Beyond the surface: Investigating the internal and external properties of silver-coated axes from eastern Bohemia

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Zusammenfassung

Jenseits der Oberfläche: Die Untersuchung der internen und externen Eigenschaften von versilberten Beilen aus Ostböhmen

In einer multiperspektivischen Studie wurden sämtliche erhaltene Aunjetitzer Metallbeile aus Ostböhmen untersucht, darunter 111 Beile und 2 beilförmige Hämmer. Mit seinen 57 Objekten stellt der Hort von Kukleny, Okr. Hradec Králové, nach wie vor das umfangreichste Beilinventar dieser Periode in Böhmen dar. Sein Fundort in Ostböhmen wird oft als Peripherie der böhmischen Aunjetitz-Besiedlung betrachtet. Dies und die einzigartige Oberflächenbehandlung der Beile mit Silber machte es nötig, auch alle anderen Artefakte der Region zu untersuchen. Es handelt sich dabei meist um Stücke aus Hortfunden oder um Einzelfunde, seltener stammen sie aus Gräbern oder gar stratifizierten Siedlungsbefunden.

Unterschiedliche Methoden wurden mit dem Ziel angewandt, Fragen zu Herstellung, Verwendung und zum symbolischen Wert solcher Artefakte zu beantworten. Untersucht wurden Materialwahl, Gusstechnik, Herstellungs- und Gebrauchsspuren sowie der Silberüberzug. Vor allem in den Horten war eine Vorliebe für Bronze- anstatt Kupferbeile sichtbar. Die Untersuchung der inneren Strukturen lässt vermuten, dass einige der Beile in geschlossenen, aufrechtstehenden Formen mit der Schnittkante nach unten gegossen wurden, worauf Gussfehler am Beilnacken hindeuten. Wo sich Gebrauchsspuren fanden, ließ sich nachweisen, dass die Beile hauptsächlich für Holzarbeiten verwendet wurden. Dieser Befund steht im direkten Widerspruch mit dem Silberüberzug auf der Mehrzahl der untersuchten Stücke. Versuche ergaben jedoch eine spezielle Beschichtungsmethode, mit der man vergleichsweise einfach mit einer geringen Menge Silberchlorid (sog. Hornsilber) eine silbrig glänzende Oberfläche erhält. Die Oberfläche lässt sich damit leicht reparieren, sodass die praktische Verwendung der Beile nicht ausgeschlossen war.

Schlagwörter Frühbronzezeit, Aunjetitzer Kultur, Hortfunde, Äxte, Silberbeschichtung

Summary

A multi-perspective study was conducted on the entire preserved assemblage of Únětice metal axes from eastern Bohemia, including 111 axes and 2 axe-shaped hammers. With 57 specimens, the hoard of Kukleny, Hradec Králové district, still remains the largest assemblage of axes from this period in Bohemia. Its location in eastern Bohemia, often seen as a periphery of the Bohemian Únětice settlement, and the unique surface treatment of the axes with silver, made it necessary to investigate all other artefacts of the region, most of them coming from hoards and single finds, more rarely from graves and even stratified settlement contexts.

Different methods were applied and aimed to answer questions about the manufacture, use, and symbolic value of such artefacts. Their manufacture process was examined in terms of the choice of material, casting process, traces of manufacture and use, and silver coating. A preference for bronze over copper axes was observed, mainly in hoards. From the study of internal structure, we can propose that some of these axes were cast in closed moulds standing upright with the edge pointing down, which is indicated by casting defects present in the butt parts. Where traces of usage could be determined, it could be confirmed that axes were used mainly for woodworking. These findings seem to be in direct opposition to coating with silver, which was present on the majority of studied specimens. However, a specific coating method was tested, which provided a silvery shining surface using a fairly simple process and a minimal amount of silver chloride, or so-called horn silver. This way, the layer could have been easily repaired and did not have to exclude the practical use of axes.

Keywords Early Bronze Age, Únětice Culture, Hoards, Axes, Silver coating

Introduction

The Únětice Culture in eastern Bohemia is relatively little known. While during its early phases, eastern Bohemia shows little evidence of settlement and the only source of information are graves, during the Classical phase (starting around 2000 BC) the settlements and cemeteries begin to appear. Outstanding graves have recently been published from the cemetery of Mikulovice, Pardubice district (Ernée et al. 2020).

This view of the eastern Bohemian Únětice Culture as a somehow peripheral region, compared to central or north-western Bohemia and Central Germany, has recently been questioned thanks to the discovery and investigation of two hoards. The most exceptional find of recent years was the deposit of metal axes from Kukleny, located in the vicin-

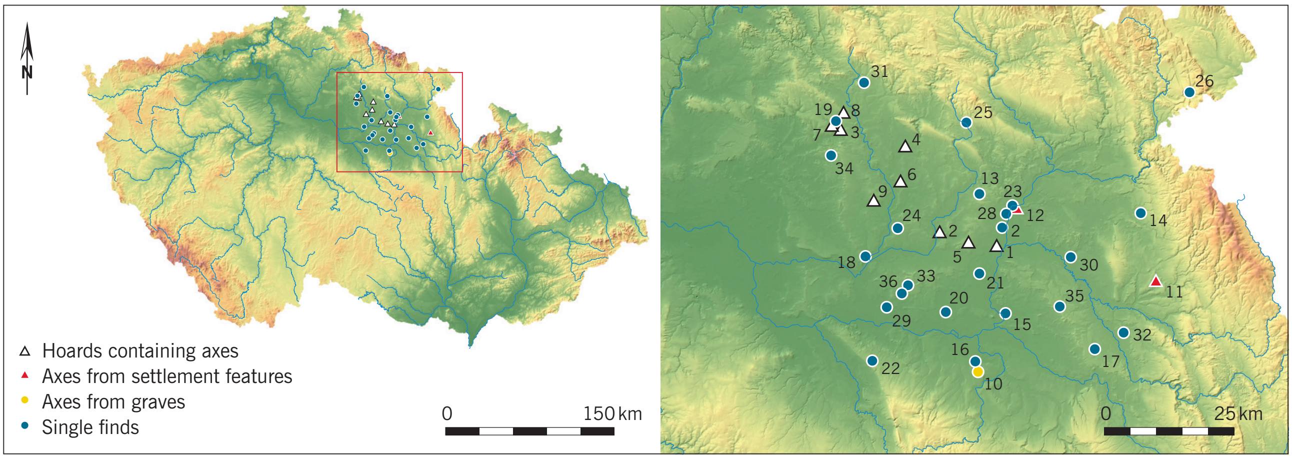

Fig. 1 Distribution of axes in eastern Bohemia according to their context. Hoards: 1 Kukleny; 2 Kunčice; 3 Jičíněves; 4 Obora; 5 Těchlovice; 6 Loučná Hora; 7 Dolany; 8 Staré Místo; 9 Starý Bydžov. Graves: 10 Mikulovice. Settlement: 11 Domašín; 12 Lochenice. Single finds: 13 Čistěves; 14 Dobruška; 15 Dražkov; 16 Dražkovice; 17 Horní Jelení; 18 Chlumec nad Cidlinou; 19 Kostelec; 20 Lázně Bohdaneč; 21 Libišany; 22 Litošice; 23 Lochenice; 24 Měník; 25 Miletín; 26 Nízká Srbská; 27 Plotiště nad Labem; 28 Předměřice nad Labem; 29 Strašov; 30 Třebechovice; 31 Valdice; 32 Velká Čermná; 33 Voleč; 34 Vršce; 35 Vysoké Chvojno; 36 Žáravice.

Abb. 1 *Verbreitung der Beile in Ostböhmen nach Fundzusammenhang. Horte: 1 Kukleny; 2 Kunčice; 3 Jičíněves; 4 Obora; 5 Těchlovice; 6 Loučná Hora; 7 Dolany; 8 Staré; 9 Starý Bydžov. Gräber: 10 Mikulovice. Siedlungen: 11 Domašín; 12 Lochenice. Einzelfunde: 13 Čistěves; 14 Dobruška; 15 Dražkov; 16 Dražkovice; 17 Horní Jelení; 18 Chlumec nad Cidlinou; 19 Kostelec; 20 Lázně Bohdaneč; 21 Libišany; 22 Litošice; 23 Lochenice; 24 Měník; 25 Miletín; 26 Nízká Srbská; 27 Plotiště nad Labem; 28 Předměřice nad Labem; 29 Strašov; 30 Třebechovice; 31 Valdice; 32 Velká Čermná; 33 Voleč; 34 Vršce; 35 Vysoké Chvojno; 36 Žáravice.*

ity of Hradec Králové. With 57 axes originally stored in a ceramic vessel, it is the largest hoard of axes found so far in the Czech Republic. Such assemblages would be expected in north-western Bohemia[1], which is close to Central Germany, where the largest axe hoards have been found (Brunn 1959). Another eastern Bohemian deposit of eight axes has recently been found in Kunčice, Hradec Králové district. Detailed observation of the surfaces of some axes of both hoards allowed archaeologists to identify traces of silver (Schimerová et al. 2023). This is particularly interesting in the context of Central Europe because practically no silver objects are known so far.

In the present study, the Early Bronze Age axes of eastern Bohemia are submitted to an interdisciplinary approach combining elemental composition, metalwork wear, and internal structure analyses. Particular attention was devoted to the possibilities of silver-coating technology and its experimental replication.

Materials and their contexts

In total, 113 axes or their fragments are preserved from Únětice contexts in eastern Bohemia (Fig. 1), from these

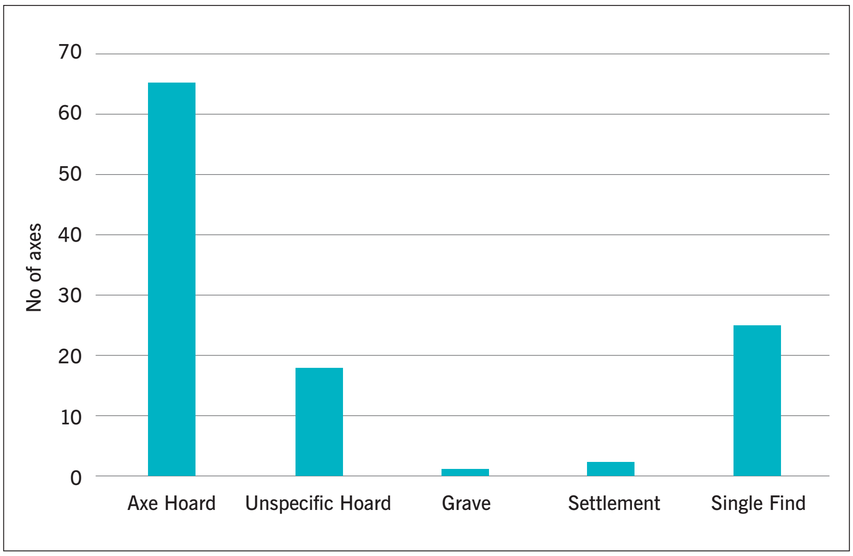

Fig. 2 Number of studied axes found in different archaeological contexts in eastern Bohemia.

