is not the oldest known in Europe (see Gray Jones 2017 and references therein), it stands out as the earliest currently known example in Scandinavia. To contextualize this unique find, I will draw comparisons with later Mesolithic cremation practices, examining four sites – Nivå 10 and Gøngehusvej 7 in Denmark, and Skateholm I and Skateholm II in southern Sweden – that reflect the diversity of mortuary treatment within the realm of cremation burial. These sites together with other European forager cremations (*e.g.* Gray Jones 2017 and references therein) provide valuable comparative material for thinking through how cremation may have functioned symbolically and ritually in Mesolithic forager societies.

Similarly to the western European examples (Gray Jones 2017), the burials structures for Scandinavian cremations varied, currently with no evidence on pyre sites available. At Nivå 10, Eastern Denmark, three Late Mesolithic cremation graves (A127, A128, A144) have been found. Cremation A127 was a small pit (20 × 5 cm) with clay infill and red ochre containing the remains of one individual, while Cremation A128 was a larger pit (60 × 14 cm) filled with cremated adult bones, soil, ashes, and charcoal (Jensen 2016, 99). Cremation A144 featured tightly packed cremated bones of a male aged 30–35 years in a 25 × 8 cm pit, with almost no surrounding soil – suggesting deliberate collection and careful handling of the remains (Jensen 2016, 99) as seen in Hammelev. Skateholm I and II (5500–4000 cal BCE) feature cremations of single individuals, often intermixed with faunal remains and pyre debris, distributed across shallow features. Grave XVIII at Skateholm II contained approximately 1000 g of human bone fragments, variably burned and layered within a rectangular structure. At Skateholm I, Grave 11 contained the remains of a possible adult male deposited alongside burnt faunal material across several small pits, postholes, and shallow features spanning roughly 10 m<sup>2</sup>. No evidence of burning or pyre debris was recorded, suggesting the absence of a formal pyre structure. In contrast, Grave 20 was a small sub-circular feature with a limited amount of burnt remains (Larsson 1988; Nilsson Stutz 2003; Persson and Persson 1988).

Pre-cremation treatment of the body appears to have varied across Mesolithic sites, both within Scandinavia and beyond (Gray Jones 2017). At Nivå 10, osteological analysis suggests that fleshed bodies or body parts were cremated, rather than dry bones, based on the condition and fragmentation patterns of the remains (Jensen 2016, 106). A similar interpretation has been proposed for Hammelev, where osteological evidence indicates that the body was likely cremated while still fleshed (Eriksen and Andersen 2016, 78). These align with broader observations that Mesolithic cremation involved varied pre-cremation treatments, including defleshing, disarticulation, and

selection of body parts (Gray Jones 2017). However, interpreting cremation practices remains inherently complex due to the challenges involved in analysing burnt human remains. These include heat-induced fragmentation, post-cremation disturbance, and differential preservation – all of which can obscure the original condition of the body and the sequence of mortuary events (Gonçalves *et al.* 2011; Lillak 2025; Symes *et al.* 2015).

The intensity of burning affecting human remains varies significantly across Mesolithic cremation sites. At Hammelev, the cremated bones are largely calcinated, indicating exposure to temperatures reaching approximately 800°C (Eriksen and Andersen 2016). In contrast, Grave XVIII at Skateholm II contained around 1000 g of human bone fragments, which were variably burned and deposited within a rectangular structure. The anthropological report described the bones as “badly burnt and extremely sooty” (Persson and Persson 1988, 97), leaving it unclear whether the remains were incompletely or thoroughly cremated. While most scholars interpret this assemblage as evidence of intentional cremation (Larsson 1988; 1993; Nilsson Stutz 2003), Fahlander (2012, 29) has referred to such cases more cautiously as “bones affected by fire”, highlighting the interpretive ambiguity surrounding these remains (see also Gray Jones 2017). These differences underscore the complexity of identifying cremation practices, especially when burning intensity, bone condition, and depositional context vary so widely.

In terms of number of individuals, most Mesolithic cremation graves in Scandinavia contain single burials, with Gøngehusvej 7 being a notable exception. Hammelev, Nivå 10 (A127, A128, A144), and Skateholm I and II graves each represent individual cremations (Jensen 2016; Larsson 1988; 1993), while Gøngehusvej 7 suggests a more communal or sequential mortuary practice. Gøngehusvej 7 stands out with a cremation of five individuals – two adults, two sub-adults, and one infant – alongside cut marks on bones and grave goods such as flint blades and roe deer remains (Brinch Petersen and Meiklejohn 2003).

Compared to other Mesolithic cremations, Hammelev stands out for its use of ochre – a feature also present at Nivå 10 – and the abundance of grave goods. Within Scandinavia, only Gøngehusvej 7 presents artefacts that can be confidently interpreted as pyre goods (Brinch Petersen and Meiklejohn 2003), while at Skateholm I, only burnt animal remains were included in the cremation context. Importantly, at Hammelev, the only artefact showing clear evidence of exposure to fire is a bone pin; similarly, as at Skateholm I, wildcat bones also bear visible burn marks. In contrast, the flint artefacts found in the grave show no evidence of heat exposure (Eriksen and Andersen 2016), suggesting they were included after the cremation or were not part of the pyre itself.

Together, these sites reveal a wide spectrum of Mesolithic cremation practices – ranging from minimal, tightly packed deposits to richly furnished, multi-individual cremations. This diversity is further reflected in variations in burning intensity, grave architecture, and associated materials, underscoring the complexity and flexibility of ritual approaches to death and the body during the Mesolithic.

### **Moving beyond the descriptions of Hammelev cremation**

Eriksen and Andersen conclude in their discussion of the Hammelev cremation that “we cannot reconstruct the exact course of the ritual or the ideology behind it, but clearly the Hammelev burial was a primary cremation with an elaborate and well-planned ritual” (2016, 78–79). Building on this observation, I propose to explore one possible interpretation of the grave through the lens of ritual practice. Rather than aiming for definitive conclusions, this is an intellectual exercise that considers the cremation as part of a broader sequence of rites of passage.

