SPRAWOZDANIA ARCHEOLOGICZNE 76/1, 2024
PL ISSN 0081-3834
DOI: 10.23858/SA76.2024.1.3569

Kamil Nowak[1], Dawid Sych[2]

TRACEOLOGY OF METALWORK – LIMITATIONS AND NEW PERSPECTIVES

ABSTRACT

Nowak K. And Sych D. 2024. Traceology of metalwork – limitations and new perspectives. *Sprawozdania Archeologiczne* 76/1, 99-121.

The article focuses on the traceology of metalwork, its methodological limitations, and new research perspectives. In the text, we explain what studies on traces on metals entail and how they are characterized. We provide examples from both Poland and other regions of Europe. We highlight possible directions for the development of the method as well as factors that hinder it.

Keywords: archaeology, traceology, metalwork, archaeometallurgy, wear analysis
Received: 30.09.2023; Revised: 18.11.2023; Accepted: 04.04.2024

INTRODUCTION

The analysis of traces found on artefacts made from various materials has been developing for many decades. Traceological studies are primarily associated with the analysis of the surfaces of stone objects (*e.g.*, Pyżewicz 2021). The precursor to the use of traceology in archaeology is often attributed to the Russian scholar S. A. Semenov, who studied artefacts made from stone (1957; English edition in 1964).

1 Institute of Archaeology, Centre for Applied Archaeology, Nicolaus Copernicus University in Toruń, Szosa Bydgoska 44/48, 87-100 Toruń, Poland; kamil.nowak@umk.pl; ORCID: 0000-0002-8137-0059
2 School of Archaeology and Ancient History, University of Leicester, University Road, Leicester, LE1 7RH, United Kingdom; dawid.sych@gmail.com; das51@leicester.ac.uk; ORCID: 0000-0002-3166-5211

Currently, this method is still used primarily to study objects made from stone materials (*e.g.*, Osipowicz 2022; Kufel-Diakowska *et al.* 2022), but also bone and antler (*e.g.*, Płonka *et al.* 2022; Orłowska 2021; Stelmasiak 2021; Orłowska and Osipowicz 2021; Winnicka 2019), as well as artefacts made from shells (*e.g.*, Alarashi *et al.* 2021; Kurzawska 2021), wood (*e.g.*, Caruso Fermé *et al.* 2015; on a broader macroscopic scale, Thomas 2018), or ceramic materials (Vieugué 2014; Gawron-Szymczyk *et al.* 2022). Many important and interesting works related to artefacts from specific sites or areas have been produced, as well as research on the methodology of wear analysis on such objects (*e.g.*, Adams 2014). It would be challenging to list all the works related to wear analysis on stone artefacts alone, as there is a specialization in specific types of rocks (flint, sandstone, etc.) and types of action that would leave wear traces.

An integral part of wear research is the creation of a reference database consisting of traces on copies of archaeological artefacts. Here, too, stone, bone, and antler artefacts take the lead in databases of experimentally acquired traces (*e.g.*, Kufel-Diakowska *et al.* 2020; Orłowska *et al.* 2022; 2023; Sobkowiak-Tabaka and Kufel-Diakowska 2019; Orłowska and Osipowicz 2017). In Polish traceology of non-metallic artefacts, researchers from the Toruń and Wrocław centres stand out in terms of the quality and scope of their studies.

Observations of the surfaces of metal objects, mainly made of copper and its alloys, in comparison to stone artefacts, have received significantly less attention among researchers. The main reason for this is the effects of the corrosion process affecting the majority of metals used in the past which was assumed to have concealed all the wear (Kasprowicz 2022, 77-78; Sych 2014, 36-37). Many researchers also believed that copper and even bronze were too soft to be a proper material for the manufacture and use of tools and weapons; therefore, it was believed that they played mostly symbolic and wealth accumulation roles (Kristiansen 2002, 319-320). However, this situation has changed dramatically in recent decades. This shift is due to a number of experiments and research publications by archaeologists who have proven that wear analysis of metalwork is as valid as the analysis of objects made of other materials. As a result, metalwork wear analysis has firmly established itself in the repertoire of research on metal artefacts (Dolfini and Crellin 2016). In Poland, too, we see a significant rise of interest in this type of research.

Metalwork wear analysis is an invaluable research tool. A careful study of metals and the objects with which they came in contact can tell us a lot about past societies: from their beliefs, economy, and social hierarchy to their sense of aesthetics and perception of quality. Currently, we are able to create new narratives not only about assemblages of artefacts but also to create detailed biographies of individual objects.

The aim of our article is to outline the state of research on the traces present on metalwork and to present new directions in the development of this method. The reader should be aware that in this text we use the terms ‘traceology’ and ‘wear analysis,’ as well as ‘wear’ and ‘trace’ interchangeably due to their significant similarity in meaning. It can differ slightly depending on the general context, but we feel that both are appropriate in the majority of cases.

CURRENT STATE OF RESEARCH

Researchers who analyse metalwork under a microscope are interested not only in whether a particular object was used in the past, how it was precisely used and how intensively but also in how it was made and whether the method and quality of production can tell us more about its function in the economic, social, and religious context of various prehistoric societies (Gener 2011; Kuijpers 2015). Similar to the field of research on stone and bone artefacts, in this case, the primary source of information is the work "*Pervobytnaia tekhnika. Opyt izucheniia drevneishikh orudii i izdelii po sledam raboty*" by S.A. Semenov from 1957, which gained more attention after being translated into English by M.W. Thompson in 1964. However, research on metal artefacts began more than two decades later, in the late 1980s (Wall 1987) and the 1990s (Bridgford 1997). It was during this time that researchers began to take an interest in particularly impressive artefacts from the Bronze Age, such as daggers and swords. The first publications dedicated to bronze tools, especially axes, also appeared (Kienlin and Ottaway 1998).

In the first decade of the 21st century, archaeologists continued to focus primarily on bronze swords (Kristiansen 2002; Molloy 2008; 2010). However, over time, their interest shifted towards other categories of artefacts, such as axes (Roberts and Ottaway 2003), halberds (O'Flaherty 2007), shields (Molloy 2009), as well as spearheads (Anderson 2011) and arrowheads (Gutiérrez *et al.* 2010; Sych 2011, Baron *et al.* 2020).

In the second decade of the 21st century, there was a significant increase in the number of analyses and an expansion of the scope of research. Researchers began to examine the impact of artefact conservation on the preservation of production traces and use-wear, especially since many of the analyzed artefacts came from museum collections (Sych *et al.* 2020). More artefacts also became available for study before conservation (*e.g.*, artefacts from Karmin IV, Kaliska I and II, Nowe Kramsko, from the vicinity of Sanok, Jodłowno; Baron *et al.* 2019; Sych 2021; 2022; Nowak 2019; 2022; Nowak and Gan 2023) and before and after the conservation process (Baron *et al.* 2019). Above all, attempts to consolidate and synthesize the results of many years of research began to emerge (Uckelmann and Mödlinger 2011; Gutiérrez and Lerma 2014; Dolfini and Crellin 2016; Hermann *et al.* 2020).

Metalwork wear analysis typically requires smaller magnifications compared to, for instance, that of flint. Magnifications of 20-50× are usually adequate. For basic initial analysis, a simple magnifying glass and natural daylight or a lamp are sufficient. However, it is necessary to observe artefacts under a microscope's eyepiece to identify traces, make notes, and prepare a written report. It is important to note that additional equipment is needed for photographic documentation of traces. Portable digital microscopes such as the Dino-Lite line or similar models are suitable for basic or initial analysis.

The recommended equipment for in-depth analysis includes stereo and metallographic microscopes with additional adjustable light sources. These tools allow the user to observe the surface under different lighting conditions, which is a key aspect of the analysis. We have tested many microscopes, such as the Zeiss Stemi 508 and 2000-C, Zeiss V20 with Axiocam 208 colour, Olympus SZX9, Nikon SMZ745T and SMZ 800N, Hirox RH-2000, and Keyence VHX-7000, all of which have proven to be suitable for metalwork wear analysis. Using high-quality digital cameras allows the creation of composite images that are sharp across the entire surface, thus, appropriate quality documentation. Recently, we have also tested 3D scanning and printing as a method of observing and recording wear on metal objects.