Abb. 2 *Anzahl der untersuchten Beile aus Ostböhmen nach archäologischem Kontext.*

1 E.g. Soběnice, Litoměřice district, 40 axes, Soběchleby, Louny district, over 30 axes; see Moucha 2005.

only 109 were available for analysis. Another two axe-shaped artefacts are usually described as hammers. A total number of 111 from the total number of 113 artefacts are discussed in the present study. All axes can be grouped according to four different find circumstances (Fig. 2); in this case hammers form a separate category:

- Axes from hoards
- Axes from graves
- Axes from settlement features
- Single finds

Axes from hoards

This group of finds is the most numerous and comprises 83 axes. The hoards can be divided into two categories. In the first category, axes are the only component. It includes the hoards of Kukleny, with 57 axes (Fig. 3), and Kunčice (Fig. 4) with eight (for details, see Schimerová et al. 2023). The second category of hoards commonly only contains one or two axes as part of a more varied assemblage of artefacts, including either pieces of jewellery, clothing accessories, or ingots. In a third group of hoards, axes are absent[2].

The mixed hoard with the largest amount of axes came from Jičíněves, Jičín district. It was found in the 19th century in two separate assemblages. Although it cannot be excluded that they all came from one hoard, the information is very incomplete and parts of the original assemblage were lost. The total number of axes of both assemblages could have been c. 25, including fragments, which seem to have been found together with other artefacts. Today, only eight axes, one hammer, and eleven ring ingots are preserved in four different museums (Moucha 2005, 114–115 Tab. 71–73).

Another hoard found in 1904 came from Obora, Jičín district. Similar to all early finds, a large part of the assemblage is lost. The total number of axes was nine, although only three of them are still extant today. The hoard was stored in a vessel, and along with the axes it also contained a metal chain and bracelets and their fragments (Moucha 2005, 133 Tab. 158).

The hoard from Těchlovice, Hradec Králové district, contained two axes, but no written report describing the find's circumstances exists (Fig. 5). The only information was provided by T. Vachta, who described the hoard context after communication with the local museum. According to this information, there were two axes deposited lengthwise next to each other; between the two axes was a pin, and eight ingots were placed on top (Vachta 2016, 84). In the published reconstruction, the ingots are in the form of ribs, which are specific for southern Bohemia, but so far remain unknown in eastern Bohemia (Chvojka et al. 2017; Moucha 2005). A misunderstaning might have been created by the fact that these ingots were most probably reshaped from the typical ring ingot by shortening them and probably filing them into sharp ends. Due to significant corrosion damage this modification is hard to prove.

Another assemblage with two axes which is described as a hoard comes from Loučná Hora, Hradec Králové district, although only these two artefacts were retrieved. Both were very different in size, but their presence in the same place is definitely not a coincidence (Fig. 6).

The remaining hoards contained just one axe each, in addition to other objects. The most notable example is the yet unpublished hoard from Dolany, Jičín district. It was found in the summer of 2020, but delivered to the museum much later. According to the finder, the assemblage contained one broken axe, four bracelets, one broken Únětice pin, a wire spiral, and a cast decorated comb. Apart from these complete artefacts, the finder also brought four fragments of thick wire – possibly from a pin and a piece of metal sheet, which could have belonged to the pin. The only available information about the find circumstances is a verbal description of the finder, who claimed that the hoard was placed in a typical large Únětice cup of the classical phase. Inside the cup was the spiral, and on top if it were the four bracelets with the axe placed in the middle. The most unusual find was a metal comb placed on the bottom of the ceramic vessel. The position of the pin and other metal fragments remains unknown (Fig. 7). Even though the compostion of the hoard is very unusual, according to the available description it can be excluded that the artefacts came from a disturbed grave.

The other two hoards contained only one axe. The first comes from Staré Místo, Jičín district, where fragments of an axe and a ring ingot were found (Moucha 2005, 156 Tab. 215); the second is the famous hoard from Starý Bydžov, Hradec Králové district, which, in addition to the axe, contained one decorated round metal disc, a decorated sheet ornament, three decorated pins, eight disc-shaped earrings, two spirals made of single wire, 18 rings made of double wire, and a bracelet – all stored in a ceramic vessel (Moucha 2005, 157–158 Tab. 96–97).

Although the find circumstances are unclear in all cases, most of the hoards appeared inside ceramic vessels. In the case of Kukleny, part of a storage vessel with copper corrosion adherences on the inner side was excavated in the shallow feature where the hoard was stored before it was disturbed by ploughing. The hoard from Dolany was stored in a classical Únětice cup. And the hoards from Starý Bydžov and Obora were also stored in a vessel, although its shape remains unknown.

Axes from graves

In eastern Bohemia, there is only one axe from a funerary context. The axe comes from grave 26 of the highly significant cemetery in Mikulovice. It probably belonged to a male who was buried with the axe that had remains of wood on it as well as with a bronze dagger, an Únětice pin, and a bone awl (for details see Ernée et al. 2020).

2 For more information see Moucha 2005; Vachta 2016; Chvojka et al. 2017.

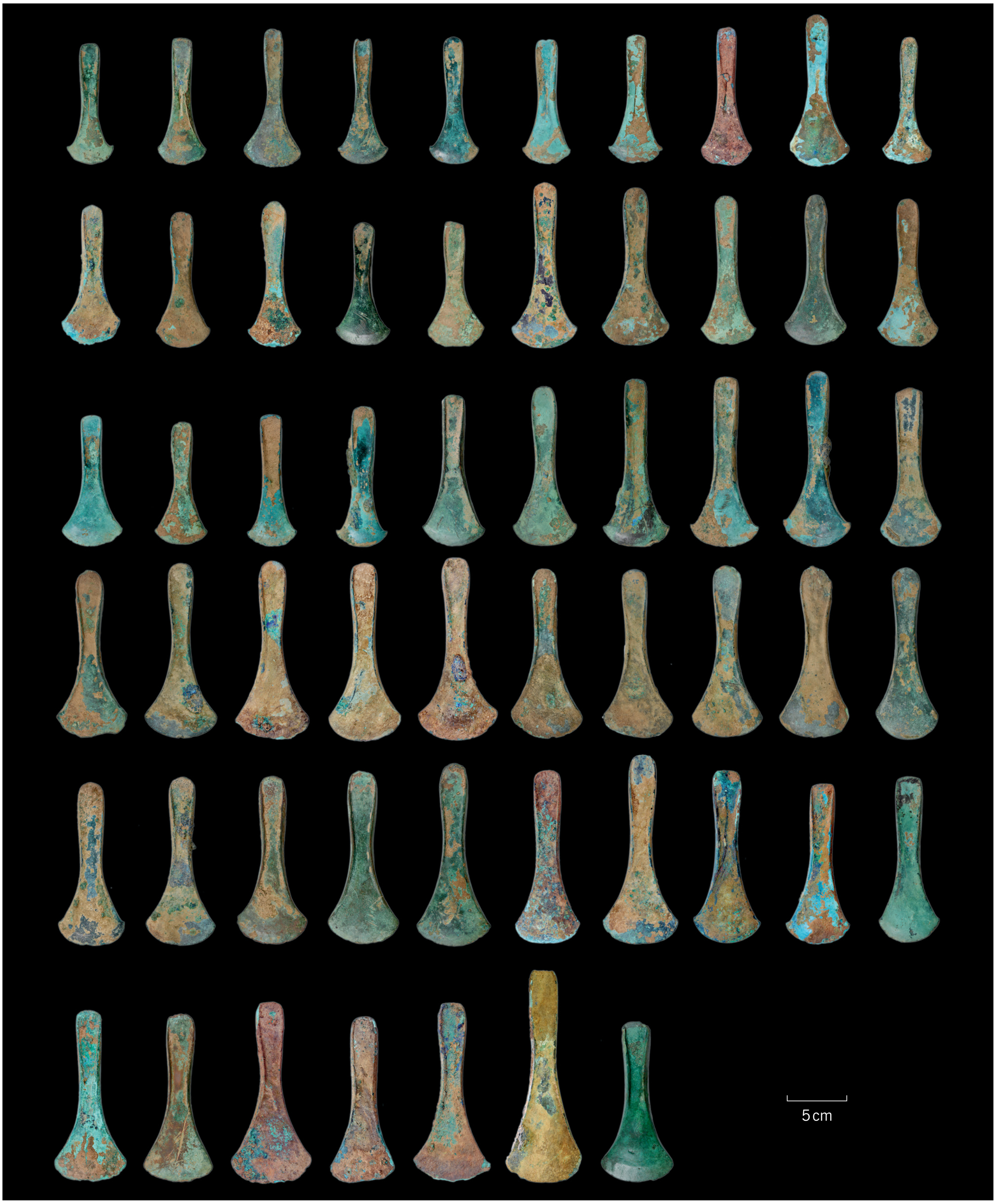

Fig. 3 The hoard from Kukleny, Hradec Králové district.

Abb. 3 *Der Hort von Kukleny, Okr. Hradec Králové.*

Axes from settlement features

Finds of axes from stratified situations are extremely rare. Only two axes have been found so far, and both specimens were small fragments: In the case of Lochenice, Hradec Králové district, it was a butt of an axe; and in case of Domašín, Rychnov nad Kněžnou district, it was the central part (Fig. 8). These small fragments are most probably pieces that were meant to be used for recasting, but for some reason they ended up in rubbish pits. These fragments could confirm that axes were used at the settlements where they were found.

Fig. 4 The hoard from Kunčice, Hradec Králové district.