#### ***Separation: from life to death***

The first phase in van Gennep’s framework of rites of passage is separation – the transition from life to death and the detachment of the individual from the living community. In the context of the Hammelev cremation, this phase is difficult to trace archaeologically, especially since some separation practices may begin while the person is still alive but socially excluded due to illness. However, certain elements may be inferred: the construction of the pyre and the transport of the deceased could have marked the start of the ritual process. If the stone tools found in the grave were made specifically for the burial, their preparation might also signal the beginning of separation. Yet, without use-wear analysis, this remains speculative. These acts may have initiated the ritual journey, symbolically distancing the individual from the world of the living.

#### ***Liminality: from presence to absence***

While the separation phase may be difficult to detect archaeologically, the liminal phase – a transitional state between life and death – is more materially visible. In the Hammelev cremation, this transformation is embodied in the act of burning, which alters the body from a recognizable human form to fragmented remains. This marks a shift from being present in the world of the living to becoming absent, yet still symbolically potent. Through fire, the deceased was ritually removed and transformed into another state of being. The presence of red ochre, often associated with regeneration and rebirth further deepens the symbolic resonance of this transition (Zvelebil 2003, 122).

Unlike Mesolithic inhumations, where the body was preserved in lifelike poses and supported by organic materials (Nilsson Stutz 2003; Törv 2018), cremation

disrupts this visual continuity. Yet both practices reflect a shared concern with bodily transformation and ritual manipulation (e.g. Gray Jones 2011; Nilsson Stutz 2003). Their coexistence within the same community is exemplified at Nivå 10, Eastern Denmark, where both cremations and inhumations were found in the same cemetery (Jensen 2016). Reopened graves further suggest that disintegration was not only accepted but may have been ritualized. Given that inhumations represent only a small fraction of Mesolithic burials, alternative treatments – such as cremation, exposure, or mummification – were likely more widespread than previously assumed. As discussed earlier, the deposition of cremated remains also varied: some were placed in pits, others scattered or stored in containers, with or without pyre debris (Gray Jones 2017). These choices reflect different ritual strategies during the liminal phase, when the body existed in a state of symbolic ambiguity – neither fully gone nor fully integrated into the ancestral realm.

#### ***Incorporation: from individual to ancestor***

The final phase in van Gennep’s rites of passage – incorporation – marks the ritual acceptance of the deceased into a new social and cosmological category. In the case of Hammelev, this phase is particularly compelling. Within the animistic worldview often attributed to Mesolithic foragers (Damm 2025), the boundaries between humans, animals, and objects were fluid, and all could be perceived as spiritually potent or animate. The deposition of cremated human remains alongside animal bones and unburnt flint artefacts invites interpretation within this framework, suggesting a convergence of ancestral presences where the material and spiritual realms intersect.

Although it is entirely possible that the flint artefacts were grave gifts from the living or personal possessions of the deceased, I will not pursue these interpretations here. Instead, I propose viewing the integration of unburnt items – whether used or unused – as part of a broader symbolic process. Rather than representing final disposal, the cremation and associated materials may reflect a transformation of identity, where the deceased becomes part of a wider network of animate beings. This network could also include the burnt animal bones or even the bone as a material (the bone pin was the only artefact with burning marks), which may have been treated in a similar way to human remains, in contrast to the flint finds. One may state that this interpretation resonates with other Mesolithic contexts, such as Olenii Ostrov, where human bones were fashioned into pendants and worn, suggesting that ancestors were materially and symbolically integrated into the lives of the living (Mannermaa *et al.* 2022). In this light, the destruction of the corporeal body through fire was not a denial of personhood, but a ritual transformation aligned with Mesolithic beliefs in continuity, fragmentation, and ancestral presence.

## Conclusions

The Hammelev cremation offers a compelling case study for applying van Gennep's tripartite model of rites of passage – separation, liminality, and incorporation – to Mesolithic mortuary practice. As a deliberate and structured act, the cremation marks the deceased's separation from the social world, initiating a ritual journey that is materially and symbolically expressed through fire. While the separation phase is less obvious in the archaeological record, the liminal phase, embodied in the transformation of the body through burning, reflects a shift from presence to absence, while maintaining symbolic potency. This phase is further enriched using red ochre and the careful treatment of remains, suggesting a ritual suspension between worlds. The final phase, incorporation, is perhaps the most intriguing here. Rather than seeing the cremation as a conclusion, together with the non-cremated flint tools, animal bones and burnt bone pin, it represents a transformation – an entry into a new cosmological category where the deceased becomes part of a broader network of animate beings.

Taken together, the Hammelev cremation challenges the notion that Mesolithic cremation was anomalous.