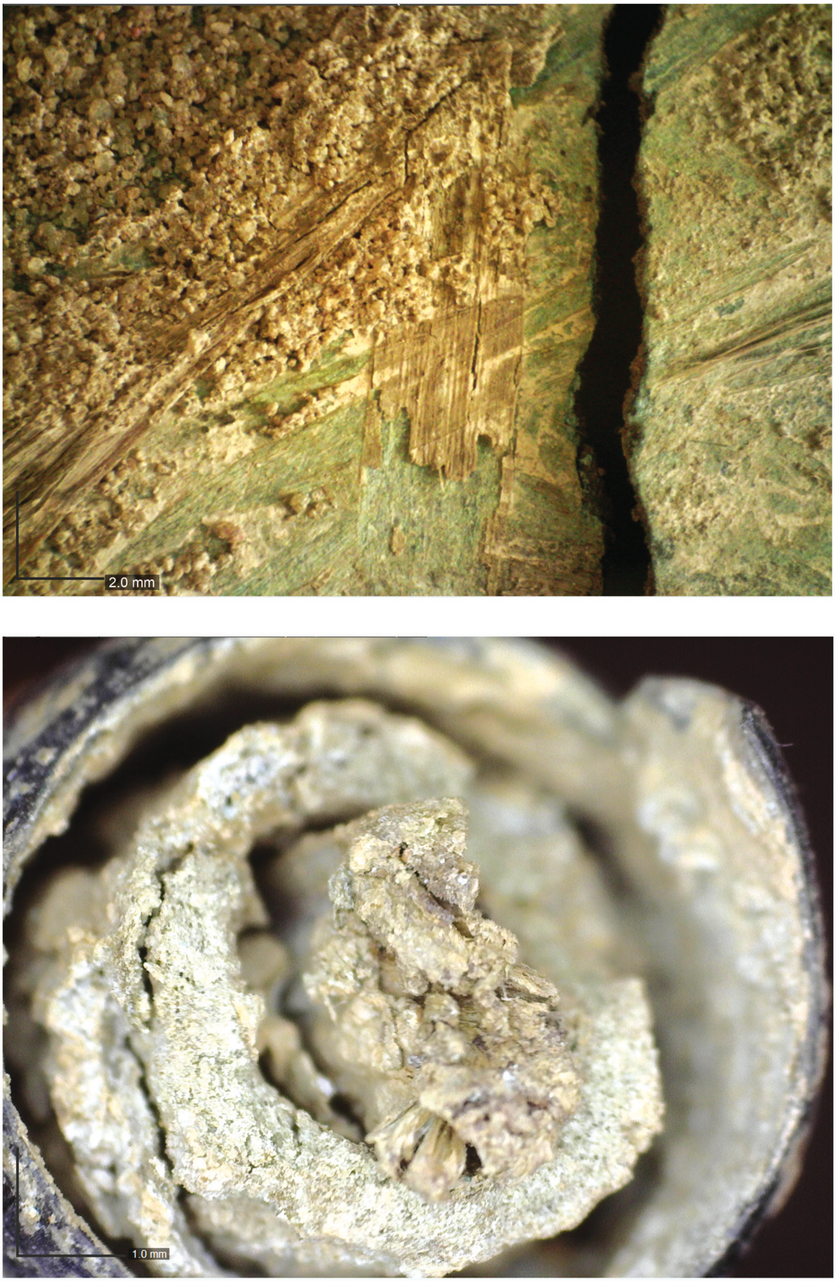
NEW PERSPECTIVES

While the traceological study of metalwork is gaining increasing popularity among Bronze Age archaeologists and researchers interested in other epochs and is slowly establishing solid methodological frameworks, some scholars are already charting new directions for its development. Until recently, archaeologists were primarily interested in the analysis of weapons and tools. The former due to their prestigious nature, and the latter due to their abundance. The fact that both categories had working edges was also significant, making it easier to observe use-wear.

The metalwork wear analysis method is evolving, and its scope of interest is expanding to include new categories of artefacts. New research questions are being posed, and valuable answers are being obtained through traceology. We have selected several examples of new research directions that we believe will be in the centre of interest in wear analysis in the near future.

Residue Analyses

A promising direction for the method is the search for traces of organic residues on bronze artefacts. “Residues refer to materials that are transferred and adhere to an artefact” (Fullagar 2014, and further literature). These residues can include organic materials (grasses, reeds, bast) or traces of textiles, used to tie or cover metal artefacts. This type of traces are often visible already at the macroscopic level (Fig. 1). The remains of organic materials used to bind deposited metals (*e.g.,* Chvojka *et al.* 2014; Nowak *et al.* 2023), that accompanied tubular applications (Blajer *et al.* 2022), or were imprints of fabrics and leather that wrapped metals (*e.g.*, casting moulds in the case of Rosko and the “from Sieniocha river” hoards – Kłosińska and Sadowski 2017, 400; Sikorski 2006) are documented. However, determining the type of organic material used requires microscopic analysis (Mueller-Bieniek and Cywa 2022). Recent discoveries in Poland and beyond have revealed previously undocumented organic residues accompanying metal artefacts.



1
2

Fig. 1. Organic residues on the surface of metal artefacts and constituting their part: 1 – Residues of grass or cereals stuck to the surface of the hollow ankle ring, 2 – A fragment of wood found inside the saltaleone spiral in the hoard from Wola Sękowa (photo: K. Nowak)

In the hoard no. I from Kaliska, the metals were accompanied by fragments of bast string attached to the metals (Przymorska-Sztuczka 2021) and fragments of leathers, probably cattle and pigs, on which the shapes of metal buttons were imprinted (Sawoszczuk *et al.* 2021). In the hoard from Sanok (Biała Góra) and Wola Sękowa, metal artefacts were accompanied by fragments of processed willow twigs, stems of green plants (grasses and millet), cereal remains and leather (Mueller-Bieniek and Cywa 2022; Kuropka 2022). The research carried out allows for obtaining detailed data on the types of raw materials and animal species used. The presence of elements made of organic substances is not always a residue in the strict sense, but usually these types of materials interact directly with metals and their identification provides us with valuable information.

Of particular interest are studies of residues of pitch-like substances that accompanied metal ornaments in the Kaliska I hoard (Kaczmarek *et al.* 2021, plate 59B; Pietrzak 2021, fig. 1). Physicochemical analyses, including infrared spectroscopy (FTIR), melting point measurements, and electron paramagnetic resonance (EPR) spectroscopy, suggest that the metal was coated with a pitch-like substance resembling resin from trees (Pietrzak 2021).

Methods commonly referred to as physicochemical provide an excellent tool for obtaining highly detailed data on residues. Recently, a team led by Isabella Caricola (2022) analyzed the surfaces of daggers from the Bronze Age. An application of biochemical staining and SEM–EDX analysis

> "has proven successful in extracting and identifying animal residues located on cutting edges, including bone, muscle, and tendons. These are interpreted as evidence of prehistoric carcass butchering and carving. Further residues were observed on blade faces and hafting plates or tangs; these are interpreted as remnants of bone handles and sheaths, the latter made of either wood fibers or processed hide and fur" (Caricola *et al.* 2022).

The identified remains suggest that these objects were used not only as weapons but also as tools for processing animal meat. In turn, the team led by Kayleigh Saunderson (2022) managed to identify remains of human skin and textiles on one of the La Tène brooches from the Potzneusiedl cemetery, Burgenland, Austria.

Another excellent example of using physicochemical methods in residue analysis is the application of gas chromatography-mass spectrometry (GC-MS). The use of this laboratory technique for the analysis of the interior of metal vessels (an amphora and three hanging vessels) from the Kaliska I hoard is considered exceptional, as GC-MS is rarely used for metals and involves an extraordinary extraction procedure (Grześkowiak *et al.* 2021, 375-376). Despite the limitations of the extraction method mentioned by the authors, animal fat residues (mainly ruminants) were identified, mixed with plant lipids. The obtained results differ for amphora and hanging vessels, which may indicate that the analyzed fatty acids are largely related to the archaeological context rather than later contamination (Grześkowiak *et al.* 2021, 380).

Analyses of Ornaments

Researchers are increasingly exploring additional categories of artefacts, such as ornaments, clothing components, and vessels. The lack of clear working edges complicates their interpretation, making further research in this direction an intriguing prospect. The initial results of Marcin Kasprowicz's experiments (2021, unpublished master's thesis) are promising because he managed to distinguish traces left by contact with various materials on bronze pins, including wool, flax, and leather (Fig. 2; Kasprowicz 2022, fig. 4-5).