Abb. 4 *Der Hort von Kunčice, Okr. Hradec Králové.*

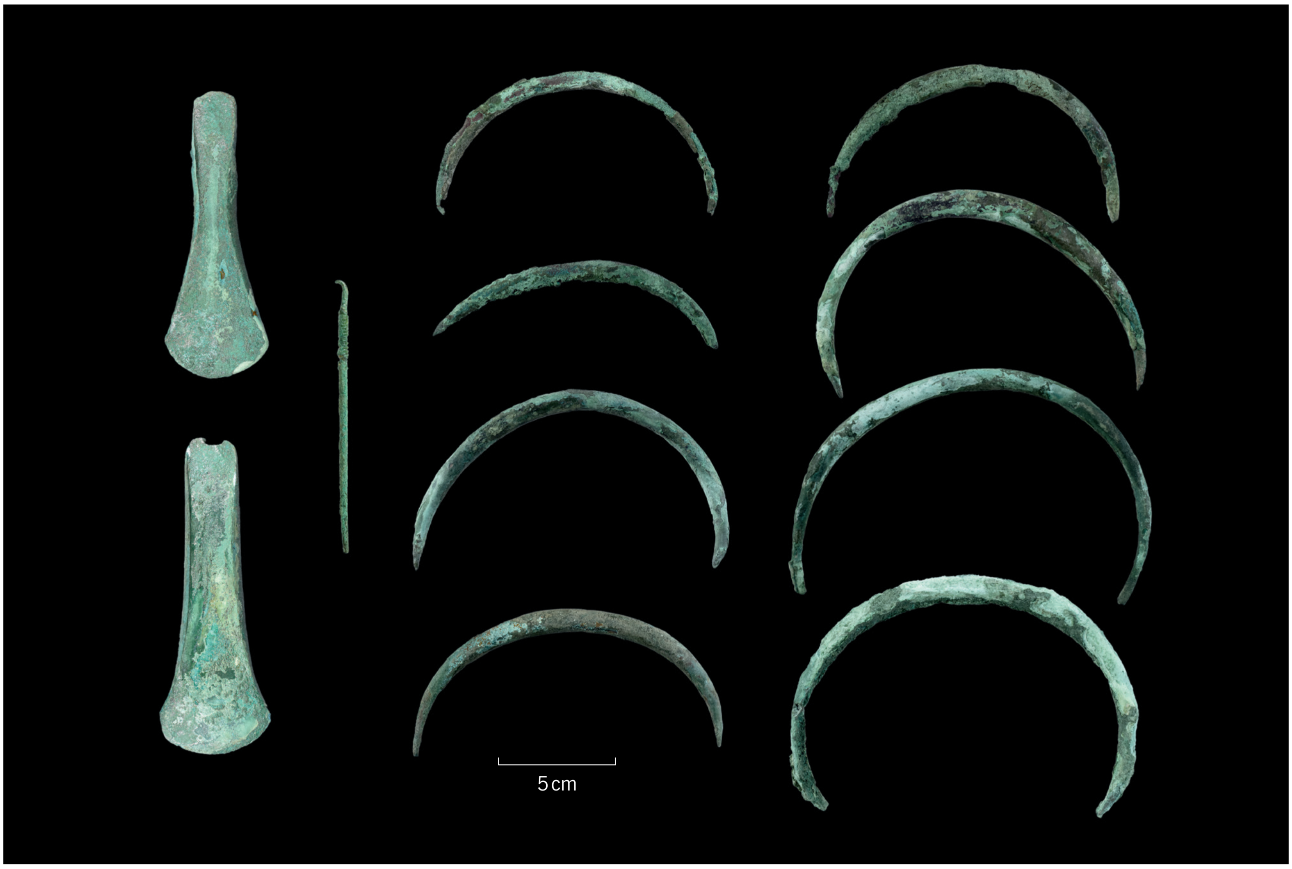

Fig. 5 The hoard from Těchlovice, Hradec Králové district.

Abb. 5 *Der Hort von Těchlovice, Okr. Hradec Králové.*

Single finds

These are the most frequent types of finds. In total, there are 25 of them (Fig. 9). Usually, they were found by metal detectorists, and the only information we have are the coordinates. Here the most important information is about the spatial distribution of axes within the studied region (see Fig. 1). These solitary finds make connections where there is

Fig. 6 The hoard from Loučná Hora, Hradec Králové district.

Abb. 6 *Der Hort von Loučná Hora, Okr. Hradec Králové.*

Fig. 7 The hoard from Dolany, Jičín district.

Abb. 7 *Hort von Dolany, Okr. Jičín.*

no previous find of the Únětice Culture. Whether these axes represent a lost item or were originally part of grave goods (most probably a hoard) remains unknown.

Hammers

A special category is represented by axe-shaped artefacts that are usually referred to as hammers, although their actual function remains unclear (Fig. 10). In the eastern Bohemian assemblage, these are represented by two specimens. The first comes from the hoard of Jičíněves, the other is a single find from Předměřice that was recovered in the 19th century.

Fig. 8a–b Fragments of axes from settlement features. a Lochenice, Hradec Králové district, axe no. 2370; b Domašín, Hradec Králové district.

Abb. 8a–b *Beilfragmente aus Siedlungsbefunden. a Lochenice, Okr. Hradec Králové, Beil-Nr. 2370; b Domašín, Okr. Hradec Králové.*

Methods

Each artefact was documented and analysed in a standardised process to obtain similar and comparable data from each sample. All the analyses performed were designed to be as non-invasive as possible. This excluded metallographical sections and the drilling of samples for elemental composition from the outset. The decision provided an opportunity to develop a set of minimally-invasive analyses summarised below.

The *elemental composition analysis* was done with a Scanning Electron Microscope (SEM; Tescan VEGA 3 LMU)

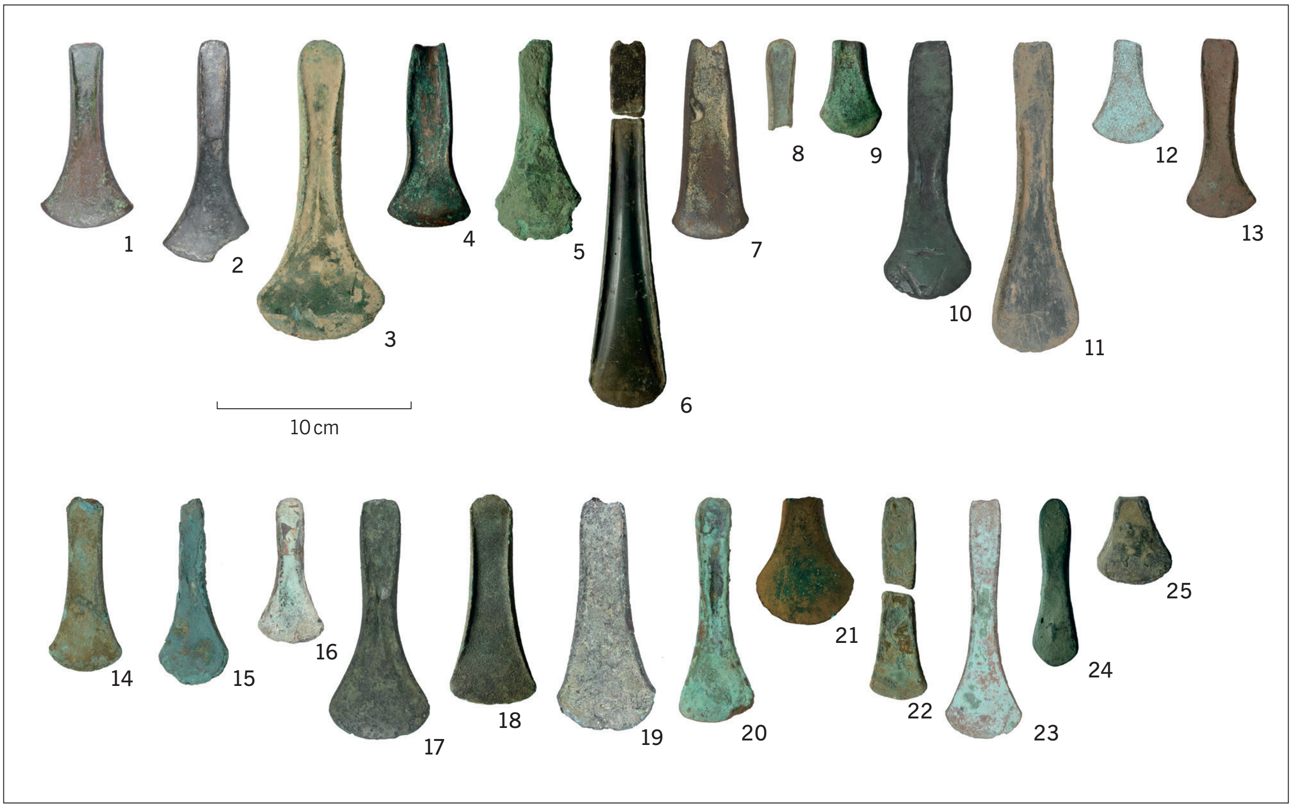

Fig. 9 Axes from settlement features. 1 Čistěves, axe no. 2034; 2 Čistěves, axe no. 2035; 3 Dobruška; 4 Dražkov, axe no. A012023; 5 Dražkovice, axe no. AR016337; 6 Horní Jelení, axe no. AR016752; 7 Chlumec nad Cidlinou, axe no. 98398; 8 Kostelec; 9 Lázně Bohdaneč, axe no. AR010156; 10 Libišany, axe no. B148124; 11 Litošice; 12 Lochenice, axe no. A95781; 13 Měník, axe no. 5_2017; 14 Miletín; 15 Nízká Srbská; 16 Plotiště nad Labem, axe no. A80637; 17 Předměřice nad Labem, axe no. 1802; 18 Strašov, axe no. AR012049; 19 Třebechovice, axe no. 58_1972; 20 Valdice axe no. 30695; 21 Velká Čermná; 22 Voleč, axe no. 12055; 23 Vršce, axe no. 96684; 24 Vysoké Chvojno, axe no. AR011868; 25 Žáravice, axe no. AR012065.

Abb. 9 *Beile aus Siedlungsbefunden. 1 Čistěves, Beil-Nr. 2034; 2 Čistěves, Beil-Nr. 2035; 3 Dobruška; 4 Dražkov, Beil-Nr. A012023;5 Dražkovice, Beil-Nr. AR016337; 6 Horní Jelení, Beil-Nr. AR016752; 7 Chlumec nad Cidlinou, Beil-Nr. 98398; 8 Kostelec; 9 Lázně Bohdaneč, Beil-Nr. AR010156; 10 Libišany, Beil-Nr. B148124; 11 Litošice; 12 Lochenice, Beil-Nr. A95781; 13 Měník, Beil-Nr. 5_2017; 14 Miletín; 15 Nízká Srbská; 16 Plotiště nad Labem, Beil-Nr. A80637; 17 Předměřice nad Labem, Beil-Nr. 1802; 18 Strašov, Beil-Nr. AR012049; 19 Třebechovice, Beil-Nr. 58_1972; 20 Valdice, Beil-Nr. 30695; 21 Velká Čermná; 22 Voleč, Beil-Nr. 12055; 23 Vršce, Beil-Nr. 96684; 24 Vysoké Chvojno, Beil-Nr. AR011868; 25 Žáravice, Beil-Nr. AR012065.*

Fig. 10a–b The axe-shaped hammers. a Jičíněves, Jičín district, no. A162; b Předměřice nad Labem, Hradec Králové district, no. 1803.

Abb. 10a–b *Die beilförmigen Hämmer. a Jičíněves, Okr. Jičín, Nr. A162; b Předměřice nad Labem, Okr. Hradec Králové, Nr. 1803.*

with Energy Dispersive Spectroscopy (EDS; Oxford Instruments INCA 350). The analysis of the elemental composition required minor intervention on the surface, which was necessary because measurements of the corrosion products tend to show increased concentrations of certain elements. This method should be regarded as semi-quantitative; its limits are in measuring the very low concentrations of elements, and the results are not as precise as samples taken from the core. We took advantage of minor damages caused by ploughing or corrosion, and we polished the surface to uncover the metal core[3]. The aim was to determine whether the axes consisted of copper or bronze and what the percentage of tin in the alloy was. In addition to the tin content, the focus was on the content of silver in the matrix in order to exclude the possibility of silver enrichment of the surface as a result of corrosion.