## References

- Albrethsen, S. E. and Brinch Petersen, E. 1977. Excavations of a Mesolithic cemetery at Vedbæk, Denmark. *Acta Archaeologica* 47(1), 1–28.
- Brinch Petersen, E. and Meiklejohn, C. 2003. Three Cremations and a Funeral: Aspects of Burial Practice in Mesolithic Vedbæk. In: Larsson, L., Kindgren, H. and Knutsson, K. (eds.), *Mesolithic on the Move: Papers Presented at the Sixth International Conference on the Mesolithic Europe, Stockholm 2000*. Oxford, Oxbow, 485–493.
- Bugajska, K., 2015. In the ground or in the basket? Burial wrapping from the Stone Age hunters' cemetery at Dudka, Masuria, NE-Poland. *Novensia* 26, 9–23.
- Bugajska, K. and Gumiński, W. 2016. How many steps to heaven? Loose human bones and secondary burials at Dudka and Szczepanki, the Stone Age foragers' sites in Masuria, NE-Poland. In: Grünberg, J. M., Gramsch, B., Larsson, L., Orschiedt, J. and Meller, H. (eds.), *Mesolithic Burials – Rites, Symbols and Social Organisation of Early Postglacial Communities*. Tagungen des Landesmuseums für Vorgeschichte Halle 13. Halle (Saale), Landesamt für Denkmalpflege und Archäologie Sachsen-Anhalt - Landesmuseum für Vorgeschichte, 511–544.
- Cullen, T., 1995. Mesolithic mortuary ritual at Franchthi Cave, Greece. *Antiquity* 69, 270–289. DOI:10.1017/S0003598X00064681
- Damm, C., 2025. Forager cosmologies in the Northernmost Europe. In: Nilsson Stutz, L., Peyroteo Stjerna, R. and Törv, M. (eds), *The Oxford Handbook of Mesolithic Europe*. Oxford, Oxford University Press, 933–948.
- Eriksen, B. V., Andersen, H. C. H., 2016. Hammelev. An Early Mesolithic cremation grave from Southern Jutland, Denmark. In: Grünberg, J. M., Gramsch, B., Larsson, L., Orschiedt, J., Meller, H. (eds.), *Mesolithic Burials – Rites, Symbols and Social Organisation of Early Postglacial Communities*. Tagungen des Landesmuseums für Vorgeschichte Halle 13. Halle (Saale), Landesamt für Denkmalpflege und Archäologie Sachsen-Anhalt – Landesmuseum für Vorgeschichte, 73–80.
- Fahlander, F., 2012. Mesolithic Childhoods: Changing Life-Courses of Young Hunter-Fishers in the Stone Age of Southern Scandinavia. *Childhood in the Past* 5, 20–34. DOI:10.1179/cip.2012.5.1.20
- Gonçalves, D., Thompson, T. J. U. and Cunha, E. 2011. Implications of heat-induced changes in bone on the interpretation of funerary behaviour and practice. *Journal of Archaeological Science* 38(6), 1308–1313. DOI:10.1016/j.jas.2011.01.006
- Gray Jones, A. 2011. *Dealing with the Dead: Manipulation of the Body in the Mortuary Practices of Mesolithic North West Europe*. PhD thesis. Manchester, University of Manchester.
- Gray Jones, A. 2017. Cremation and the Use of Fire in Mesolithic Mortuary Practices in North-West Europe. In: Cerezo-Román, J. I., Wessman, A. and Williams, H. (eds), *Cremation and the Archaeology of Death*.

## Acknowledgements

The author gratefully acknowledges the editors of this compendium, Sascha Krüger and Daniel Groß, for inviting me to contribute to this project celebrating the fascinating career of Berit V. Eriksen. The writing of this article was supported by the Ministry of Education and Research through the Centres of Excellence grant TK215 *Estonian Roots: Centre of Excellence for Transdisciplinary Studies on Ethnogenesis and Cultural Diversity*.

Note: This paper has been edited using Microsoft 365 Copilot to support the non-native English-speaking author in refining the language.