Production traces and use-wear are also clearly visible on artefacts from hoards I and II from Kaliska (Sych 2021; 2022). These include traces created by contact with human skin or other materials, as well as repair traces using the cast-on technique (Fig. 3) and

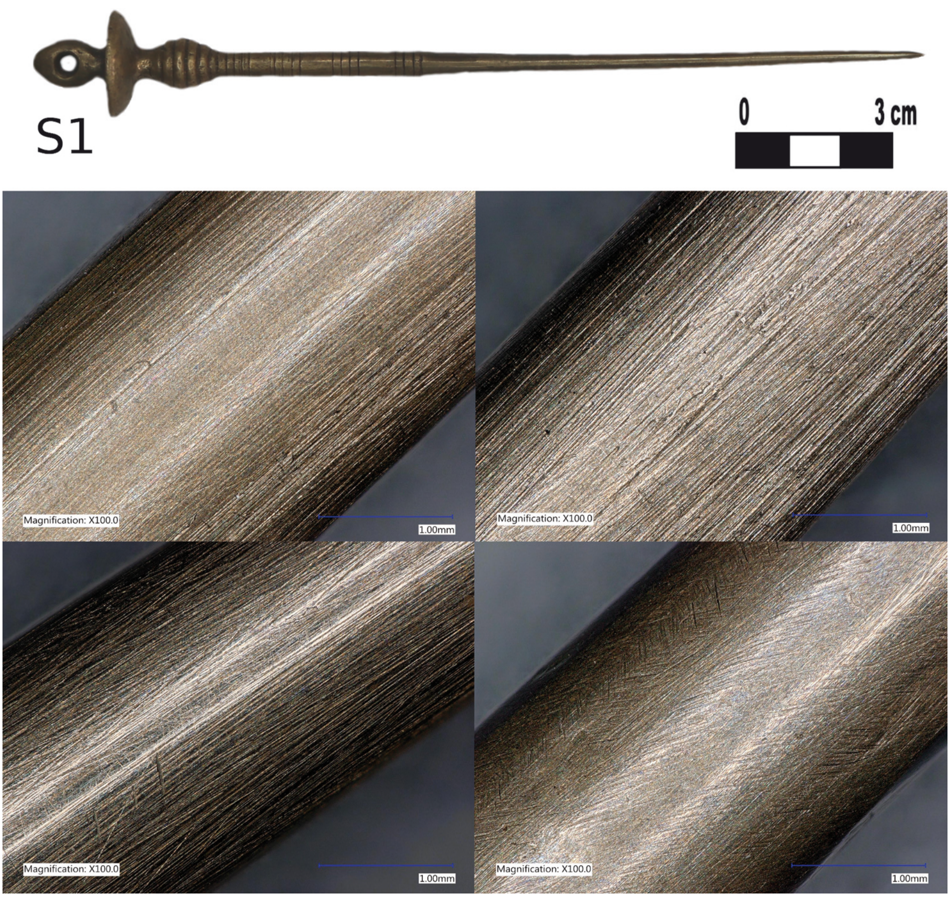


Fig. 2. Surface traces of contact of a pin with different materials (from the top left to lower right): nothing, linen, leather, wool (photo: M. Kasprowicz)

Fig. 3. Repair using cast-on technique on different necklaces from the Kaliska I hoard (photo: D. Sych)

grinding of broken elements. Bracelets from the hoards in Falejówka exhibit characteristic flattening and wear of ornamentation associated with intensive use (Nowak 2022, 82, fig. 37). The surfaces of folded tubes and knobs from the Sanok (Biała Góra) hoard are heavily worn. In this case, the rubbing of the external side of the objects against some type of surface (possibly fabric or animal fur) erased previous manufacture traces (Nowak 2022, 84-85, fig. 39-40). Additionally, in the case of these discussed hoards, traces related to the creation of ornamentation on bracelets and decorated plaques have been identified, including its imperfections (Nowak 2022, fig. 36: 3; 41: 7-8).

Focusing on New Types of Traces – Manufacturing, Repairs, Fragmentation

Wear studies are not limited to traces associated solely with the use of objects. As indicated above, the repertoire of analyzed traces is no longer restricted to those related to combat, agricultural activities, or cutting (*e.g.*, meat or flesh). New directions in wear research include the examination of activities related to production, repairs, or fragmentation.

Objects made of copper and its alloys provide an excellent basis for identifying traces associated with their manufacture. They were created through forging or casting techniques, and both production methods allow for determining the *chaîne opératoire* that resulted in the manufacture of the object. Through comparison with the analysis of the negatives of casting moulds used for casting specific categories of objects, it is possible to identify the locations of sprues or the places where casting seams were formed. Comparisons with casting moulds can rule out the drilling of holes by identifying the core technique and the location of the placement of casting cores that create hollow spaces (*e.g.*, Stolarczyk *et al.* 2020, 158, fig. 45). Sometimes, metal artefacts are accompanied by remains directly related to the casting process. This includes unremoved casting mould remnants, documented, for instance, in the case of kidney-shaped bracelets from the Stolpe auf Usedom hoard, Mecklenburg-Western Pomerania, Germany (Bartel *et al.* 2009, 25-26, fig. 8), or inside a hollow bracelet recently discovered in Jodłowno, Gdańsk County (Nowak *et al.* 2023, fig. 8). The analysis of traces related to production allows for determining whether the object was ever used or whether it was deposited in a raw state (Nowak 2019, 180-183, fig. 1.4; Nowak *et al.* 2022; 2023).

Production by using the forging technique is associated with all sorts of metal cracking and deformation resulting from substantial force applied to it. Cracks on the surfaces of artefacts due to plastic deformation are visible in the case of Early Bronze Age necklaces (Ösenhalsringe) from the Marcinowice hoard, Krosno County, Lubusz Voivodeship (Nowak 2020, fig. 8), or bracelets from the Falejówka hoard, Sanok County, Podkarpackie Voivodeship (Nowak 2022, fig. 35). The manufacture of objects from sheet metal also leaves distinctive production traces. In the Sanok (Biała Góra) hoard, folded tubes were hammered out of sheet metal, and knobs were formed, leaving traces of cutting and bending (Nowak 2022, fig. 39-40). In the Zarszyn hoard, dense forging traces, which were used to shape the vessel, were documented on one of the metal vessels made of thin sheet metal (Nowak 2022, fig. 42.3-4).

Another interesting issue is the identification and documentation of traces of repairs to metal objects. Two types of repair can be distinguished: usually clearly visible repairs using cast-on technique and using riveted elements, and less conspicuous traces of repairs involving grinding of broken tools or weapons. The first category often includes fillings of incomplete holes in the case of vessels, joining with cast-on technique (with or without the use of additional elements) of cracked objects, or riveting elements of collars. All traces of that kind are clearly visible in the case of the Kaliska I hoard (Kaczmarek *et al.* 2021, plates 4B-4C, 6B, 9B, 10A-10B, 24A-24B [selection]).

Traces of the second type of repairs are decidedly more challenging to interpret, as they often do not differ from traces associated with production, such as sharpening or grinding. Occasionally, the shape of the artefact – especially in the case of weapons and tools – may suggest that it underwent numerous repairs, as can be inferred, for example, from the asymmetry of the blade. In the case of arrowheads from the Wrocław-Widawa hoard, such traces associated with sharpening and repairing of the barbs were identified (Baron *et al.* 2020).