The *metalwork wear analysis*[4] was performed using a trinocular microscope with transmitted direct illumination providing up to 200x magnification and a binocular magnifier with side illumination. Optical microscopy was complemented using the Olympus DSX1000 opto-digital microscope, Reflectance Transformation Imaging (RTI), and thorough macro-photo documentation on selected pieces. The combination of optical methods and the utilised magnification helps to capture and document all kinds of damage and traces on the surface of the artefact, from macro-scale to the finest details.

The *analysis of the silver coating* was the result of combining the previously described methods. Thorough documentation of the surfaces coated with silver was done by equipment used for the metalwork wear analysis; selected samples were documented by digital microscope to obtain two- and three-dimensional images under visible light (Keyence VHX 7000 Elemental Analyzer). The character of the layers and their composition was documented and analysed by SEM-EDS, and selected samples were examined using Laser Induced Plasma Spectroscopy (LIPS, using a Keyence VHX 7000 EA) to further determine their character and thickness. To exclude the possibility that the silver layers were the result of corrosion of the matrix and to prove that could be in fact an applied layer of metallic silver, we conducted X-Ray Diffraction (XRD; diffractometer PANanalytical X'pert PRO).

The information was gathered not only from the surface, but also from the *internal structure*. Each axe was X-rayed to obtain information about possible casting defects (with Explorer X-test 200-120/400 by Testima), and a few selected samples were analysed with Computer Tomography (CT; TORATOM – Twinned Orthogonal Adjustable Tomograph).

Here we have to stress that the level of information gained from the surface is strongly influenced by the conservation practice. The silver coating turned out to be best preserved on axes that did not go through any conservation treatment and were not mechanically cleaned. Some axes also bore traces of harsh mechanical cleaning that not only destroys the silver layers but also any traces of manufacture and use. Solutions used for conservation (organic polymers dissolved in solvents) are also problematic. They can cover the surface so densely that its study is often impossible. In consequence, some samples had to be excluded from some of the analyses (Fig. 11).

Results

Elemental composition

The results of the SEM-EDS elemental composition analysis show that the majority of the axes, regardless of the context, were cast from copper with different amounts of tin. The measured range of tin was between 1.3 and 13.1 wt%, whereas silver was between 0.1 and 2.9 wt%. This allowed us to observe three main variants (Tab. 1). The first are axes consisting of fahlore copper without any added tin. This composition is similar to the so-called Ösenring copper (Junk et al. 2001). Another variant are axes of fahlore copper to which high amounts of tin had been added. The natural content of tin in tetrahedrite ores is in the tenths of 1 wt%, implying that tin was definitely added intention-

3 This minor invasive treatment was approved by the lending institutions.

4 Since the analysis includes not only use-wear traces but also manufacturing marks and potential repairs, which often predominate on metal artefacts, we use the term »metalwork wear analysis« as established by A. Dolfini and R. Crellin in their 2016 study (Dolfini/Crellin 2016).

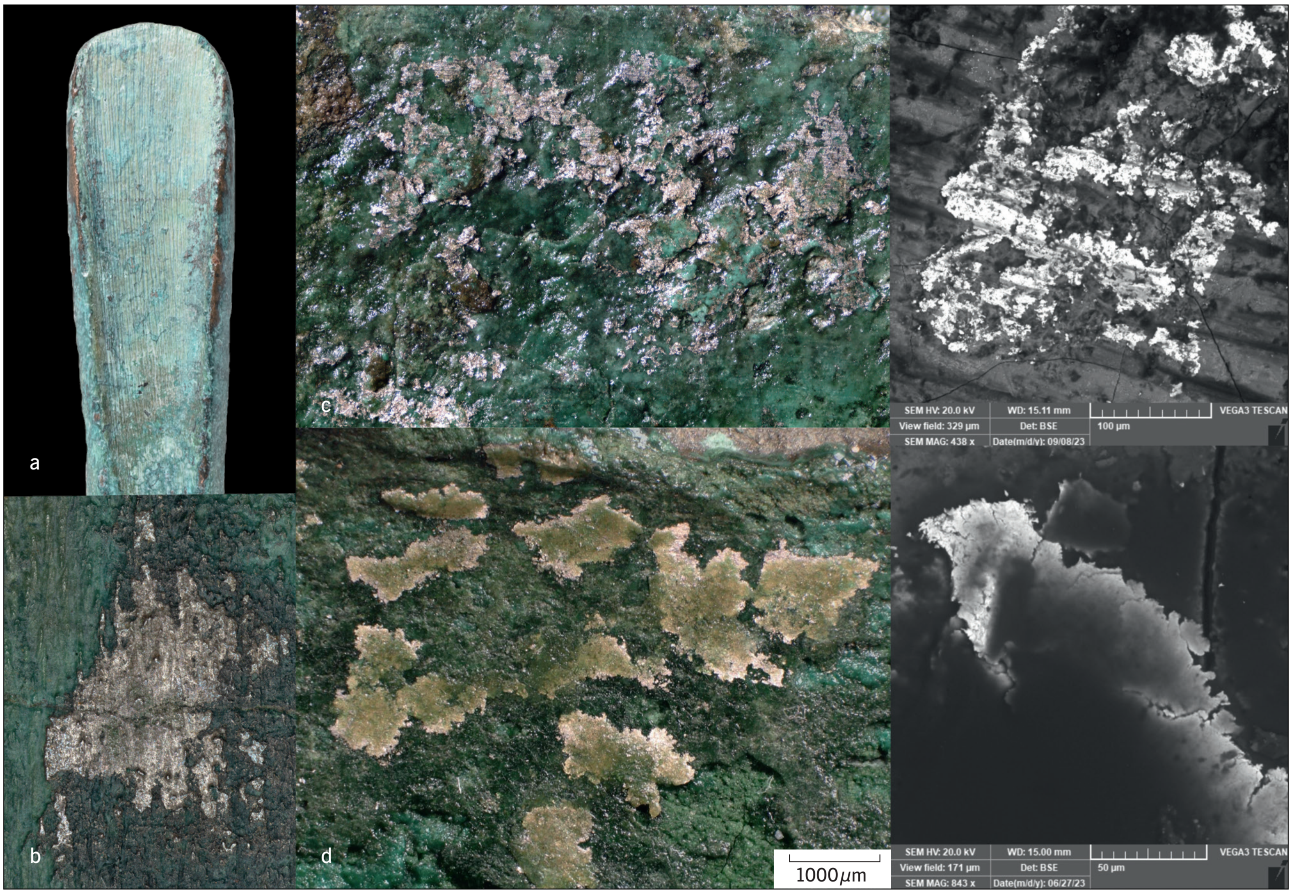

Fig. 11a–d Results of inappropriate conservation procedures. a Traces of harsh mechanical cleaning, probably with metal brush; b Traces of harsh mechanical cleaning, probably with metal brush over the silver coating (optical microscopy); c Traces of harsh mechanical cleaning that completely destroyed all the polishing traces on copper and silver (optical microscopy and SEM); d Remains of conservation solution that covered the silver coating remains and degraded into a yellow colour (optical microscopy and SEM).

Abb. 11a–d *Ergebnisse ungeeigneter Konservierungsverfahren. a Spuren grober mechanischer Reinigung, vermutlich mit einer Drahtbürste; b Spuren grober mechanischer Reinigung, vermutlich mit einer Drahtbürste auf der Silberbeschichtung; c Spuren grober mechanischer Reinigung, die sämtliche Polierspuren auf Kupfer und Silber vollständig zerstört hat (Licht- und Rasterelektronenmikroskopie [REM]); d Reste einer Konservierungslösung, welche die Überreste der Silberbeschichtung bedeckt und sich gelblich verfärbt hat (Lichtmikroskopie und REM).*

ally (George et al. 2017). In the remaining axes, the majority of elements were below the detection limit of the applied method; the only measurable elements were copper, tin, and, in few cases, also lead.

In the case of the large hoard from Kukleny, only 13 of 57 axes did not contain intentionally added tin. The range of tin in the remaining 44 specimens varied between 1.3 and 11.4 wt%. The range of silver in 49 axes varied between 0.4 and 2.7 wt%. In the remaining eight cases, silver was below the detection limit of the applied method (Schimerová et al. 2023, Tab. 1).

The results show a clear preference for axes made of bronze. Although there are axes made of fahlore copper with no added tin, in the entire assemblage they form a minority. Taking all hoards together, from the total number of 83 axes, 15 were made of copper (13 from Kukleny and two from the hoard of Loučná Hora). The axe from the Mikulovice grave was made of bronze with high tin content, and so were the axes from settlement situations. In case of the single finds, from the total number of 25, eleven axes were made of copper. Of the two hammers, one was made of copper and one of bronze.

Metalwork wear analysis

The metalwork wear analysis was systematically applied to the whole studied assemblage. This surface analysis is indispensable for a comprehensive understanding of the significance/meaning of artefacts, providing a new perspective on both objects and the activities themselves (e.g., Dolfini/Crellin 2016; Dolfini et al. 2023; Hermann et al. 2020). The methodology was established by T. L. Kienlin and B. S. Ottaway (1998), and, with modifications or additions, these steps are still in use today[5].

There are two basic groups of traces – manufacture and use – that must first be distinguished from each other. In the case of bronze objects, other traces can be distin-

5 E.g., Crellin 2018; Dolfini et al. 2023; Dolfini/Crellin 2016; Kienlin 2004; Molloy et al. 2016; Roberts/Ottaway 2003; Sáez/Lerma 2015; Sych 2014.