- Oxford, Oxford University Press, 25–51. DOI:10.1093/oso/9780198798118.003.0009
- Gray Jones, A. 2025. Human remains in ‘non-burial’ contexts. In: Nilsson Stutz, L., Peyroteo Stjerna, R. and Törv, M. (eds), *The Oxford Handbook of Mesolithic Europe*. Oxford, Oxford University Press, 873–886. DOI:10.1093/oxfordhb/9780198853657.013.53
- Grünberg, J. 2016. Mesolithic burials – rites, symbols and social organisation of early postglacial communities. In: Grünberg, J. M., Gramsch, B., Larsson, L., Orschiedt, J. and Meller, H. (eds), *Mesolithic Burials – Rites, Symbols and Social Organisation of Early Postglacial Communities*. Tagungen des Landesmuseums für Vorgeschichte Halle 13. Halle (Saale), Landesamt für Denkmalpflege und Archäologie Sachsen-Anhalt – Landesmuseum für Vorgeschichte, 13–24.
- Grünberg, J. M., 2024. Mesolithic burials and mortuary practices: Traditions, developments and individuality of the early postglacial hunter-fisher-gatherers in Europe. *L’Anthropologie, Sépultures paléolithiques et mésolithiques* 128, 103278. DOI:10.1016/j.anthro.2024.103278
- Gumiński, W. and Bugajska, K. 2016. Exception as a rule. Unusual Mesolithic cemetery and other graves at Dudka and Szczepanki, Masuria, NE-Poland. In: Grünberg, J. M., Gramsch, B., Larsson, L., Orschiedt, J. and Meller, H. (eds), *Mesolithic Burials – Rites, Symbols and Social Organisation of Early Postglacial Communities*. Tagungen des Landesmuseums für Vorgeschichte Halle 13. Halle (Saale), Landesamt für Denkmalpflege und Archäologie Sachsen-Anhalt – Landesmuseum für Vorgeschichte, 467–510.
- Hertz, R. 2009. A Contribution to a Study of the Collective Representation of Death. In: Mauss, M., Hubert, H., and Hertz, R. (eds), *Saints, Heroes, Myths, and Rites. Classical Durkheimian Studies of Religion and Society*. New York, Routledge.
- Jensen, O. L. 2016. Double burials and cremations from the Late Mesolithic site of Nivå 10, Eastern Denmark. In: Grünberg, J. M., Gramsch, B., Larsson, L., Orschiedt, J. and Meller, H. (eds.), *Mesolithic Burials – Rites, Symbols and Social Organisation of Early Postglacial Communities*. Tagungen des Landesmuseums für Vorgeschichte Halle 13. Halle (Saale), Landesamt für Denkmalpflege und Archäologie Sachsen-Anhalt – Landesmuseum für Vorgeschichte, 95–108.
- Kristiansen, K. 2014. Towards a New Paradigm? The Third Science Revolution and Its Possible Consequences in Archaeology. *Current Swedish Archaeology* 22(1), 11–34. DOI:10.37718/CSA.2014.01
- Larsson, L. (ed.), 1988. *The Skateholm project I. Man and environment*. Acta Regiae Societatis Humaniorum Litterarum Lundensis 79. Almqvist & Wiksell, Stockholm.
- Larsson, L. 1993. The Skateholm Project: late Mesolithic coastal settlement in southern Sweden, in: Bogucki, P. I. (ed.), *Case Studies in European Prehistory*. Boca Raton, CRC Press, 31–62.
- Larsson, L. 2016. Some aspects of mortuary practices at the Late Mesolithic cemeteries at Skateholm, southernmost Sweden. In: Grünberg, J. M., Gramsch, B., Larsson, L., Orschiedt, J. and Meller, H. (eds), *Mesolithic Burials – Rites, Symbols and Social Organisation of Early Postglacial Communities*. Tagungen des Landesmuseums für Vorgeschichte Halle 13. Halle (Saale), Landesamt für Denkmalpflege und Archäologie Sachsen-Anhalt – Landesmuseum für Vorgeschichte, 175–184.
- Larsson, Å. M. 2003. Secondary Burial Practices in the Middle Neolithic. Causes and Consequences. *Current Swedish Archaeology* 11, 153–170.
- Lillak, A. 2025. *From ashes to interpretation: Fragmented, commingled and cremated human remains in Estonian Roman Iron Age (50–450 CE) tarand cemeteries*. Doctoral dissertation. Tartu, University of Tartu.
- Mannermaa, K., Malyutina, A., Zubova, A. and Gerasimov, D. 2022. First evidence of human bone pendants from Late Mesolithic Northeast Europe. *Journal of Archaeological Science: Reports* 43, 103488. DOI:10.1016/j.jasrep.2022.103488
- Nilsson Stutz, L. 2003. *Embodied Rituals and Ritualized Bodies: Tracing Ritual Practices in Late Mesolithic Burials*. Acta Archaeologica Lundensia Series in 8° 46. Stockholm, Almqvist and Wiksell.
- Nilsson Stutz, L. 2025. The Handling of the Dead Body: Transformations from Life to Death. In: Nilsson Stutz, L., Peyroteo Stjerna, R. and Törv, M. (eds), *The Oxford Handbook of Mesolithic Europe*. Oxford, Oxford University Press, 915–930. DOI:10.1093/oxfordhb/9780198853657.013.56
- Persson, O. and Persson, E. 1988. Anthropological report concerning the interred Mesolithic populations from Skateholm, Southern Sweden In: Larsson, L. (ed.), *The Skateholm Project I. Man and Environment*, Acta Regiae Societatis Humaniorum Litterarum Lundensis 79. Almqvist and Wiksell, Stockholm, 89–105.
- Peyroteo Stjerna, R., Nilsson Stutz, L., Mickleburgh, H. and Cardoso, J. 2022. Mummification in the Mesolithic: New Approaches to Old Photo Documentation Reveal Previously Unknown Mortuary Practices in the Sado Valley, Portugal. *European Journal of Archaeology* 25(3), 309–330.
- Schulting, R.J. 2015. Mesolithic ‘skull cults’? In: von Hackwitz, K. and Peyroteo Stjerna, R. (eds), *Ancient Death Ways. Proceedings of the Workshop on Archaeology and Mortuary Practices*. Uppsala, Uppsala University Press, 19–46.
- Symes, S.A., Rainwater, C. W., Chapman, E. N., Gipson, D.R. and Piper, A. L. 2015. Patterned Thermal Destruction

- in a Forensic Setting. In: Schmidt, C. W. and Symes, S. A. (eds), *The Analysis of Burned Human Remains*. Amsterdam, Academic Press, 17–60.
- Turner, V., Abrahams, R. and Harris, A. 1996. *The Ritual Process: Structure and Anti-Structure*. Chicago, Aldine.
- Tõrv, M. 2018. *Persistent Practices: A Multi-Disciplinary Study of Hunter-Gatherer Mortuary Remains from c. 6500–2600 cal BC, Estonia*. Untersuchungen und Materialien zur Steinzeit in Schleswig-Holstein und im Ostseeraum 9. Kiel/Hamburg: Wachholtz/Murmann.
- van Gennep, A. 1960. *The Rites of Passage*. Translated by Vizedom, M. B. and Caffee, G. L. Chicago, University of Chicago Press.
- Wallduck, R. and Bello, S. 2015. Manipulation of the dead during the Mesolithic-Neolithic period in the Danube Georges, Serbia: A reassessment of the burial data using taphonomic analysis. In: *The Ninth International Conference on the Mesolithic in Europe. 14th–18th September, 2015, Belgrade, Serbia. Book of Abstracts*. Belgrade, University of Belgrade, National Museum of Serbia, Cardiff University, 52.
- Wickholm, A. and Raninen, S. 2006. The broken people: deconstruction of personhood in Iron Age Finland. *Estonian Journal of Archaeology* 10(2), 150–166. DOI:10.3176/arch.2006.2.03
- Zagorskis, F. 1987. *Zvejnieku akmens laikmeta kapulauks*. Rīga, Zinātne.
- Zvelebil, M. 2003. People behind the lithics. Social life and social conditions of Mesolithic communities in temperate Europe. In: Bevan, L. and Moore, J. (eds), *Peopling the Mesolithic in a Northern Environment*, BAR International Series 1157, 1–26.

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# Two lithic sickle blades from the neolithic wooden structure of Bad Buchau-Möwenweg

Julia Goldhammer

## Abstract

A massive wooden structure was discovered in Bad Buchau-Möwenweg, a site located in the Federsee fen, Baden-Württemberg, Germany. The possible walkway dates to the Younger Neolithic Pfyn-Altheim-Horizon (around 3800–3500 cal BCE). Around 50 finds were discovered in contextual connection with the wooden structure. Among them were two sickle blades, one complete and one fragmented, both made of tabular chert. The complete sickle has sickle gloss on the concave edge and adhesive residue on the surface, suggesting that it was mounted in a missing handle. The fragmented sickle blade appears to have broken during use or while being resharpened.