The issue of dividing and destroying metal objects has recently gained a lot of interest (*e.g.*, Knight 2021; Lago *et al.* 2023). The topic of fragmentation has been the subject of many studies and is associated with many behaviours, ranging from ritual and symbolic, through social, and purely utilitarian ones connected with issues of weights and premonetary systems of exchange (*e.g.*, Rezi 2011; Chapman 2012; Ialongo and Lago 2021; Nowak and Ialongo, in press). The places of fractures are also examined, thanks to which it is possible to reconstruct the process of dividing objects and indicate whether the fragmentation was intentional or could be related to use (Knight 2021). There are traces of bending and breaking on the edges of broken objects (*e.g.*, sickles from the hoard from Paszowice, Jawor district or Velké Bílovice, Breclav district; Nowak *et al.* 2019, 448, fig. 3.b-d; Parma *et al.* 2021, 126, fig. 10). Traces of intensive bending were often associated with the ritual destruction of objects (Nebelsick 2000). However, as per

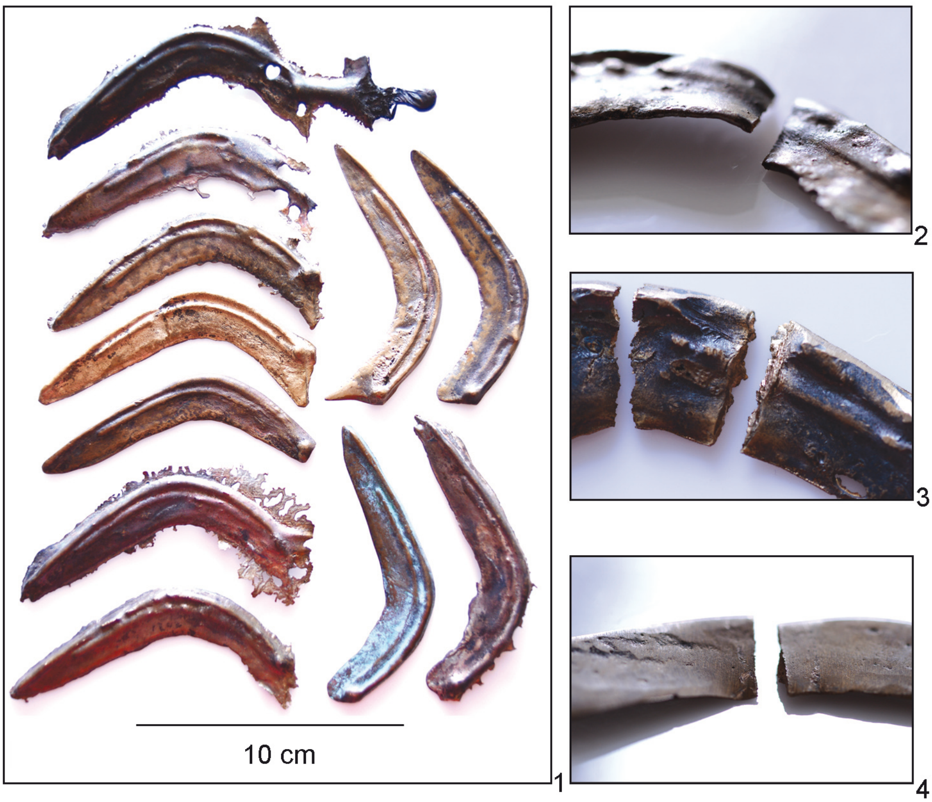


Fig. 4. Archaeological experiment related to the fragmentation of bronze sickles: 1 – Replicas of Lusatian knobbed sickles made in analogous casting moulds. Various casting quality, 2 – Fragmentation using wooden basis and wooden hammer, 3 – Granite basis and metal (Fe) chisel, wooden hammer as impact factor, 4 – Granite base and wooden hammer (photo: K. Nowak)

M. Knight's observations and experimental research, we now understand that intentional damage may not produce discernible marks on metal owing to the controlled application of heat to the item. Moreover, bending is just one among several characteristics linked with deliberate destruction, others include twisting, crushing, notching, breakage, burning, stabbing with a pointed object and, in the instance of socketed objects, the plugging of sockets. Considering all of these factors and discerning their quantitative and qualitative relationships would enable us to attempt to answer the questions: was the destruction intentional, and if so, was it for ritualistic or practical purposes? If not, was it a result of intense use or just corrosion (Knight 2021)?

Another category of traces related to fragmentation are longitudinal concavities and cuts, which are intended to indicate the place of breaking and also to facilitate it. These types of marks are often observed on the surfaces of plano-convex ingots (casting cakes) and were intended to divide the raw material into smaller portions (Nessel 2014, 405). In Poland, such fragmentation was identified in the case of a small casting cake from the Paszowice hoard (Nowak *et al.* 2022, 96, fig. 4.d), it is also visible on objects discovered in neighbouring areas (*e.g.*, Drslavice 2, Uherské Hradiště district or Feldkirch, Vorarlberg; Salaš 2005, plate 169.340; Nessel 2014, 406, fig. 6). Cuts intended to facilitate and divide the object, as well as even division lines indicating the use of this technique, were also identified on fragments of sickles and bracelets from the hoard from Nowy Kramsko, Zielona Góra district (Nowak and Ialongo, fig. 8.3, 9.1, in press). Experiments are also performed on dividing objects after heating them (Knight 2019; Lago *et al.* 2023). One such experiment was carried out using replicas of Lusatian knobbed sickles (Fig. 4). Experiments related to the fragmentation of sickles were carried out on replicas made by one of the authors of this paper and broken by him and by archaeology students of the Institute of Archaeology University of Wrocław during a seminar led by Dr. Bernadeta Kufel-Diakowska. Some of the recorded traces are analogous to those visible on the original artefacts.

Traces of Metal Implements on Bone, Antler, Stone, and Wood Artefacts

Equally intriguing as the analyses of bronze artefacts are studies of objects that had direct contact with them, including bones and antlers. A good example of a pioneering approach to this issue is the research conducted in recent years by Justyna Baron and Marcin Diakowski (Baron *et al.* 2018; 2023). Although traces of bronze tools have been found in older periods (Osipowicz *et al.* 2018; Baron *et al.*, in press), J. Baron and M. Diakowski demonstrated that even in the late Bronze Age in southwestern Poland, metal tools were rarely used for working bones (2018). The change in this regard only came with the Early Iron Age.

Stone objects also bear traces of processing, which can be associated with the use of metal tools. Preparing the surface of rocks requires appropriate equipment and knowledge.

1

2

Fig. 5. Manufacture traces on the stone casting moulds from the Legnica, Spokojna Street:
1 – Chiselling of the outer surface of the mould from Grave 42, 2 – Narrow and longitudinal chisel marks on the mould from Grave 153 (photo K. Nowak)

In addition to the remains of direct use of casting moulds, crucibles and nozzles in the pyrometallurgical process (*e.g.*, Erb-Satullo *et al.* 2015; Miazga 2016; Figueiredo *et al.* 2021; Żurkiewicz *et al.* 2023), traces of production are often visible on their surfaces. Such traces, made with saws, chisels, or axes, have been noted in the literature. Lüben Leschtakow describes traces related to the production of casting moulds from the Pobit Kamak hoard in Bulgaria (2016 [2019], 219-221). Burger Wanzek (1989, 35) also points to the use of saws and chisels in the initial processing of rock surfaces.

Traces of production have also been identified in the case of casting moulds discovered in southwestern Poland. Casting moulds for the production of socketed axes from Wołów (Wohlau-Ost), Lower Silesia bear traces of sawing and breaking, as well as chiselling. On one of the narrower sides of the mould, there is a distinct, even incision trace approximately 0.5 cm deep. Below it is an uneven surface, indicating that the stone was first incised in a characteristic manner and then broken. On the remaining narrower sides, there are also dense traces of a small tool, most likely a chisel. Chiselling was aimed at smoothening the break (Nowak, in press). Traces of processing are also visible in the case of stone moulds discovered at the cemetery in Legnica, Spokojna Street (Nowak and Stolarczyk 2016). Tool marks such as wedge-shaped chisels or small axes are visible on the external and lateral surfaces of the moulds for producing axes from Graves No. 42 and 153 (Fig. 5).

Wear and metal residue on tools used in the metallurgical process are also of interest to researchers. The results recently published by Czech researchers indicate that metal processing residues (in this case silver) are identified on percussion tools made of copper (Peška *et al.* 2023). The surfaces of stone objects used in metal forming have been analyzed for many years (*e.g.*, Butler and van der Waals 1966, 72). The surfaces of hammers and anvils are examined macro- and microscopically and by using spectral methods to identify metal remnants (*e.g.*, Freudenberg 2009; 2014; Müller *et al.* 2023). Gold and tin residues on stone objects from the United Kingdom have been recently identified, altering our perspective on the interconnections between different materials used in the past (Crellin *et al.* 2023; Carey *et al.* 2023). These connections between different materials are further explored through the "A New History of Bronze: crafting, leadership, and violence" (https://bit.ly/a-new-history-of-bronze) project at the University of Leicester under the supervision of Rachel Crellin. This project is the largest in terms of the amount and diversity of analyzed artefacts so far in the field of metalwork wear analysis, and one of the present authors is involved in it.