Site	Arch. ID	Context	Sn	Ag	Sb	Bi	As	Pb	Ni	Cu
Kukleny	79435	Hoard	4.6	0.7	-	-	-	-	-	94.7
Kukleny	79436	Hoard	2.9	-	-	-	-	-	-	97.1
Kukleny	79437	Hoard	0.9	1.0	0.8	-	-	-	0.4	96.9
Kukleny	79438	Hoard	3.7	1.1	0.6	-	-	0.2	-	94.4
Kukleny	79439	Hoard	4.1	-	-	-	0.3	-	-	95.6
Kukleny	79440	Hoard	6.3	0.6	0.4	-	-	-	-	92.7
Kukleny	79441	Hoard	5.0	-	-	-	-	-	-	95.0
Kukleny	79442	Hoard	6.9	1.0	0.7	-	1.4	-	-	90.0
Kukleny	79443	Hoard	11.4	0.4	-	-	-	-	-	88.2
Kukleny	79444	Hoard	3.1	-	-	-	-	-	-	96.9
Kukleny	79445	Hoard	3.8	0.7	0.4	-	-	-	-	95.1
Kukleny	79446	Hoard	4.5	1.0	0.6	-	1.1	-	-	92.8
Kukleny	79447	Hoard	5.2	0.8	0.4	-	-	-	-	93.6
Kukleny	79448	Hoard	4.9	0.6	-	-	-	-	-	94.5
Kukleny	79449	Hoard	1.3	-	-	-	-	-	-	98.7
Kukleny	79450	Hoard	2.7	0.7	-	-	-	-	-	96.6
Kukleny	79451	Hoard	7.4	1.8	0.5	-	0.9	-	-	89.4
Kukleny	79452	Hoard	4.9	0.6	0.3	-	-	-	-	94.2
Kukleny	79453	Hoard	0.6	1.8	2.3	0.3	2.7	-	-	92.3
Kukleny	79454	Hoard	6.1	1.4	1.0	-	1.9	-	-	89.6
Kukleny	79455	Hoard	6.7	-	-	-	-	-	-	93.3
Kukleny	79456	Hoard	4.4	1.1	0.7	-	0.3	-	-	93.5
Kukleny	79457	Hoard	7.6	0.4	0.6	-	-	-	-	91.4
Kukleny	79458	Hoard	5.3	0.5	-	-	-	-	-	94.2
Kukleny	79459	Hoard	6.0	0.8	-	-	-	-	-	93.2
Kukleny	79460	Hoard	5.2	0.5	0.5	-	-	-	-	93.8
Kukleny	79461	Hoard	3.9	0.6	0.6	-	-	-	-	94.9
Kukleny	79498	Hoard	3.1	0.7	-	-	-	-	-	96.2
Kukleny	79462	Hoard	5.4	0.6	-	-	-	-	-	94.0
Kukleny	79463	Hoard	2.8	1.0	0.8	-	1.8	-	-	93.6
Kukleny	79464	Hoard	0.4	1.5	1.2	-	1.1	-	-	95.8
Kukleny	79465	Hoard	1.3	0.9	1.2	-	1.7	-	-	94.9
Kukleny	79466	Hoard	-	1.6	2.1	-	2.9	-	-	93.4
Kukleny	79467	Hoard	-	1.3	1.3	-	1.1	-	-	96.3
Kukleny	79468	Hoard	-	1.2	0.9	-	1.2	-	-	96.7
Kukleny	79469	Hoard	-	1.9	1.2	-	1.2	-	-	95.7
Kukleny	79470	Hoard	-	2.2	1.5	-	2.0	-	-	94.3
Kukleny	79471	Hoard	-	1.9	1.7	-	3.1	-	-	93.3
Kukleny	79472	Hoard	-	1.6	1.9	-	1.0	-	-	95.5
Kukleny	79473	Hoard	-	0.6	0.7	-	0.9	-	-	97.8
Kukleny	79474	Hoard	2.3	1.0	0.6	-	0.7	-	-	95.4
Kukleny	79475	Hoard	1.4	1.3	0.6	-	1.4	-	-	95.3
Kukleny	79476	Hoard	-	1.5	0.9	0.2	1.5	-	-	95.9
Kukleny	79477	Hoard	-	1.3	1.7	-	2.2	0.2	-	94.6
Kukleny	79478	Hoard	3.6	1.4	1.1	-	1.9	-	-	92.0
Kukleny	79479	Hoard	-	2.7	1.7	-	-	-	1.8	93.8
Kukleny	79480	Hoard	-	1.2	1.0	-	1.4	-	-	96.4

Silver coating	Weight	Length	Edge width	Central width	Butt width	Thickness
x	200.7	121	47	18	19	16
?	171.2	121	46	18	19	13
x	193.4	133	56	14	17	12
x	206.1	126	51	16	18	14
x	219.1	135	53	17	20	14
x	170.7	118	46	17	20	13
x	213.5	123	52	17	18	15
x	196.6	131	48	17	17	14
x	258.3	139	56	17	18	15
?	172.6	125	49	14	15	14
?	207.7	122	53	18	18	14
x	203.7	124	50	17	19	15
?	212.5	130	49	15	21	17
?	179.9	119	52	17	20	14
?	162.0	114	52	16	18	13
?	208.2	140	56	16	19	15
x	228.2	135	58	18	20	14
x	193.9	128	48	17	19	13
x	191.9	136	56	18	15	13
x	186.6	127	53	17	17	14
x	185.7	112	53	17	18	14
x	139.2	108	46	14	17	12
x	170.5	113	43	16	18	15
x	176.2	120	43	19	18	14
x	191.3	128	53	18	19	13
x	181.8	133	54	16	18	13
x	254.4	140	56	19	18	16
x	216.8	136	55	18	19	14
x	237.3	146	58	15	19	14
x	207.2	128	50	19	22	14
x	191.0	139	59	17	20	11
-	197.0	145	61	15	20	13
-	201.7	141	59	17	21	13
?	188.1	135	55	17	20	12
-	185.4	136	59	16	20	13
x	174.0	131	56	22	19	11
-	198.3	136	57	18	19	12
?	187.2	134	56	16	22	12
?	178.4	135	55	18	25	12
?	183.4	136	50	17	22	13
-	193.2	132	54	18	21	9
?	198.0	130	54	17	20	14
-	181.7	128	53	17	19	13
-	183.6	131	54	18	20	12
?	216.1	137	56	17	19	11
x	170.7	132	50	17	20	11
x	207.4	145	58	17	20	12

Tab. 1 Overview of elemental composition results, presence of silver coating, and measurements of studied axes. The elemental composition was measured by SEM-EDS, the silver coating by SEM-EDS and XRD, the weight is measured in grams, size measurements in millimetres. The presence of silver-coating is marked with ›x‹; in case the coating was not visible by optical microscopy with 200x magnification and visible only with SEM its marked as questionable with ›?‹; in case its not present at all, it marked with ›-‹; measurements of axes that were not available for examination are marked as not available (N/A.)

***Tab. 1** Überblick über die Elementzusammensetzung, das Vorhandensein einer Silberbeschichtung und die Maße der untersuchten Beile. Die Elementzusammensetzung wurde mittels Rasterelektronenmikroskopie/energiedispersiver Röntgenspektroskopie (REM-EDX) bestimmt, die Silberbeschichtung mittels REM-EDX und Röntgenbeugung (XRD); das Gewicht ist in Gramm angegeben, die Größenangaben in Millimetern. Das Vorhandensein einer Silberbeschichtung ist mit ›x‹ gekennzeichnet; wenn die Beschichtung bei der optischen Mikroskopie mit 200-facher Vergrößerung nicht sichtbar war und nur im REM sichtbar ist, wird sie mit ›?‹ als fraglich gekennzeichnet; wenn sie überhaupt nicht vorhanden ist, mit ›-‹; Messungen an Beilen, die für die Prüfung nicht zur Verfügung standen, werden als nicht verfügbar (N/A) gekennzeichnet.*

Site	Arch. ID	Context	Sn	Ag	Sb	Bi	As	Pb	Ni	Cu
Kukleny	79481	Hoard	-	1.2	1.6		1.4			95.8
Kukleny	79482	Hoard	5.5	0.4	0.3	-	-	-	-	93.8
Kukleny	79483	Hoard	7.1	1.1	-	-	-	-	-	91.8
Kukleny	79484	Hoard	3.4	1.1	-	-	-	-	-	95.5
Kukleny	79485	Hoard	1.2	2.3	4.9	4.5	2.0	-	-	85.1
Kukleny	79486	Hoard	1.8	1.4	0.9	-	1.6	-	-	94.3
Kukleny	79487	Hoard	1.3	0.5	0.5	-	0.7	-	-	97.0
Kukleny	79488	Hoard	2.3	-	-	-	-	-	-	97.7
Kukleny	79489	Hoard	3.3	-	-	-	-	-	-	96.7
Kukleny	79490	Hoard	4.0	0.6	0.4	-	-	-	-	95.0
Kunčice	82441	Hoard	11.5	-	-	-	-	-	-	88.5
Kunčice	82442	Hoard	10.0	-	-	-	-	-	-	90.0
Kunčice	82443	Hoard	12.1	-	-	-	-	1.2	-	86.7
Kunčice	82444	Hoard	11.8	-	-	-	-	1.5	-	86.7
Kunčice	82445	Hoard	7.0	1.0	1.0	-	-	-	-	91.0
Kunčice	82446	Hoard	8.2	-	-	-	-	-	-	91.8
Kunčice	82447	Hoard	5.5	-	-	-	-	-	-	94.5
Kunčice	82448	Hoard	10.3	-	-	-	-	3.0	-	86.7
Jičíněves	6824	Hoard	5.5	-	-	-	-	-	-	94.5
Jičíněves	14799	Hoard	3.2	0.1	0.7	-	-	-	-	96.0
Jičíněves	52271	Hoard	5.4	0.7	0.3	-	0.7	-	-	92.9
Jičíněves	A161	Hoard	6.2	1.2	0.7	-	-	-	-	91.9
Jičíněves	A163	Hoard	1.4	0.9	-	-	0.7	-	-	97.0
Jičíněves	A165	Hoard	1.7	1.5	0.5	-	1.0	-	-	95.3
Jičíněves	19	Hoard	3.6	0.6	0.6	-	0.3	-	-	94.9
Jičíněves	710	Hoard	4.1	0.6	0.7	-	0.7	-	-	93.9
Obora	1	Hoard	5.9	0.9	0.6	-	-	-	-	92.6
Obora	2	Hoard	2.9	-	-	-	-	-	-	97.1
Obora	3	Hoard	2.7	0.7	0.6	-	1.6	-	-	94.4
Těchlovice	A74795	Hoard	5.2	0.5	0.6	-	0.3	-	-	93.4
Těchlovice	A74800	Hoard	12.4	0.9	1.0	-	-	-	-	85.7
Loučná Hora	A81007	Hoard	-	1.7	1.2	-	-	-	-	97.1
Loučná Hora	A81008	Hoard	-	0.8	1.0	-	0.8	-	1.5	95.9
Dolany	96953	Hoard	9.6	0.7	-	-	-	-	-	89.7
Staré Místo	-	Hoard	3.0	-	-	-	-	-	-	97.0
Starý Bydžov	522_6	Hoard	1.4	2.1	1.4	-	-	-	1.5	93.6
Mikulovice	4920	Grave	12.5	-	-	-	-	-	-	87.5
Domašín	-	Settlement	-	-	-	-	-	-	-	-
Lochenice	2370	Settlement	6.0	1.5	1.4	-	2.4	-	-	88.7
Čistěves	2034	Single find	-	1.8	0.8	-	0.9	-	-	96.5
Čistěves	2035	Single find	-	2.4	0.5	-	0.6	-	-	96.5
Dobruška	-	Single find	1.9	2.0	1.7	-	-	-	1.9	92.5
Dražkov	A012023	Single find	10.1	-	-	-	-	-	0.7	89.2
Dražkovice	AR016337	Single find	5.2	1.1	-	-	-	-	-	93.7