*Keywords: Federsee fen, sickle blade, chert, walkway, Neolithic*

## Introduction

During a rescue excavation in the development area for residential building ‘Am Möwenweg’ in Bad Buchau, District of Biberach, Baden-Wuerttemberg, Germany (Goldhammer and Hohl 2019; Goldhammer *et al.* 2019), a massive wooden structure made of piles, planks and round log timbers was documented in 2018. The site is located within the ‘hotspot’ of southern German wetland archaeology, the Federsee fen (Ebersbach *et al.* 2021), 90 km southeast of Tübingen. Around 50 artefacts directly related to the wooden structure were discovered on the site Möwenweg. Most of the finds are made of ceramic but also bone and stone artefacts occur. As this article was written in honour of a jubilarian who has dealt with various types of silices throughout her scientific career, it focuses on two stone sickle blades that were found during the excavation. In order to understand the context of the finds, the wooden structure will first be presented in more detail.

## Feature and Stratigraphy

The wooden structure of Möwenweg preserved in the wetland extends from the former moraine island, on which the contemporary town of Bad Buchau now stands, in a south-westerly direction into the peatland around lake Federsee. So far, a 75 metre long segment of this 2.5 to 3 metre wide structure has been excavated, but it extends beyond the boundaries of the construction area (Goldhammer *et al.* 2019), consequently, the landward and lakeward ends of the pile structure could not be excavated.



Figure 1: Part of the wooden structure from Bad Buchau-Möwenweg in an orthophotograph (LAD in the RPS, W. Hohl).

Planks and round log timbers were arranged lengthwise between two parallel rows of piles (Fig. 1). These longitudinal timbers include at least six so-called 'Lochbohlen' (boards with rectangular holes at both ends, Fig. 2), which must have been important structural elements of the construction. Two of those boards with rectangular holes were almost completely preserved, while others were found only in fragments. No evidence of a substructure was found underneath the longitudinal

poles and planks (Goldhammer *et al.* 2019). The structure could be interpreted as a walkway built on two parallel rows of piles. The boards with rectangular holes could have been stabilising cross-connections, while the longitudinal timbers may have served as the surface of the walkway and probably fell between the rows of piles when the structure collapsed (Goldhammer *et al.* 2019).

In total, 1400 samples of wood were collected during the excavation. According to initial investigations, the walkway



Figure 2: Plank with holes from the Neolithic wooden structure at Bad Buchau-Möwenweg *in situ* (LAD in the RPS, W. Hohl).

was constructed from round log timbers of oak, hazel, alder, elm, maple, poplar, willow, and pome fruit trees. With an average diameter of 10–12 cm, the piles have a small number of annual rings. The oak samples examined by the Dendrochronology Lab Hemmenhofen were felled in the same year (Goldhammer *et al.* 2019).

An absolute dendrochronological dating of the piles was not possible because of the low number of annual rings. To resolve an absolute date, radiocarbon dating was applied.

A sample taken from the last 10 annual rings of an oak stake was dated to 3635–3518 cal BCE (MAMS-37162: 4766 ± 23 BP), indicating that the wooden structure dates to the late Younger Neolithic according to Lüning (1996). In order to fully understand the construction and to reconstruct the number of construction phases, a more detailed evaluation of the feature, more radiocarbon and dendrochronological dates are currently underway. A publication of these findings is planned.

Within two excavation trenches at Bad Buchau-Möwenweg, several sedimentological profiles had been recorded to create a transect from land to lake and to gather information about the formation of the sediment layers in connection to the features (Goldhammer *et al.* 2019).

Based on the elevated construction method of the wooden structure and its stratigraphic position within the lake sediments, we assume that the structure might have served as a crossing over an open waterbody. The exact purpose of the structure has not yet been fully clarified. It may have led to a not yet known settlement or may have been used to cross open water between the former island and the mainland. No settlements associated with the walkway have been found. However, pottery from the Early Neolithic period (5500–5000 cal BCE) of the Bandkeramik type and from the Middle Neolithic period (5000–4400 cal BCE) of the Grossgartach (4900–4700 cal BCE) and Rössen (4700–4500 cal BCE) types is known from the former island of Buchau, as are the finds from the Younger Neolithic (4400–3500 cal BCE), that could indicate the presence of settlements during this time. No features have been found to date.

Due to the preservation of the longitudinal timbers and because we could document many vertical piles stuck in the ground with matching fragments which may have broken off (Goldhammer *et al.* 2019), we assume that the structure must have collapsed while it was still largely intact.

Elevated wooden structures dating from the 4<sup>th</sup> millennium BCE are known from the Campe Bog between Lake Dümmer and Osnabrück in Lower Saxony (Heumüller 2022) and from Shapwick Heath in the Somerset Levels in England, the so called ‘Sweet Track’ (Coles *et al.* 1973). The Campe Bog Structure Pr 33/36, dates to around 3798 BCE, was built from pairs of oak piles set up in two rows 60 to 80 centimetres apart. They are considered to have been the pile bents for an elevated walkway (Heumüller 2022). The Sweet Track, built in 3807 and 3806 BCE (Hillam *et al.* 1990), crossed a waterbody and was constructed with crossed pegs driven into the peat to form an ‘X’ above a base rail. The crossed pegs supported planks up to 40 cm wide, which lay in the upper part of the ‘X’ (Coles *et al.* 1973, 265–271). Pr 33/36, Sweet Track and Möwenweg differ in their construction techniques, but were all built in the first half of the 4<sup>th</sup> millennium BCE to cross a waterbody.

### **Finds in between and around the structure**

Around 50 artefacts directly related to the wooden structure were discovered on the site Möwenweg, most of them on, next to and between the timbers of the wooden structure. The finds are mainly pottery shards, net sinkers made of ceramic, but also worked bones and stone tools. The most outstanding finds here are a rock axe made of a greenish, presumably metamorphic serpentinite-like stone

(Goldhammer *et al.* 2019), whose surface is completely polished, a rim sherd with finger pinch decoration, two silex arrowheads with preserved birch bark tar for hafting, and two sickle inserts made of grey tabular chert. In general, sickle blades and rim shards are typochronologically comparable to those of Pfyn-Altheim complexes which date between 3800–3500 cal BCE.