Modern Methods of Documenting Traces

The development of metalwork wear analysis involves not only expanding the method to new categories of artefacts and deepening analysis but also advancing documentation methods. In earlier analyses, dental impression materials were used to record wear (Roberts and Ottaway 2003). Today, digital photography is primarily used, along with photogrammetry and 3D scanning (Molloy *et al.* 2016; Sych *et al.* 2018). The results of such pairing can be seen at: https://www.bit.ly/traseoskan3d.

LIMITATIONS

Challenges and Limitations in Traceological Analysis

One significant limitation of the traceological method is the conservation process. Often, conservation procedures are necessary to preserve artefacts and prevent irreversible damage. Surfaces damaged by rapidly advancing corrosion are also less amenable to reliable analysis. For many years, we have appealed to the archaeological community, museum professionals, and conservators to make artefacts available for wear analysis before undertaking conservation procedures. To minimize the impact of post-depositional processes on the identification and interpretation of traces, it would be beneficial to examine artefacts shortly after their discovery, still retaining soil deposits, or to document each step of artefact cleaning meticulously. This way, we can ensure that any new trace resulting from the use of brushes or other cleaning/conservation tools is not mistakenly attributed to prehistoric times.

We advocate that such actions should be adopted as standard procedure for metalwork wear analysis. For this to succeed, the dissemination of information about the method among archaeologists is necessary. Curators and those responsible for artefacts should be made aware that before conserving artefacts, it is worthwhile to have them analyzed by a metalwork wear specialist. They should also inform conservators about plans for such analyses in the future, so they are extra careful while cleaning metal surfaces.

Another limitation of the method, besides issues related to the preservation state of artefacts and conservation, is that many researchers conduct independent analyses rather than working in teams or groups. Traceological analyses are often carried out as part of researchers' individual interests, master's or doctoral theses, or grant projects. Researchers seldom convene at thematic conferences to discuss methodological issues, resulting in a lack of clearly defined methodological frameworks. The issue of a common nomenclature for identifying traces remains unresolved, as highlighted by Andrea Dolfini and Rachel Crellin a few years ago (2016). Information on recommended equipment and observation conditions or trace documentation protocols is also hard to find.

The issue of conducting archaeological experiments and creating databases of traces obtained on replicas, as is the case with artefacts made of other materials (stone, bone, antler), poses a significant limitation to the traceology of metals. It is no longer just a lack of easily accessible digitized databases; the problem lies in the absence of any reference database created according to universally accepted and established standards. This issue is a pressing concern for future traceological research, and this gap should be filled in the near future. One of the steps we have taken is an attempt to create a database of traces on original and replica Lusatian socketed axes. The research is conducted by the authors with the participation of Mr. Albin Sokół from the Archaeological Museum in Biskupin. The preliminary results of the experiments were presented during the 13th Experimental Archaeology Conference #EAC13, which took place on April 30-May 3, 2023, in Toruń (paper: Nowak K., Sokół A., Sych D. "From Mould to Earth: Experimental and Traceological Study of Lusatian Socketed Axes"; link to the presentation: https://bit.ly/from-mould-to-earth-exarc-2023).

DISCUSSION AND CONCLUSIONS

In recent years, the traceology of metal artefacts has experienced significant growth. The method is no longer just a curiosity but is increasingly used as a standard analysis in the examination of deposits of bronze artefacts (and more). The short outline of the state of research and new perspectives we have presented indicates the possibilities of further development of the traceological method.

Simultaneously, individual experiments are being conducted that push the boundaries of metal traceology, such as the search for organic residues on artefacts or the analysis of various categories of objects that came into direct contact with bronzes. Unfortunately, despite all the positive aspects mentioned above, the postulates of A. Dolfini and R. Crellin (2016, 82-85) from a few years ago still remain relevant. Researchers are dispersed throughout Europe, rarely collaborating with each other, and they do not strive for the standardization of the method and the creation of common frameworks. Until this happens, we will not be able to take the next step forward.

The works published so far on traceology of the metalwork in Poland are mainly focused on the work of researchers descending from the Wrocław centre. We are developing the method, but we see that other researchers are interested in methodological issues (Kasprowicz 2022) and creating databases of traces. It is worth mentioning here the works of Paweł Dziechciarz, a PhD student at the Faculty of Archaeology of the University of Warsaw, focused on the multi-aspect analysis of traces on spearheads. The preliminary results were presented during the meeting "SIDEROS. Seminarium z archeologii Europy Środkowej w I tys. przed Chr.," May 24, 2023, and are very promising. We hope that our article will be an encouragement and inspiration to use the metalwork wear analysis method in the research of metal artefacts and to the development of traceology of metalwork in Poland.

Acknowledgments

This paper is part of a research project financed by the National Science Centre (NCN), Poland (project no. 2021/40/C/HS3/00097).

References

Adams J. L. 2014. Ground stone use-wear analysis: a review of terminology and experimental methods. *Journal of Archaeological Science* 48, 129-138.

Alarashi H., Gourichon L., Khalidi L., Chambon P., Sellier P. Maines E., Aoudia L., Anderson P.C., Baumann M. and Langlois O. 2021. Survival kit for the afterlife or instruction manual for prehistorians? Staging artefact production in Middle Neolithic cemetery Kadruka 23, Upper Nubia, Sudan. *Antiquity* 95(E31 384), 1-8.

Anderson K. 2011. Slashing and thrusting with Late Bronze Age spears: analysis and experiment. *Antiquity* 85(328), 599-612.

Baron J. and Diakowski M. 2018. Tools make tools: changes in bone and antler manufacture at Late Bronze and Early Iron Age Polish sites. *Antiquity* 92(363), 1-7.

Baron J., Diakowski M., Kufel-Diakowska B., Nowak K. and Sych D. From flint to metal? Techniques of bone and antler processing in the early Bronze Age Poland, in press.

Baron J., Diakowski M., Badura B. and Stolarczyk T. 2023. Bone, antler, and tooth objects from the late bronze/early Iron Age urnfields in south-western Poland. *Quaternary International* 665-666, 82-92.

Baron J., Puziewicz J., Nowak K., Sych D., Miazga B. and Ziobro M. 2020. Same but different. Composition, production and use of bronze arrowheads from the Late Bronze Age deposit from Wrocław-Widawa in SW Poland. *Journal of Archaeological Science: Reports* 32, 102459.

Baron J., Maciejewski M., Jarysz R., Kuźbik R., Łaciak D., Łucejko J. J., Mackiewicz M., Miazga B., Nowak K. and Sych D. 2019. *Fenomen powtarzalności. Skarby z Karmina*. Wrocław: Uniwersytet Wrocławski.

Bartel B., Kelp A. and Schmidt J.-P. 2009. Von der Ausgrabung in die Werkstatt. Die Restaurierung des bronzezeitlichen Hortfundes von Stolpe, Lkr. Ostvorpommern. *Kulturerbe* 5, 111-116.

Blajer W., Kotowicz P. and Maciejewski M. (eds) 2022. *Ku czci bogów i ludzi: skarby z okolic Sanoka. Studium interdyscyplinarne*. Lublin, Sanok: UMCS w Lublinie, Muzeum Historyczne w Sanoku.

Bridgford S. D. 1997. Mightier than the pen? An edgewise look at Irish Bronze Age sword. In J. Carman (ed.), *Material harm: archaeological studies of war and violence*. Glasgow: Cruithne Press, 95-115.

Butler J. J. and van der Waals J. D. 1966. Bell Beakers and Early Metal-working in the Netherlands. *Palaeohistoria* 12(1967), 41-139.

Carey C., Tsoraki C., Jones A. M., Harris O. J. T., Crellin R. J. and Lyons P. 2023. Beaker and Early Bronze Age Tin Exploitation in Cornwall: Cassiterite Processing Identified through Microwear and pXRF Analyses. *European Journal of Archaeology* 26/2, 147-167.

Caricola I., Charles A., Tirillň J., Charlton F., Barton H., Breglia F., Rossi A., Deflorian M.C., De Marinis A. M., Harris S., Pellegrini Alessio, Scacchetti F., Boccuccia P., Miari M. and Dolfini A. 2022. Organic residue analysis reveals the function of bronze age metal daggers. *Scientific Reports* 12, 6101.

Caruso Fermé L., Clemente I. and Civalero M.T. 2015. A use-wear analysis of wood technology of patagonian hunter-gatherers. The case of Cerro Casa de Piedra 7, Argentina. *Journal of Archaeological Science* 57, 315-321.