Silver coating	Weight	Length	Edge width	Central width	Butt width	Thickness
?	176.7	131	51	17	22	13
x	191.6	121	49	17	18	13
x	171.6	124	46	17	19	12
x	198.8	131	56	17	19	13
?	188.7	132	55	18	21	12
x	188.5	134	60	16	20	12
x	167.1	124	48	19	17	11
-	190.1	134	57	16	18	13
?	243.4	167	60	21	22	11
x	216.8	126	57	20	22	14
?	401.1	196	64	27	32	10
?	361.0	178	66	30	26	13
?	389.5	195	64	26	27	12
?	309.0	150	60	23	25	12
x	170.2	125	48	15	18	15
?	187.9	120	43	24	22	11
?	166.0	122	46	15	19	13
?	142.0	154	45	16	16	7
N/A	N/A	N/A	N/A	N/A	N/A	N/A
N/A	N/A	N/A	N/A	N/A	N/A	N/A
-	N/A	N/A	N/A	N/A	N/A	N/A
?	75.8	70	-	15	19	13
?	177.5	100	53	19		14
?	207.6	142.5	53	19	18	12
-	N/A	N/A	N/A	N/A	N/A	N/A
-	N/A	N/A	N/A	N/A	N/A	N/A
?	271.7	142	56	16	22	16
?	209.0	135	46	17	21	15
?	212.1	147	54	15	19	14
x	230.0	138	51	21	22	19
x	311.3	151	52	27	25	14
x	215.0	122	53	18	20	16
x	77.8	83	29	15	12	12
?	168.0	152	51	17	17	9
?	231.7	151	56	15	20	13
?	128.1	102	47	16	17	12
-	99.3	133	34	15	15	9
-	6.0	17	-	-	-	5
-	16.2	23	-	-	19	9
?	186.8	101	51	17	19	14
?	182.3	115	-	16	15	16
x	320.9	147	63	20	22	16
-	108.4	94	43	23	15	9
x	116.9	107	46	19	16	10

Site	Arch. ID	Context	Sn	Ag	Sb	Bi	As	Pb	Ni	Cu
Horní Jelení	AR016752	Single find	9.0	-	-	-	-	-	-	91.0
Chlumec nad Cidli-nou	98398	Single find	-	1.1	1.1	-	-	-	1.4	96.4
Kostelec	-	Single find	-	1.4	1.2	-	-	-	1.3	96.1
Lázně Bohdaneč	AR010156	Single find	-	1.5	0.6	-	-	-	-	97.9
Libišany	B148124	Single find	13.1	-	-	-	-	-	-	86.9
Litošice	-	Single find	6.1	-	0.5	-	-	-	-	93.4
Lochenice	95781	Single find	-	1.2	1.9	-	-	-	1.8	95.1
Mělník	5_2017	Single find	-	2.1	0.9	-	-	-	1.7	95.3
Miletín	-	Single find	-	1.3	3.2	-	1.7	-	3.0	90.8
Nízká Srbská	-	Single find	5.8	1.1	1.0	-	-	-	-	92.1
Plotiště nad Labem	A80637	Single find	-	1.4	2.0	-	-	-	1.8	94.8
Předměřice nad Labem	1802	Single find	3.7	0.5	-	-	-	-	-	95.8
Strašov	AR012049	Single find	-	0.9	1.5	-	1.2	-	2.9	93.5
Třebechovice	58_1972	Single find	2.0	2.0	1.4	-	-	-	-	94.6
Valdice	30695	Single find	-	2.3	0.8	-	-	-	-	96.9
Velká Čermná	-	Single find	-	-	-	-	-	0.6	-	99.4
Voleč	AR012055 AR 010256	Single find	11.8	-	-	-	-	-	-	88.2
Vršce	96684	Single find	-	-	-	-	1.4	-	3.9	94.7
Vysoké Chvojno	AR011868	Single find	9.8	-	-	-	1.1	-	1.3	97.8
Žáravice	AR012065	Single find	-	1.9	2.1	-	1.2	-	0.5	94.3
Jičíněves	A162	Hammer	4.2	1.1	0.6	-	-	-	-	94.1
Předměřice nad Labem	1803	Hammer	1.9	2.9	0.7	-	-	-	-	94.5

guished, which have also been described, such as manipulation wear, repairs, post-depositional traces, and traces of recent origin (Schimerová et al. 2023). Only then can a more detailed interpretation of the individual traces occur, which is necessarily associated with controlled experiments (Dolfini et al. 2023; Hermann et al. 2020; Roberts/Ottaway 2003). Experimental verification (a controlled experiment) can identify a certain type of damage with a specific activity (Dolfini et al. 2023). However, in the case of axes, we still encounter insufficient experimental data, especially for the interpretation of the often-present random striations and grooves.

These fine traces are very challenging to interpret, but repetitive so-called manipulative traces[6] can be observed, making their origin more likely to be identified. Repairs that are observable and recorded on artefacts but that prevent or distort knowledge of practical use are also an important factor. Recycling, repairs (including resharpening), and rapid metal loss could also be reasons why metalwork wear analysis as a method began to be applied relatively late compared to the original use-wear analysis in the stone artefacts (Roberts/Ottaway 2003).

The informative potential of most of the examined axes from eastern Bohemia was limited for metalwork wear

6 E.g., Schimerová et al. 2023; M. Havlíková, Sword-fighting in Bronze Age Europe: assessing the use of bronze swords from Bohemia and Moravia. AWRANA Barcelona 2022 Congress, <https://www.academia.edu/81152164/Sword_fighting_in_Bronze_Age_Europe_assessing_the_use_of_bronze_swords_from_Bohemia_and_Moravia> (28.05.2024).

Silver coating	Weight	Length	Edge width	Central width	Butt width	Thickness
-	197.3	152	41	26		12
-	226.0	101	39	26	19	15
?	33.6	40	-	-	15	11
-	66.8	51	33	17		11
-	195.0	129	44	20	18	13
-	114.2	156	43	19	20	9
?	60.0	53	36	14	-	11
?	103.5	90	35	16	18	13
?	106.4	89	37	18	19	12
x	77.8	96	36	13	11	11
?	72.3	76	34	14	14	10
?	193.1	121	51	17	19	14
?	165.2	109	45	23	22	13
?	242.5	117	50	27	23	14
?	158.4	113	38	15	14	15
-	93.0	57	45	-	-	12
-	94.2	109	30	17	16	8
-	66.4	124	40	14	16	7
-	56.0	89	25	14	12	10
?	60.5	45	38	-	-	10
?	172.3	99	36	20	13	12
x	273.2	101	48	22	21	14

analysis due to conservation and mechanical cleaning. The main issue in this case is the removal of patina, which serves as an indicator of the age of the trace, as well as conservation solutions, through which the surface of the artefact cannot be analysed (Fig. 11).

Despite conservation, it was possible to identify some use-wear traces on nearly all axes from eastern Bohemia (Fig. 12). Most specimens feature multiple traces, including striations running at an angle to the cutting edge, blade blunting, and flattening of the cutting edge. Overall, these traces are compatible with woodworking activities[7]. At the same time, traces of forging, grinding, and the sharpening of the blade are often present. Resharpening the blades is very common, demonstrating repeated (frequent) use of the axe. It is indicated by various degrees of asymmetry of the blade and metal loss (Dolfini et al. 2023; Dolfini 2011; Moyler 2008). Resharpening the blade results in the loss of traces of use in this area, so whether the axe was used can be observed based on the asymmetry of the blades and the presence of manipulative traces on the surface. The intensity of use based on the asymmetry of the blade and the loss of metal (see Moyler 2008) is then influenced by the mechanical properties of the metal, namely, the elemental composition and hardness of the blade due to forging. The

7 Crellin 2018; Dolfini et al. 2023; Dolfini 2011; Kienlin/Ottaway 1998; Roberts/Ottaway 2003; Schimerová et al. 2023.

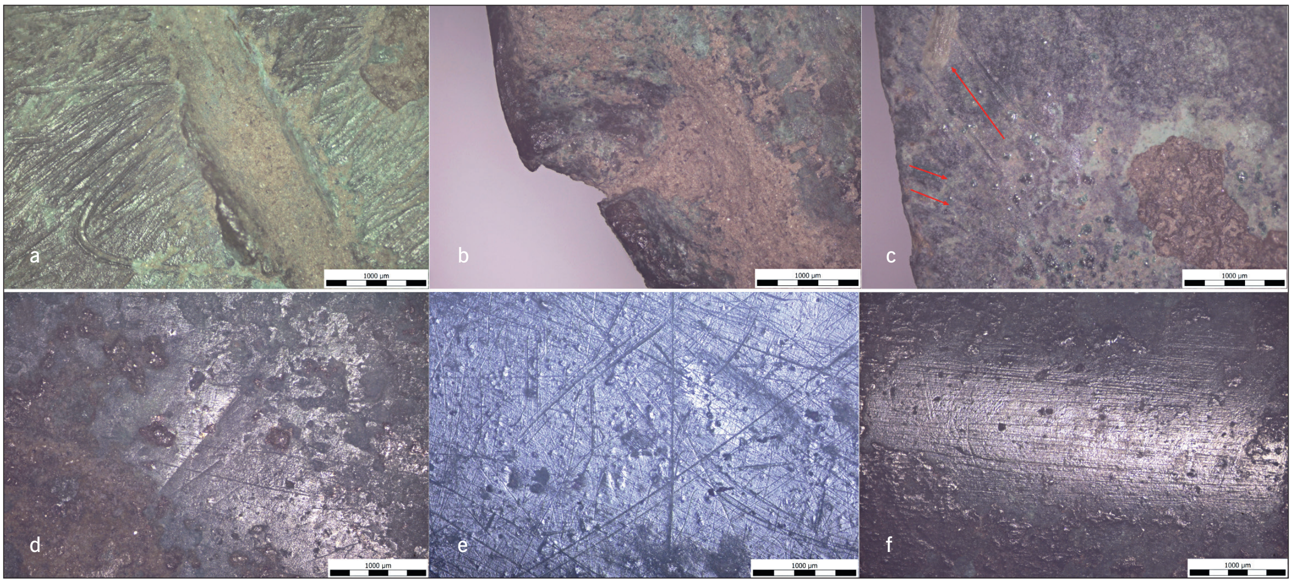

Fig. 12a–f Representation of metalwork wear traces. a Massive cut mark on the flange of axe, Kukleny, Hradec Králové district, axe no. 79484; b Damage of edge (cut with the surrounding metal) from impacts with a harder material, Kukleny, axe no. 79461; c Oblique grooves on the edge, Kukleny, axe no. 79453; d Manipulative traces on the blade, Nízká Srbská, Náchod district; e Manipulative traces with a dent on the blade, Kunčice; f Polishing of the flange, Staré Místo, Jičín district. Magnified 50x.

Abb. 12a–f *Beispiele für Abnutzungsspuren auf Metall. a Starke Schnittspur auf der Randleiste eines Beils, Kukleny, Okr. Hradec Králové, Beil-Nr. 79484; b Beschädigung der Schnittkante (einschließlich des umgebenden Metalls) durch Zusammenstöße mit einem härteren Material, Kukleny, Beil-Nr. 79461; c Schräge Kerben auf der Schneide, Kukleny, Beil-Nr. 79453; d Nutzungsspuren auf der Klinge, Nízká Srbská, Okr. Náchod; e Nutzungsspuren und eine Delle auf der Klinge, Kunčice; f Polierspuren auf der Randleiste, Staré Místo, Okr. Jičín. Fünfzigfache Vergrößerung.*

Fig. 13 Documented degrees of metal loss on the blade from probably new (or only briefly used and once repaired) to almost complete blade disappearance.