### **Sickles from tabular chert**

Both sickle blades represent the Altheim type (Schlichtherle 1992a), although there is a striking difference in size between the objects. Fragmented sickle no. 31 measures 8.1 cm x 3.5 cm and might have been significantly smaller (Find No. 2018\_0143-31; Fig. 3; Fig. 5) than find no. 11, which is fully preserved and measures 19.8 cm in length and 5.4 cm in width (Find No. 2018\_0143-11, Fig. 4). The fragmented one (no. 31, 0.8 cm thickness) is significantly thinner than the fully preserved one (no. 11, 1.1 cm thickness).

Both sickles from Möwenweg were made of tabular chert, which is convenient for the chert knappers – they only had to work out the edges. A significant part of the original surface with cortex remains. The edges of the sickles as well as parts of the surface of sickle no. 11 were carefully retouched, presumably with a soft knapping technique.

The chert variety of both sickles is comparable: it is non-translucent, compact, is of light grey to greyish colour below the cortex and with a grey to caramel brown core. The cortex is of light grey colour and has a rough surface with small depressions. One side of the tabular nodule has a slightly coarser cortex structure than the other. The raw material might originate from primary sources of table chert in the Franconian Jurassic’s south, located in Lower Bavaria (Binsteiner 2005; Moser 1978), in c. 180–200 km distance to Bad Buchau. The appearance differs from the chert known from Abensberg-Arnshofen, because the Möwenweg chert is lacking the clear and fine lamination as well as the smooth cortex of this chert variety (Engelhardt and Binsteiner 1988). To clarify whether the objects originate from other known chert deposits such as Baiersdorf or Tempelhof (Binsteiner 2005), further analysis is required.

The fragmented sickle (no. 31) shows no traces of sickle gloss on the preserved convex side, while the concave side of the large sickle (no. 11) is covered with sickle gloss. This could have been caused by cutting grain, grass or other natural products (Schlichtherle 1992a). A use-wear analysis has not yet been carried out.

Presumably, the convex side was not used as a working edge, it was covered by a handle as reconstructed by Schlichtherle (1992a, 34 Fig. 9: 1). The fully preserved sickle (no. 11) shows traces of a brown adhesive substance, presumably birch tar remains from the attachment of the sickle into a handle. Retouches without sickle gloss in some areas of the working edge of find no. 11 indicates resharpening of the sickle blade after a certain time of use.

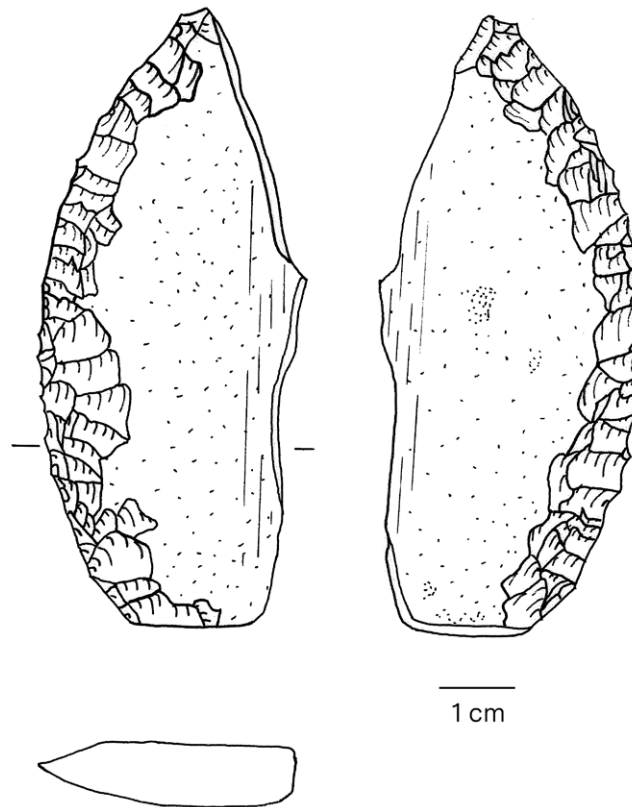


Figure 3: Fragmented lithic sickle blade (no. 31) from Bad Buchau-Möwenweg (LAD in the RPS, drawing: J. Hoffstadt).

The fragmented sickle (no. 31) might have been broken during resharpening or using. The fracture runs from the pointed side to the wider base of the preserved fragment.

Sickle blades made from tabular chert like the ones outlined above are known from other Pfyn-Altheim contexts: One was found at the pile dwelling settlement Wolpertswende-Schreckensee (District of Ravensburg; Schlichtherle 1992a, 34 fig. 9: 4), another one is known from Seekirch-Ödenahlen (District of Biberach; Schlichtherle 1992b). Other sickle blades from tabular chert are known from Bad Buchau-Kappel (District of Biberach; Schlichtherle 1992b, Fig. 3: 1), Bad Schussenried-Aichbühl/Riedschachen (District of Biberach) and Bad Buchau-Henauhof (District of Biberach) as well as several from Lake Constance without stratification (Schlichtherle 1992a, 33).

It remains unclear how long sickle blades were manufactured and commonly used, and when they were completely replaced by bronze sickles. In the Terminal Neolithic ('Endneolithikum' according to Lüning 1996), simple reaping knives were also used to cut plants (Schlichtherle 1992a, 36–37). A lithic sickle blade from the Early to Middle Bronze Age settlement Bad Buchau-Forschner (Schlichtherle 1992a, 39) indicates that lithic sickle blades were also used in southwestern Germany

during the Bronze Age, as was the case in other European regions (Eriksen 2010).