Chapman J. 2012. *Fragmentation in Archaeology: People, Places and Broken Objects in the Prehistory of South Eastern Europe*. London: Routledge.

Chvojka O., Kraijc R., Bumerl J., Korený R., Michálek J., Militký J., Šálová M. and Thomová Z. 2014. *Poklady, Depoty, Obetiny. Jihoceske depoty od doby bronzove do novoveky*. Česke Budějovice: Jihočeská univerzita v Českých Budějovicích.

Crellin R. J., Tsoraki C., Standish C. D., Pearce R. B., Barton H., Morriss S. and Harris O. J. T. 2023. Materials in movement: gold and stone in process in the Upton Lovell G2a burial. *Antiquity* 97(391), 86-103.

Dolfini A. and Crellin R. J. 2016. Metalwork wear analysis: the loss of innocence. *Journal of Archaeological Science* 66, 78-87.

Erb-Satullo N. L., Gilmour B. J. J. and Khakhutaishvili N. 2015. Crucible technologies in the Late BronzeeEarly Iron Age South Caucasus: copper processing, tin bronze production, and the possibility of local tin ores. *Journal of Archaeological Science* 61, 260-276.

Figueiredo E., Bottaini C., Miguel C., Lackinger A., Mirăo J., Comendador Rey B. 2021. Study of a Late Bronze Age Casting Mould and Its Black Residue by 3D Imaging, pXRF, SEM-EDS, Micro-FTIR and Micro-Raman. *Heritage* 4, 2960-2972.

Freudenberg M. 2009. Steingeräte zur Metallbearbeitung: Einige neue Aspekte zum spätneolithischen und frühbronzezeitlichen Metallhandwerk vor dem Hintergrund des schleswig-holsteinischen Fundmaterials. *Archäologisches Korrespondenzblatt* 3, 1-19.

Fullagar R. 2014. Residues and Usewear. In J. Balme and A. Paterson (eds), *Archaeology in Practice: A Student Guide to Archaeological Analyses (2nd edition)*. Malden: Blackwell Publishing, 232-263.

Gawron-Szymczyk A., Łaciak D. and Baron J. 2020. To smooth or not to smooth? A traceological and experimental approach to surface processing of Bronze and Iron Age ceramics. *Sprawozdania Archeologiczne* 72/2.

Gener M. 2011. Integrating Form, Function and Technology in Ancient Swords. The Concept of Quality. In M. Uckelmann and M. Mödlinger (eds), *Bronze Age Warfare: Manufacture and Use of Weaponry* (= *BAR International Series* 2255). Oxford: Archaeopress, 117-124.

Grześkowiak M., Fleszar M. and Wiśniewski J. 2021. Wstępne wyniki analiz lipidów z naczyń brązowych ze skarbu z Kalisk, pow. szczecinecki, woj. zachodniopomorskie. In Kaczmarek M., Szczurek G. and Krzysiak A. *Kaliska I. Skarb przedmiotów metalowych z późnej epoki brązu na Pomorzu* (= *Hyperborea. Poznańskie studia nad epoką brązu i wczesną epoką żelaza* 6). Poznań: UAM w Poznaniu, 373-384.

Gutiérrez Sáez C. and Lerma I. 2014. Traceology on Metal. Use-Wear Marks on Copper-Based Tools and Weapons. In J. Marreiros, J. Gibaja Bao. and N. Ferreira Bicho (eds), *Use-Wear and Residue Analysis in Archaeology* (= *Manuals in Archaeological Method, Theory and Technique*). Cham, Heidelberg, New York, Dordrecht, London: Springer, 171-188.

Gutiérrez Sáez C., López del Estal A., Simón Martín A., Muńoz Moro P., Bashore Acero Ch., Chamón Fernández J., Martín Lerma I., Sanz Salas E., Pardo Naranjo A. I. and Marín de Espinosa J. A. 2010. Puntas de Palmela: procesos tecnológicos y experimentación. *Trabajos de Prehistoria* 67/2, 405-428.

Hermann R., Crellin J. R., Uckelmann M., Wang Q. and Dolfini A. 2020. *Bronze Age Combat: An Experimental Approach* (= *BAR International Series* 2967). Oxford: BAR Publishing.

Ialongo N. and Lago G. 2021. A small change revolution. Weight systems and the emergence of the first Pan-European money. *Journal of Archaeological Science* 129, 105379.

Kaczmarek M., Szczurek G. and Krzysiak A. 2021. *Kaliska I. Skarb przedmiotów metalowych z późnej epoki brązu na Pomorzu* (= *Hyperborea. Poznańskie studia nad epoką brązu i wczesną epoką żelaza* 6). Poznań: UAM w Poznaniu.

Kasprowicz M. 2022. Use-Wear Analysis of Copper-Alloy Artifacts. A Window of Opportunity or a Dead End? *Folia Praehistorica Posnaniensia* 27, 73-85.

Kasprowicz M. 2021. *Ślady tkanin oraz skór na szpilach brązowych – analiza eksperymentalna i traseologiczna*. Unpublished Master thesis. Poznań: UAM w Poznaniu.

Kienlin T. L. and Ottaway B. S. 1998. Flanged Axes of the North-Alpine Region: An Assessment of the Possibilities of Use Wear Analysis on Metal Artifacts. In C. Mordant, M. Pernot, V. Rychner (eds), *L'Atelier du bronzier en Europe du XXe au VIIIe siècle avant notre ère. Du minerai au métal, du métal à l'objet* (= *Documents préhistoriques* 10). Paris: CTHS Edition, 271-286.

Kłosińska E. M. and Sadowski S. 2017. Long-distance connections of the south-eastern peripheries of the Lublin region at the time of the Lusatian culture in the light of archival and newly discovered materials. *Sprawozdania Archeologiczne* 69, 391-408.

Knight M. 2021. There's Method in the Fragments: A Damage Ranking System for Bronze Age Metalwork. *European Journal of Archaeology* 24/1, 48-67.

Knight M. 2019. Going to Pieces: Investigating the Deliberate Destruction of Late Bronze Age Swords and Spearheads. *Proceedings of the Prehistoric Society* 85, 251-272.

Kristiansen K. 2002. The tale of the sword – swords and swordfighters in Bronze Age Europe. *Oxford Journal of Archaeology* 21/4, 319-332.

Kufel-Diakowska B., Baron J., Buchner A., Lipert M. and Ziewiecka I. 2020. Functions of early Iron Age handstones. Experimental and traceological approach. *Praehistorische Zeitschrift* 95/1, 267-289.

Kufel-Diakowska B., Chłoń M. and Baron J. 2022. A Neolithic ground stone tool as an Early Iron Age funerary gift. *Antiquity* 96(390), 1621-1627.

Kuijpers M. H. G. 2015. Contradicting Context: Understanding Early Bronze Axes from the Perspective of Production. In P. Suchowska-Ducke, S. Scott Reiter and H. Vandkilde (eds), *Forging Identities. The Mobility of Culture in Bronze Age Europe* (= *BAR International Series* 2771). Oxford: BAR Publishing, 203-212.

Kuropka P. 2022. Analiza morfologiczna próbek pobranych z wnętrza brązowych okuć stanowiących elementy skarbu z Sanoka (Białej Góry). In W. Blajer, P. Kotowicz and M. Maciejewski (eds), *Ku czci bogów i ludzi: skarby z okolic Sanoka. Studium interdyscyplinarne*. Lublin, Sanok: UMCS w Lublinie, Muzeum Historyczne w Sanoku, 149-152.

Kurzawska A. 2021. Archeomalakologia. In A. Kurzawska, I. Sobkowiak-Tabaka (eds), *Mikroprzeszłość. Badania specjalistyczne w archeologii*. Poznań: UAM w Poznaniu, 155-178.

Lago G., Cianfoni M., Scacchetti F., Pellegrini L. and La Torre A. 2023. Breaking sickles for shaping money. Testing the accuracy of weight-based fragmentation. *Journal of Archaeological Science: Reports* 49, 103968.

Leschtakow L. 2019. Der Gussformen-Depotfund bei Pobit Kamak und die Entwicklung der Metallurgie in Nordostbulgarien in der zweiten Hälfte der Spätbronzezeit. *Eurasia Antiqua* 22(2016), 185-247.