Abb. 13 *Metallschwund an der Klinge von vermutlich neu (oder nur kurz benutzt und einmal repariert) bis zum fast vollständigen Abtrag.*

symmetry of the blade is often distorted due to the condition of the axe, particularly because of corrosive processes. It is essential to consider the cutting edge condition in the analysis and exclude corrosion as the cause of traces and damage during the interpretation (Horn/Holstein 2017). Among the axes analysed within our dataset, we can observe all degrees of metal loss on the blade, ranging from the probably new (or only briefly used and once repaired) blade to almost complete blade disappearance (Fig. 13).

In the corrosion layers, organic residues are often present as well. In the case of the axes, these are primarily remnants of wooden hafts in the area of the hafting. For example, in the case of Kukleny, we can observe attachment points due to manipulative traces corresponding to contact with wood (Fig. 14a). On an axe from grave 26 from Mikulovice, on the other hand, wood in the blade area has been preserved (Fig. 14b).

Optical microscopy has also facilitated the identification of metallic flakes, which are bound to attached impurities. These flakes are separated from the original surface by corrosion products and occur across the entire surface of the axe, both on the functional part and in the hafting area.

Analysis of the silver coatings

Coating of the axes with metal of different colour was observed with both electron and optical microscopy. After this discovery, all axes were first examined without magnification. It was confirmed that some specimens showed the residues of silvery layers even without magnification (Fig. 15). Then all axes were examined with an optical microscope and with SEM-EDS (Fig. 16). The SEM-EDS elements distribution map showed that these layers were made of silver (Fig. 17). To determine the character of the layers, X-Ray Diffraction (XRD) was applied, and it proved that the coating was Ag0, which means that the layers were elemental silver whereas the possibility of corrosion from the matrix could be excluded. Only where the element distribution maps showed scattered particles of silver on very crumbly layers was silver also present as a product of corrosion of the matrix that contained silver. Such layers have a very different character from the actual silver coating (Fig. 18). While the silver coating lies on the patina and clearly forms another layer, often polished, the corroded silver from the matrix is below the patina in the form of a crumbly uneven layer. Traces of polishing were clearly visible on the residues of the silver coating (Fig. 19). In this case, only non-conservated axes were considered relevant because silver is an extremely soft metal and polishing traces could also be created during conservation. This became evident on some conservated specimens, where the traces of mechanical cleaning were detected all over the silvery layers, in some cases even over the copper or bronze (Fig. 11).

Another result confirming that the silver coating observed on some axes cannot be caused by corrosion in an acidic environment is the low silver content detected in the matrix, in some cases even below the detection limit of the method used. The concentration of silver between 0.1 and 2.9 wt% is not sufficient to create the observed layers (see Giumlia-Mair 2020). Moreover, the appearance of working traces on the silver layer could be additional evidence of intentional coating with silver (La Niece 1993, 207).

The best-preserved examples came from Kukleny and Kunčice, as they were not submitted to conservation (see Schimerová et al. 2023). Here, the layers were preserved under calcified soil, which kept the otherwise very loose silver layers attached to the surface. In some cases, the layers of silver appear within the copper corrosion, which seems to have grown through the silver layers and attached them to the surface. These layers were preserved also on some conserved specimens (Fig. 20). In other cases, the copper corrosion completely destroyed the layers of silver, which helps to explain the poor preservation. So far, it has been impossible to measure the thickness of the layers in a precise way. We measured silver foils trapped between cracks in the patina only in one case. They measured approximately 1 µm (Fig. 21). However, with further analyses conducted with LIPS it became clear that the thickness of the layers is very uneven. The precise thickness has to be examined by future research as it could be important in determining the process of coating.

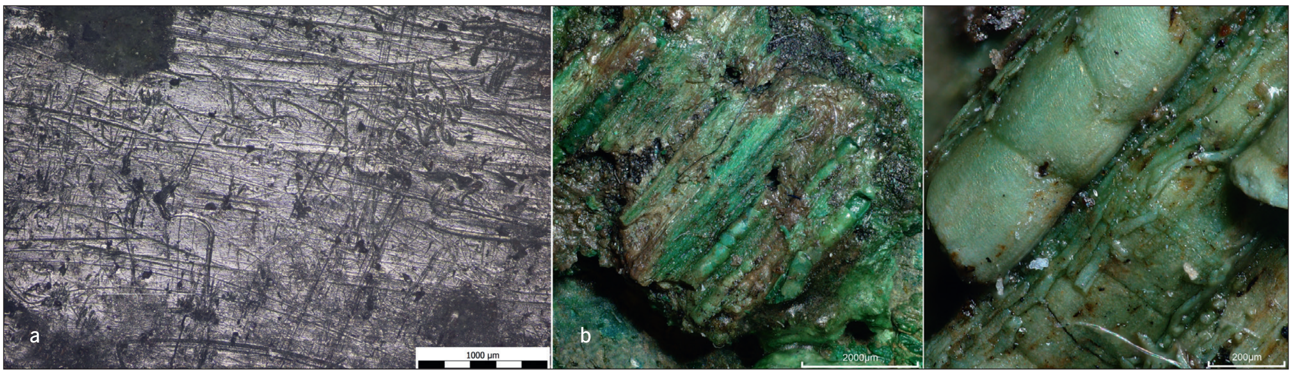

Fig. 14a–b Details of metal after contact with wood and organic residues. a Manipulative traces corresponding to contact with wood, Kukleny, Hradec Králové district, axe no. 79440; b Detail of wood preserved in the blade area, Mikulovice, Pardubice district, axe no. 4920.

Abb. 14a–b *Detailaufnahmen von Metall nach dem Kontakt mit Holz und mit organischen Überresten. a Nutzungsspuren, die zum Kontakt der Klinge mit Holz passen, Kukleny, Okr. Hradec Králové, Beil-Nr. 79440; b im Klingenbereich erhaltenes Holz, Mikulovice, Okr. Pardubice, Beil-Nr. 4920.*

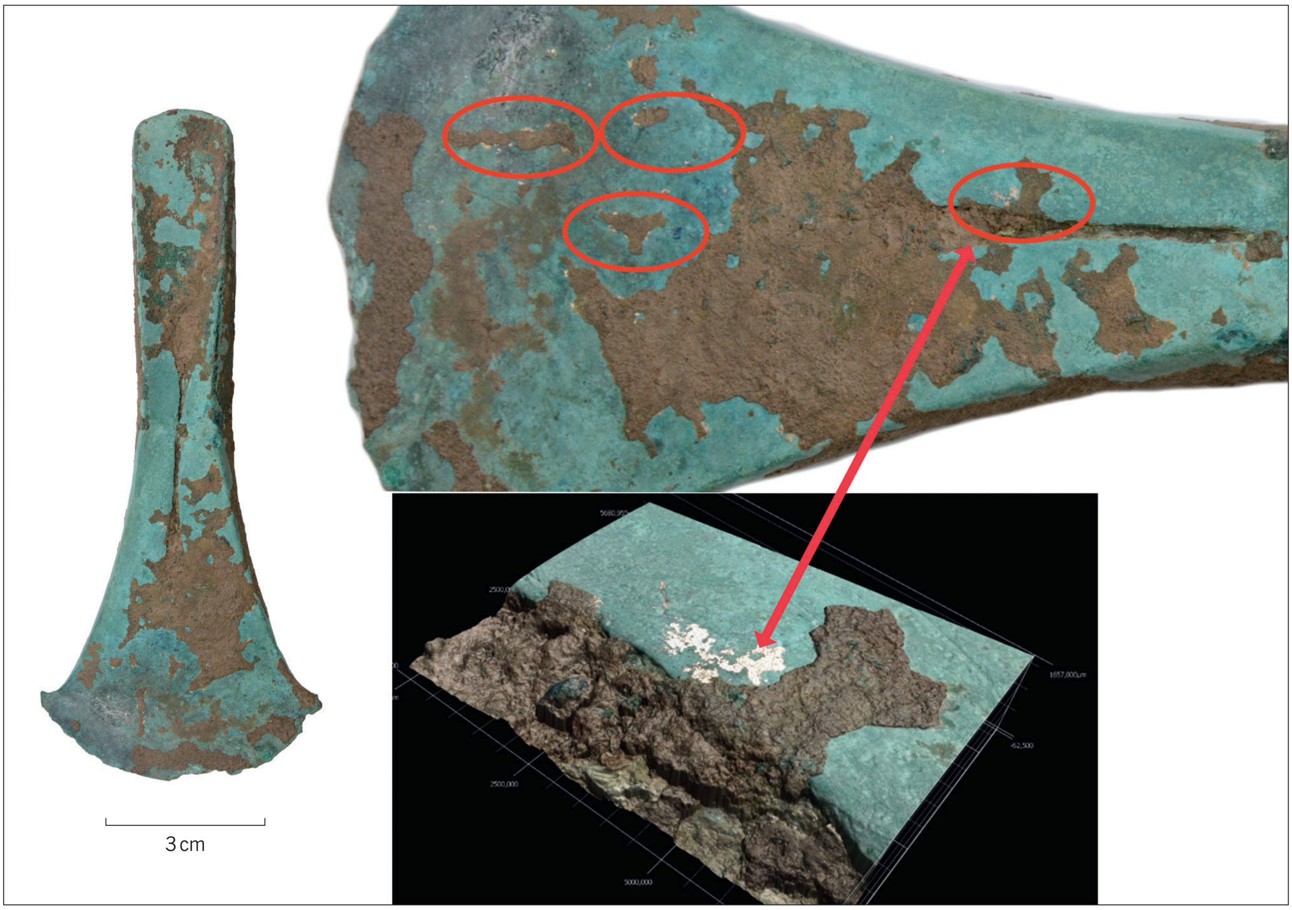

Fig. 15 Residues of silver coating without magnification and magnified detail on axe no. 79441 from Kukleny, Hradec Králové district.

Abb. 15 *Überreste der Silberbeschichtung ohne Vergrößerung und vergrößertes Detail auf Beil-Nr. 79441 aus Kukleny, Okr. Hradec Králové.*

If we take into account the frequency of silver coating with respect to the find context, from the 83 studied axes that came from hoards, 81 of them were available for examination. A silver coating was detected either optically or by optical microscopy on 38 of them. That represents nearly 47 % of the whole hoard assemblage. Using SEM, silver was detected on another 32 axes, but these results should be taken with caution, as no significant layer could be observed microscopically and the character of the silver particles was unclear. In contrast, the axes from graves and settlement contexts (three specimens in total) did not have any silver coating present on their surface. From 25 single finds, silver was positively detected only on three, which represents 12 %. In 12 more cases silver was detected only by SEM. Surprisingly, both of the axe-shaped hammers also bore traces of silver coating – in one case detected even macroscopically and in the other only with SEM. Adding everything together, silver coating was positively proven on 38 % of the entire studied assemblage. If we add also the more doubtful ones, the percentage would rise to 78 %.