The sickles from Möwenweg were found in wet conditions in a fen. Antler or wood are likely to remain well preserved in such circumstances. If the sickles had been used with a wooden or antler handle, the handles would have been removed before the lithic inlets ended up at the walkway. Either they were deliberately discarded there, or they were lost before a new handle was attached. In case of the broken sickle (no. 31), a disposal is conceivable. The completely preserved sickle (no. 11) could have been used for longer. In that case an offering can also be considered but is not certain. Other finds from the site, including a stone axe blade and two stone arrowheads, were not found with axe handles or arrow shafts. This supports an interpretation that some of the finds were intentionally deposited along the walkway. More detailed investigations are necessary in this regard.

### Summary and outlook

The structure of Bad Buchau-Möwenweg from the Pfyn-Altheim-Horizon can be considered as one of the oldest walkways in Central Europe to date – where it began or where it ended is yet not known. It dates to the time shortly before the wheel was invented in southern Germany. The walkway was constructed with longitudinal timbers to walk

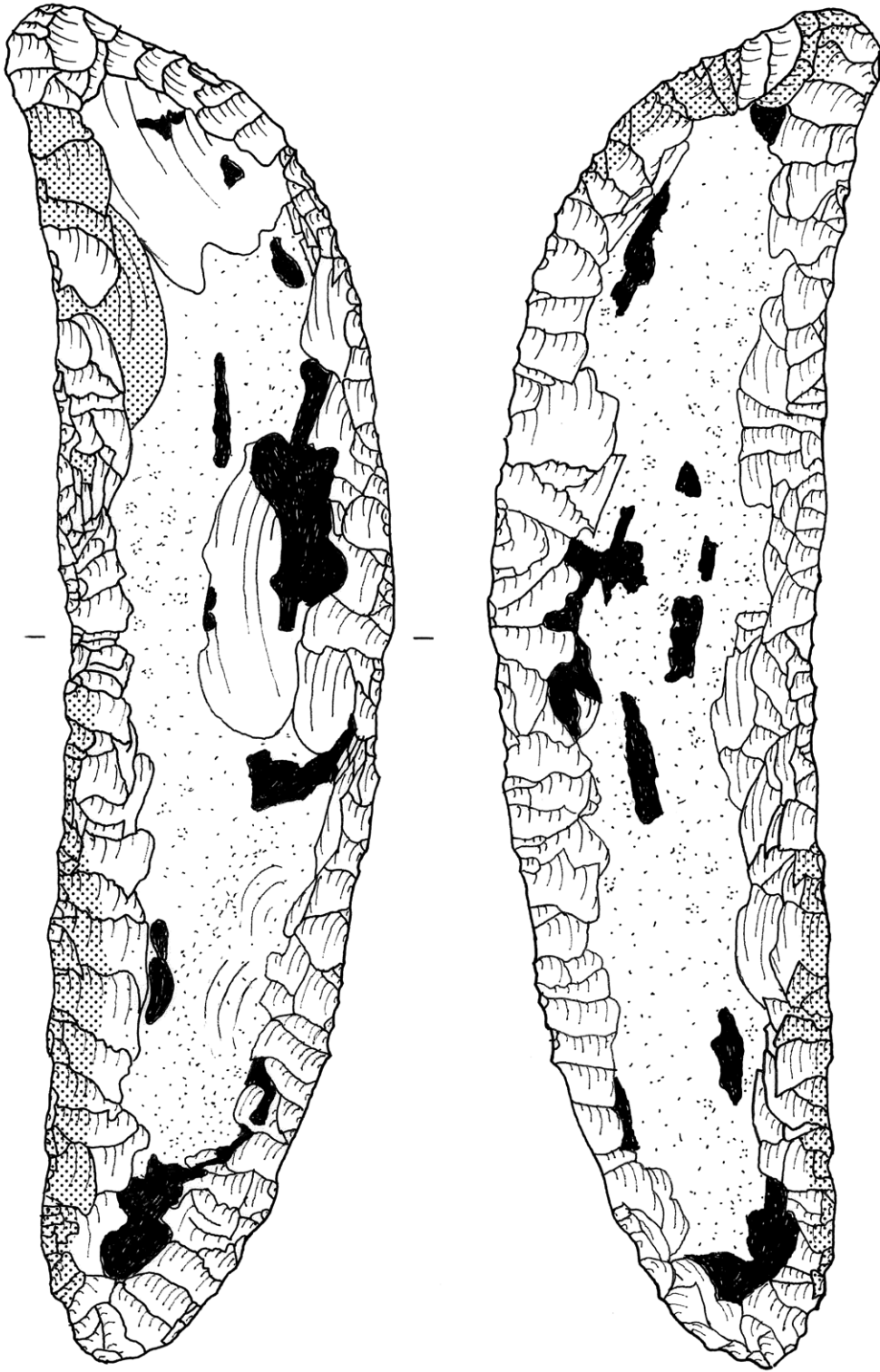


Figure 4: Lithic sickle blade (no. 11) from Bad Buchau-Möwenweg with adhesive residue (black) and sickle gloss (dotted), (LAD in the RPS, drawing: J. Hoffstadt, graphic: J. Goldhammer).



Figure 5: Photograph of lithic sickle blade (no. 11) from Bad Buchau-Möwenweg (LAD in the RPS, M. Erne).

on. Later bridges or boardwalks were built with transverse timbers or logs.

Two sickle blades made from tabular chert have been discovered: One is complete and shows sickle gloss, one is a sickle blade fragment, and both can be assigned to the Altheim type. The sickle blades may have been lost or deposited on purpose. More detailed investigations of the wood, the layout of the feature, the finds as well as the stratigraphic situation are currently underway. These studies will provide more detailed information about the wooden structure, the construction phases, and taphonomic processes that began after the walkway was abandoned. Furthermore, they will shed more light on the circumstances under which the finds ended up in the ground.