Miazga B. 2016. Formy odlewnicze z cmentarzyska przy ul. Spokojnej w Legnicy w świetle analizy funkcjonalnej. In K. Nowak and T. Stolarczyk (eds), *Metalurdzy Znad Kaczawy. Cmentarzysko ciałopalne z epoki brązu odkryte w Legnicy przy ul. Spokojnej*. Legnica: Muzeum Miedzi, 91-108.

Molloy B. 2010. Swords and Swordsmanship in the Aegean Bronze Age. *American Journal of Archaeology* 114, 403-428.

Molloy B. 2009. For Gods or for men? A reappraisal of the function of European Bronze Age shields. *Antiquity* 83, 1052-1064.

Molloy B. 2008. Martial arts and materiality: a combat archaeology perspective on Aegean swords of the fifteenth and fourteenth centuries BC. *World Archaeology* 40/1, 116-134.

Molloy B., Wiśniewski M., Lynamc F., O'Neill B., O'Sullivan A. and Peatfield A. 2016. Tracing edges: A consideration of the applications of 3D modelling for metalwork wear analysis on Bronze Age bladed artefacts. *Journal of Archaeological Science* 76, 79-87.

Mueller-Bieniek A. and Cywa K. 2022. Pozostałości roślinne towarzyszące skarbom przedmiotów brązowych z Sanoka (Białej Góry) i Woli Sękowej. In W. Blajer, P. Kotowicz and M. Maciejewski (eds), *Ku czci bogów i ludzi: skarby z okolic Sanoka. Studium interdyscyplinarne*. Lublin, Sanok: UMCS w Lublinie, Muzeum Historyczne w Sanoku, 141-148.

Müller J., Delgado-Raack S., Escanilla N., Kienle L., Kneisel J., Czebreszuk J., Jaeger M., Szmyt M., Schürmann U. 2023. First evidence for the forging of gold in an Early Bronze Age Site of Central Europe (2200–1800 BCE). *Journal of Archaeological Science: Reports* 47, 103748.

Nebelsick L. 2000. Rent Asunder: Ritual Violence in Late Bronze Age Hoards. In C. F. E. Pare (ed.) *Metals Make the World Go Round: The Supply and Circulation of Metals in Bronze Age Europe*. Oxford: Oxbow, 160-175.

Nessel B. 2014. Bronze Age portioning of raw material-concepts, patterns and meaning of casting cakes. In N. Boroffka, G. T. Rustoiu and R. Ota (eds), *Carpathian-Heartlands. Studies on the prehistory and history of Transylvania in European contexts, dedicated to Horia Ciugudean on his 60th birthday* (= *Apulum* 51). Alba Iulia: Muzeul National al Unirii, 401-416.

Nowak K. *Metalurgia brązu w czasach łużyckich pól popielnicowych w ujęciu transgranicznym*. Wrocław: Yellow Point Publications, in press.

Nowak K. 2022. Badania śladów produkcji i używania przedmiotów brązowych ze skarbów z Woli Sękowej, Falejówki (skarb II), Sanoka (Białej Góry) i Zarszyna (skarb II). In W. Blajer, P. Kotowicz and M. Maciejewski (eds), *Ku czci bogów i ludzi: skarby z okolic Sanoka. Studium interdyscyplinarne*. Lublin, Sanok: UMCS w Lublinie, Muzeum Historyczne w Sanoku, 79-93.

Nowak K. 2020. Badania śladów produkcji oraz śladów użytkowania zachowanych na przedmiotach ze skarbu z Marcinowic. In A. Michalak and E. Przechrzta (eds), *Marcinowice. Skarb przedmiotów* *metalowych z wczesnej epoki brązu*. Zielona Góra: Muzeum Archeologiczne Środkowego Nadodrza w Zielonej Górze, 75-99.

Nowak K. 2019. Analiza traseologiczna przedmiotów brązowych wchodzących w skład skarbu z Nowego Kramska. In A. Michalak and J. Orlicka-Jasnoch (eds), *Skarb z Nowego Kramska. Analizy. Konteksty*. Zielona Góra: Muzeum Archeologiczne Środkowego Nadodrza w Zielonej Górze, 179-196.

Nowak K. and Gan P. 2023. Early Iron Age hoard from Jodłowno, Northern Poland. *Communicationes Archaeologicae Hungariae*, 105-119.

Nowak K. and Ialongo N. Late Bronze Age hoard from Nowe Kramsko. Is there a method in fragments? In M. Maciejewski, J. G. Tarbay and K. Nowak (eds), *Current Research on European Bronze and Iron Ages Hoards*, in press.

Nowak K. and Stolarczyk T. (eds) 2016. *Metalurdzy znad Kaczawy. Cmentarzysko ciałopalne z epoki brązu odkryte w Legnicy przy ul. Spokojnej*. Legnica: Muzeum Miedzi w Legnicy.

Nowak K., Gan P., Fudziński P., Palej A., Gólczyński M. and Kwiatkowska M. 2023. Skarb z Jodłowna, gm. Przywidz, pow. gdański, woj. pomorskie. Kontekst osadniczy oraz zagadnienia typologiczno-chronologiczne. *Pomorania Antiqua* 32, 91-114.

Nowak K., Tarbay J. G., Stos-Gale Z. A., Derkowski P. and Sielicka K. 2023. A complex case of trade in metals: The origin of copper used for artefacts found in one hoard from a Late Bronze Age Lusatian Urnfield Culture in Poland. *Journal of Archaeological Science: Reports* 49, 103970.

Nowak K., Sielicka K. and Miazga B. 2022. Skarb z Paszowic, woj. dolnośląskie. Analiza śladów produkcji i (nie)używania. *Archeologia Polski* 67, 81-115.

Nowak K., Baron J., Puziewicz J. and Ziobro M. 2019. Multi-faceted analysis of metal sickles from the late Bronze Age scrap deposit found in Paszowice, SW Poland. *Geochemistry. Chemie der Erde* 73/3, 446-452.

O'Flaherty R. 2007. A weapon of choice – experiments with a replica Irish Early Bronze Age halberd. *Antiquity* 81, 423-434.

Orłowska J. 2021. Późnopaleolityczna motyka typu Lyngby z Murowanej Gośliny (pow. poznański) w świetle wyników analiz traseologicznych. *Acta Universitatis Nicolai Copernici Archeologia* 37, 25-40.

Orłowska J. and Osipowicz G. 2017. Searching for the function of the Early Holocene heavy duty bevel-ended tools. Remarks from experimental and use-wear studies. In A. G. Sitdikov (ed.), *Каменный век и начало эпохи раннего металла. Технология изготовления и функции костяных изделий в древних культурах Евразии* (= *Archaeology of the Eurasian Steppes Journal* 2). Kazan: Academy of Sciences of the Republic of Tatarstan, 103-121.

Orłowska J. and Osipowicz G. 2021. Accuracy of the typological classifications of the Late Glacial and Early Holocene osseous projectile points according to the new AMS dates of selected artifacts from Poland. *Archaeological and Anthropological Sciences* 14/8.

Orłowska J., Cyrek K., Kaczmarczyk G. P., Migal W. and Osipowicz G. 2023. Rediscovery of the Palaeolithic antler hammer from Biśnik Cave, Poland: New insights into its chronology, raw material, technology of production and function. *Quaternary International* 665-666, 48-64.

Orłowska J., Ćwiek M. and Osipowicz G. 2022. Was it ground? A closer look at various prehistoric bone grinding techniques – An experimental and traceological study. *Journal of Archaeological Science: Reports* 46, 103675.

Osipowicz G. 2022. Wyniki analizy traseologicznej wytworów krzemiennych kultury ceramiki sznurowej ze stanowisk kurhanowych zlokalizowanych na Grzędzie Sokalskiej i Roztoczu. In A. Szczepanek, P. Jarosz, J. Libera, P. Włodarczak (eds), *Społeczności schyłkowego eneolitu w południowo-wschodniej Polsce w świetle badań archeologicznych i analiz interdyscyplinarnych*. Kraków: Wydawnictwo i Pracownia Archeologiczna Profil-Archeo, 213-262.

Osipowicz G., Kuriga J., Makowiecki D., Bosiak M. and Grygiel R. 2018. Evidence for widespread occurrence of copper in Late Neolithic Poland? A deposit of Funnel Beaker Culture bone products at site 2 in Osłonki (Kuyavia, central Poland). *Quaternary International* 472 (Part A), 60-74.

Parma D., Havlíková M., Petřík J. and Trampota F. 2021. Zlomkový depot z mladší doby bronzové z Velkých Bílovic (okr. Břeclav). *Zborník Slovenského národného múzea. Archeológia* 115/31, 107-141.

Peška J., Bartík J. and Fikrle M. 2023. The Oldest Evidence of Silver Processing in Europe. A Hoard from Košíky (Okr. Uherské Hradiště/CZ). *Archäologisches Korrespondenzblatt* 53, 23-37.

Pietrzak S. 2021. Badania archeometryczne substancji smolistej z ozdoby brązowej pochodzącej ze skarbu z Kalisk, pow. szczecinecki, woj. zachodniopomorskie. In M. Kaczmarek, G. Szczurek and A. Krzysiak, *Kaliska I. Skarb przedmiotów metalowych z późnej epoki brązu na Pomorzu* (= *Hyperborea. Poznańskie studia nad epoką brązu i wczesną epoką żelaza* 6). Poznań: UAM w Poznaniu, 393-402.

Płonka T., Diakowski M., Kufel-Diakowska B., Bronowicki W., Miazga B. and Stefaniak K. 2022. A new find o fa Mesolithic antler axe from western Poland. *Sprawozdania Archeologiczne* 74/2, 93-109.

Przymorska-Sztuczka M. 2021. Analiza fragmentów sznurka ze skarbu przedmiotów brązowych z Kalisk, pow. szczecinecki, woj. zachodniopomorskie. In M. Kaczmarek, G. Szczurek and A. Krzysiak, *Kaliska I. Skarb przedmiotów metalowych z późnej epoki brązu na Pomorzu* (= *Hyperborea. Poznańskie studia nad epoką brązu i wczesną epoką żelaza* 6). Poznań: UAM w Poznaniu, 407-410.

Pyżewicz K. 2021. Traseologia. In A. Kurzawska and I. Sobkowiak-Tabaka (eds), *Mikroprzeszłość. Badania specjalistyczne w archeologii*. Poznań: UAM w Poznaniu, 333-350.

Rezi B. 2011. Voluntary Destruction and Fragmentation in Late Bronze Age Hoards from Central Transylvania. In S. Berecki, R. E. Németh and B. Rezi (eds), *Bronze Age Rites and Rituals in the Carpathian Basin*. Târgu Mureş: Editura MEGA, 303-34.

Roberts B. and Ottaway B. 2003. The Use and Significance of Socketed Axes During the Late Bronze Age. *European Journal of Archaeology* 6/2, 119-140.

Salaš M. 2005. *Bronzové depoty střední až pozdní doby bronzové na Moravě a ve Slezsku* 1-2. Brno: Moravské zemské muzeum.

Saunderson K., Grömer K. and Formato L. C. 2022. Missing Link: Early Roman Textiles and Norican-Pannonian female dress from Potzneusiedl, Austria. *Archaeological Textiles Review* 64, 28-39.

Sawoszczuk T., Żurowski J. and Betyna K. 2021. Oznaczenia gatunkowego pochodzenia skór zachowanych w skarbie z Kalisk. In M. Kaczmarek, G. Szczurek and A. Krzysiak, *Kaliska I. Skarb przedmiotów metalowych z późnej epoki brązu na Pomorzu* (= *Hyperborea. Poznańskie studia nad epoką brązu i wczesną epoką żelaza* 6). Poznań: UAM w Poznaniu, 385-392.

Semenov S. A. 1957. Pervobytnaia tekhnika. Opyt izucheniia drevneishikh orudii i izdelii po sledam raboty (= *Materialy i issledovaniia po arkheologii* 54). Moscow-Leningrad: Academy of Sciences of the USSR.

Semenov S. A. 1964. *Prehistoric Technology. An Experimental Study of the Oldest Tools and Artifacts from Traces of Manufacture and Wear* (translated, and with a preface by M. W. Thompson). Totowa, New Jersey: Barnes & Noble Books.

Sikorski A. 2006. Wyrób sprangowy na brązowej formie do odlewu siekierek z Roska. In H. Machajewski and J. Rola (eds), *Pradolina Noteci na tle pradziejowych i wczesnośredniowiecznych szlaków handlowych*. Poznań: SNAP Oddział w Poznaniu and UAM w Poznaniu, 153-156.

Sobkowiak-Tabaka I. and Kufel-Diakowska B. 2019. The shining piece of the puzzle: evidence of plant use in the Late Palaeolithic. *Archaeological and Anthropological Sciences* 11, 1373-1389.

Stelmasiak M. 2021. Comparison of the use-wear traces on bone awls and styluses – an experimental study. In S. Beyries, C. Hamon and Y. Maigrot (eds), *Beyond Use-Wear Traces. Going from tools to people by means of archaeological wear and residue analyses*. Leiden: Sidestone Press, 79-88.

Stolarczyk T., Paruzel P., Łaciak D., Baron J., Hałuszko A., Jarysz R., Kuźbik R., Łucejko J. J., Maciejewski M. and Nowak K. 2020. *Czernikowice. Cmentarzyska z epoki brązu i wczesnej epoki żelaza*. Legnica: Muzeum Miedzi w Legnicy.

Sych D. 2022. Analiza traseologiczna przedmiotów brązowych z depozytu z Kalisk, pow. szczecinecki, woj. zachodniopomorskie. In G. Szczurek and M. Kaczmarek, *Kaliska II. Skarb przedmiotów metalowych z późnej epoki brązu na Pomorzu* (= *Hyperborea. Poznańskie studia nad epoką brązu i wczesną epoką żelaza* 7). Poznań: UAM w Poznaniu, 371-381.

Sych D. 2021. Analiza traseologiczna przedmiotów brązowych z depozytu z Kalisk, pow. szczecinecki, woj. zachodniopomorskie. In M. Kaczmarek, G. Szczurek and A. Krzysiak, *Kaliska I. Skarb przedmiotów metalowych z późnej epoki brązu na Pomorzu* (= *Hyperborea. Poznańskie studia nad epoką brązu i wczesną epoką żelaza* 6). Poznań: UAM w Poznaniu, 357-371.

Sych D. 2014. Research perspectives of the traceology of metal artefacts. *Śląskie Sprawozdania Archeologiczne* 56, 31-40.

Sych D. 2011. Badania makro- i mikrośladów na grotach strzał ze stanowiska Wrocław-Widawa 17. *Silesia Antiqua* 47, 93-101.

Sych D., Nowak K., Maciejewski M., Miazga B. and Baron J. 2020. Influence of conservation of copper and bronze artefacts on traces of production and use-wear. *Archaeological and Anthropological Sciences* 12, 141.

Sych D., Badura B., Momot M. and Pazdur K. 2018. TraseoSkan 3D – zastosowanie skanowania 3D w analizach traseologicznych artefaktów brązowych. *Śląskie Sprawozdania Archeologiczne* 60/1, 399-408.

Thomas P. 2018. *Studien zu den bronzezeitlichen Bergbauhölzern im Mitterberger Gebiet. Forschungen zur Montanlandschaft Mitterberg* 1 (= *Der Anschnitt Beiheft* 38). Bochum: VML Verlag Marie Leidorf.

Uckelmann M. and Mödlinger M. eds 2011. *Bronze Age Warfare: Manufacture and Use of Weaponry* (= *BAR International Series* 2255). Oxford: Archaeopress.

Vieugué J. 2014. Use-wear analysis of prehistoric pottery: methodological contributions from the study of earliest ceramic vessels in Bulgaria (6100-5600 cal BC). *Journal of Archaeological Science* 41, 622-630.

Wall J. 1987. The Role of Daggers in Early Bronze Age Britain: The Evidence of Wear Analysis. *Oxford Journal of Archaeology* 6/1, 115-118.

Wanzek B. 1989. *Die Gußmodel für Tüllenbeile im südostlichen Europa* (= *Universitätsforschungen zur prähistorischen Archäologie* 2). Bonn: Dr. Rudolf Habelt GmbH.

Winnicka K. 2019. Pointed objects of the Mierzanowice Culture (Early Bronze Age). A study of function by use-wear analysis. *Cuadernos de Prehistoria y Arqueología de la Universidad de Granada* 29, 87-103.

Żurkiewicz D., Stróżyk M., Garbacz-Klempka A., Szmyt M. and Silska P. 2023. The earliest traces of metallurgy in Greater Poland: tuyčre from Kotowo, Poland. *Documenta Praehistorica* 50, 420-433.