### **Acknowledgements**

Many thanks to my colleagues from Hemmenhofen who were involved in the Bbm project and some of whom still are: Wolfgang Hohl, Sebastian Böhm, Mario Schöttl, Karl-

Heinz Thiel, Karim Fayez-Fazel, Paul Scherrer, Richard Vogt, Oliver Nelle, Sebastian Million, Nuria Schäfer, Monika Erne, Jutta Hoffstadt, Arno Harwath, Oriol López Bulto, and Helmut Schlichtherle. Many thanks to the Federseestation Bad Buchau (Chair of Comparative Zoology, University Tübingen), Kleinheinz excavator company Bad Buchau, and the municipality of Bad Buchau, which contributed to the costs of the archaeological excavation. Many thanks to two anonymous reviewers for helpful comments and remarks. I dedicate this essay with a big thank you to Berit Valentin Eriksen, co-supervisor of my doctoral thesis from 2009 to 2014: Thank you very much for all your great help, your incredible commitment, your inspiring tips and your wonderful support. Thank you for giving me the opportunity to participate in the Nordic Blade Technology Workshop in Paris and the use-wear course in Schleswig, and for encouraging me to continue and successfully complete my dissertation. De bedste ønsker og hilsner fra syd til nord.

## References

- Binsteiner, A. 2005. Die Lagerstätten und der Abbau bayerischer Jurahornsteine sowie deren Distribution im Neolithikum Mittel- und Osteuropas. *Jahrbuch Römisch-Germanisches Zentralmuseum Mainz* 52(1), 43–155.
- Coles, J. M., Hibbert, F. A., Orme, B. J. 1973. Prehistoric roads and tracks in Somerset, England, 3: The Sweet Track. *Proceedings of the Prehistoric Society* 39, 256–293. DOI: 10.1017/S0079497X00011683
- Ebersbach, R., Goldhammer, J., Hohl, W., Marinova-Wolff, E., Nelle, O., Scherrer, P. and Vogt, R. 2021. Brücken, Stege, Einbäume – neue Entdeckungen am Federsee. *Archäologie in Deutschland* 2021(4), 8–13.
- Engelhardt, B. and Binsteiner, A. 1988. Vorbericht über die Ausgrabungen im neolithischen Feuersteinabbaurevier von Arnhofen, Ldkr. Kehlheim. *Germania* 66, 1–28.
- Eriksen, B. V. 2010 (ed.). *Lithic Technology in metal using societies. Proceedings of a UISPP Workshop, Lisbon, September 2006*. Højbjerg, Jutland Archaeological Society.
- Goldhammer, J. and Hohl, W. 2019: Holzsteg aus dem 4. Jt. v. Chr. *Archäologie in Deutschland* 2019(4), 48.
- Goldhammer, J., Hohl, W., Nelle, O. and Vogt, R. 2019. „Übers Wasser führt ein Steg“ – Das Holzbauwerk von Bad Buchau, Möwenweg. *Archäologische Ausgrabungen in Baden-Württemberg* 2018, 94–97.
- Heumüller, M. 2022. Moore als Siedlungs- und Verkehrsraum in der Jungsteinzeit, in: Klimscha, F. and Wiggering, L. (eds.). *Die Erfindung der Götter. Steinzeit im Norden*, Hannover and Petersberg, Michael Imhof Verlag, 196–211.
- Hillam, J., Groves, C. M., Brown, D. M., Baillie, M. G. L., Coles, J. M. and Coles, B. J. 1990. Dendrochronology of the English Neolithic, *Antiquity* 64(243), 210–220. DOI: 10.1017/S0003598X00077826
- Lüning, J. 1996. Erneute Gedanken zur Benennung der neolithischen Perioden. *Germania* 74(1), 233–237. DOI: 10.11588/ger.1996.57483
- Moser, M. 1978. Der vorgeschichtliche Bergbau auf Plattensilex in den Kalkschiefern der Altmühl-Alb und seine Bedeutung im Neolithikum Mitteleuropas. *Archäologische Informationen* 4, 45–81.
- Schlichtherle, H., 1992a. Jungsteinzeitliche Erntegeräte am Bodensee. *Plattform* 1, 24–44.
- Schlichtherle, H., 1992b. Ödenahlen – eine neolithische Siedlung der „Pfyn-Alzheimer Gruppe Oberschwabens“ im nördlichen Federseeried, Archäologische Untersuchungen 1981-1986. In: Landesamt für Denkmalpflege im Regierungspräsidium Stuttgart (ed.), *Siedlungsarchäologie im Alpenvorland III*. Forschungen und Berichte zur Vor- und Frühgeschichte in Baden-Württemberg 46. Stuttgart, Konrad Theiss.

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# Between Thy and Tübingen

This volume brings together twenty peer-reviewed studies honouring the scholarly career of Berit V. Eriksen, whose research has been highly influential in the study of Late Palaeolithic and Mesolithic hunter-gatherers in central Europe and southern Scandinavia. The contributions focus on the Late Glacial and Early Holocene, a time marked by profound environmental, social, and technological transformations that reshaped hunter-gatherer lifeways.

Reflecting both Eriksen's research interests and current debates in the field, the contributions address a broad range of themes in hunter-gatherer research. These include lithic technology and raw material procurement, long-distance connections and exotic materials, subsistence strategies, burial practices, and aesthetic expression. Several contributions emphasise methodological and theoretical innovation, employing approaches such as geophysical survey, palynology, isotopic analyses, and taphonomic studies to refine chronologies, reconstruct past environments and human-environmental interactions.

Geographically, the volume spans across northern Germany, Denmark, southern Scandinavia, the Baltic region, and adjacent areas, offering case studies that illuminate



both regional variability and wider patterns of transition. Particular attention is given to processes of change and continuity, including the emergence of Mesolithic lifeways, shifting relationships between humans, animals, and environments, and the complex responses of hunter-gatherer societies to climatic and ecological challenges. Together, the contributions question linear narratives of cultural development and highlight the diversity and dynamism of Late Palaeolithic and Mesolithic worlds.

Aimed at researchers, students, and readers with an interest in early prehistory, this volume presents new data, innovative interpretations, and critical reflections that advance our understanding of hunter-gatherer societies at the end of the Ice Age and the beginning of the Holocene, while celebrating Berit V. Eriksen's lasting impact on the discipline.



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ISBN: 978-94-6427-156-0



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