Attempt at reconstructing an Early Bronze Age silvering technique

Today, various methods of silvering base metals are known: leaf silvering, fire silvering, galvanic silvering using electricity, and electroless silvering.

For the Early Bronze Age, only electroless silvering seems plausible, as the use of electric current can be excluded[8]. Leaf silvering would have required extremely thin silver leaves and an organic adhesive to attach them to the base metal. Such silvering would have been mechanically fragile due to insufficient adhesion. Fire silvering would have required the availability of mercury, which would have been detectable in analyses.

Chemical silvering (electroless plating) presupposes the availability of aqueous solutions of silver that can be applied to less noble metals. In this process, silver precipitates as an element on the metal surface, while the less noble metal (in this case, copper) passes into the solution. Many such methods are known today and are mostly based on silver nitrate or cyanide complexes. However, this would have meant that

8 The theories that have repeatedly surfaced since 1934, suggesting that there were already batteries generating electricity in ancient times and that the Parthians had executed galvanic gilding with them, have actually been debunked for years as a scientific legend (Eggert 1996).

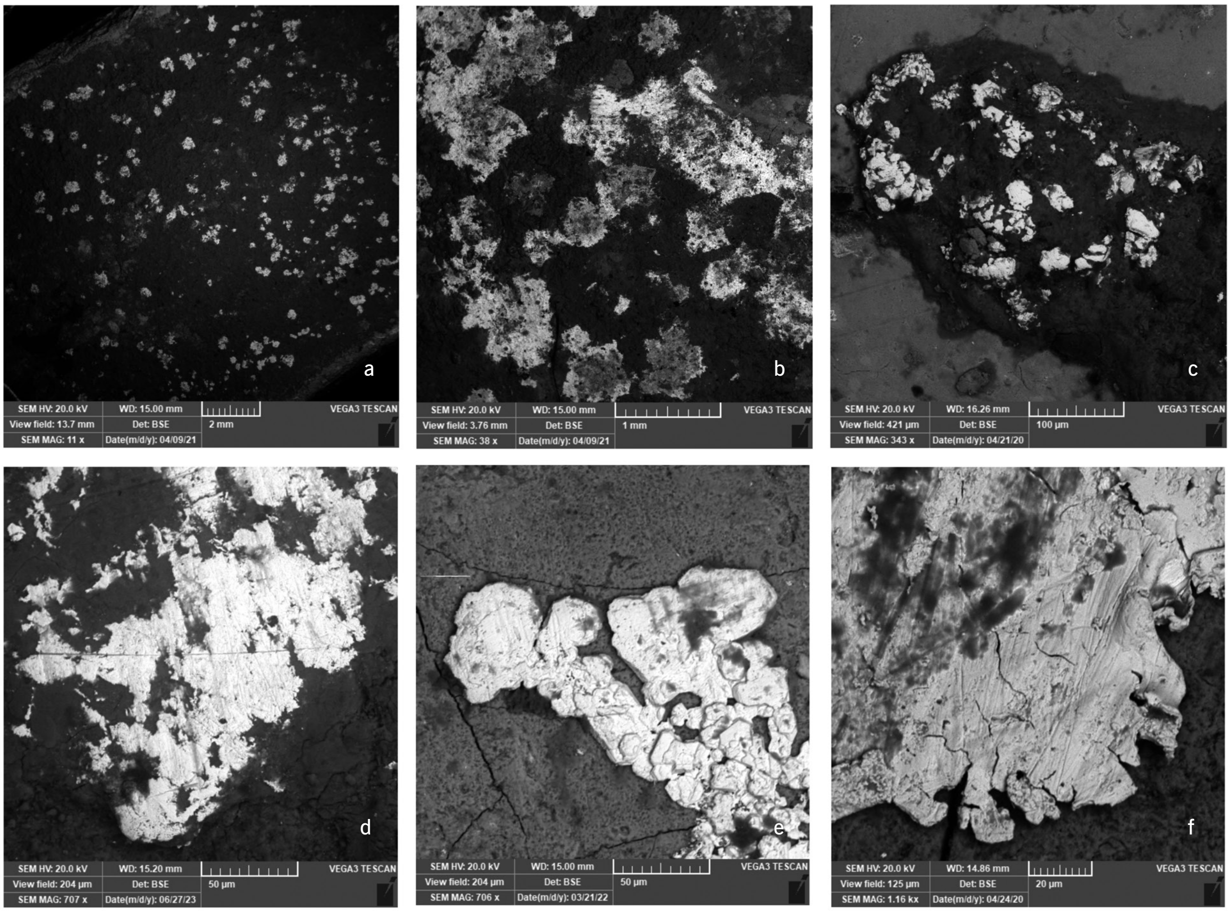

Fig. 16a–f Details of preserved silver coating from SEM, all samples are not conservated. a Jičíněves, Jičín district, axe no. A161; b Jičíněves axe no. A163; c Kunčice, Hradec Králové district, axe no. 82455; d Žáravice, Pardubice district, axe no. 12065; e Kukleny, Hradec Králové district, axe no. 79482; f Kukleny axe no. 79441.

Abb. 16a–f *Details von erhaltener Silberbeschichtung unter dem Rasterelektronenmikroskop; unkonservierte Proben. a Jičíněves, Okr. Jičín, Beil-Nr. A161; b Jičíněves, Beil-Nr. A163; c Kunčice, Okr. Hradec Králové, Beil-Nr. 82455; d Žáravice, Okr. Pardubice, Beil-Nr. 12065; e Kukleny, Okr. Hradec Králové, Beil-Nr. 79482; f Kukleny Beil-Nr. 79441.*

nitric acid or even alkali cyanides were available during the Bronze Age. Nitric acid (aqua fortis) only appeared in alchemical laboratories at the end of the 15th century, and cyanides emerged in the 19th century. These substances were unknown during the Bronze Age. So how could silver be brought into an aqueous solution? Two quite old,

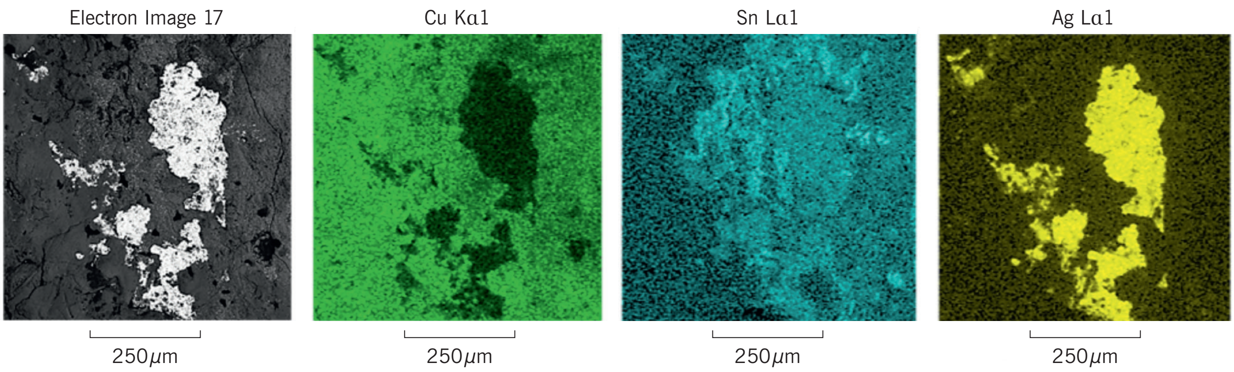

Fig. 17 The map of elements distribution in the place of the silver coating residues of axe no. 79456 from Kukleny, Hradec Králové district (SEM).

Abb. 17 *Elementverteilung an der Stelle mit Überresten von Silberbeschichtung von Beil-Nr. 79456 aus Kukleny, Okr. Hradec Králové (REM).*

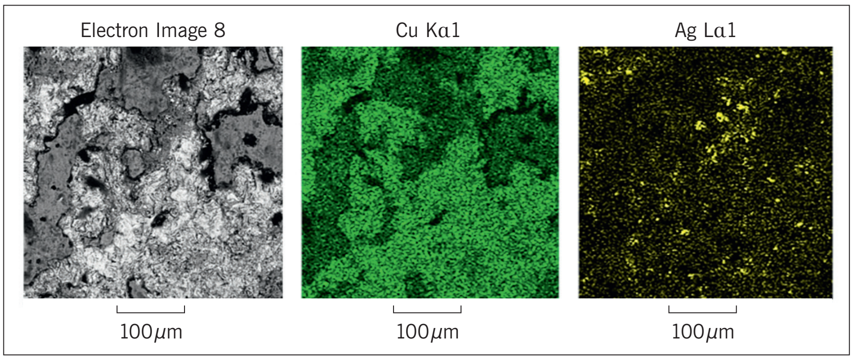

Fig. 18 The map of elements distribution in the silver-rich places on the surface of axe no. 79476 from Kukleny, Hradec Králové district (SEM).

Abb. 18 *Elementverteilung an den silberreichen Stellen auf der Oberfläche von Beil-Nr. 79476 aus Kukleny, Okr. Hradec Králové (REM).*

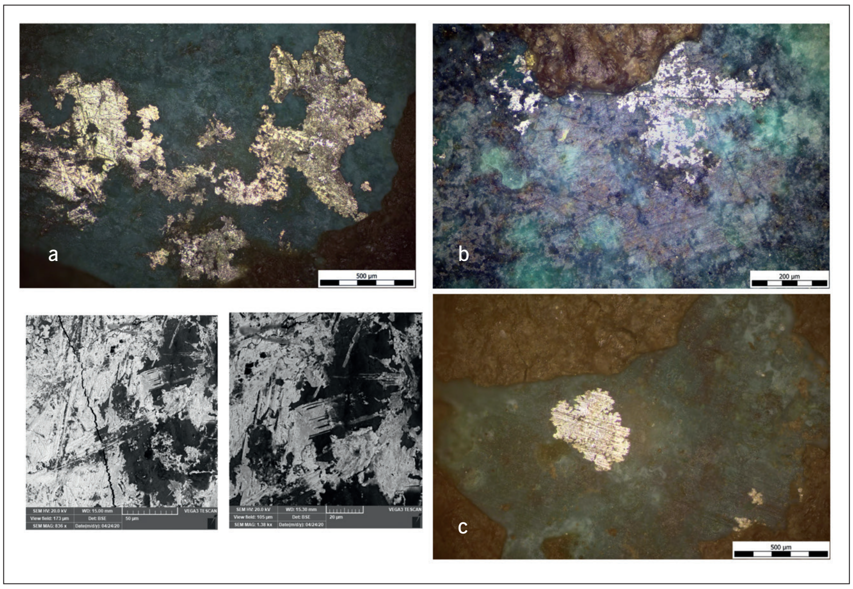

Fig. 19a–c Silver coating layers with traces of polishing/wear traces on non-conservated axes. a Kukleny, Hradec Králové district, axe no. 79441; b Kukleny axe no. 79441 from (SEM); c Kukleny axe no. 79462.

Abb. 19a–c *Silberbeschichtung mit Polier-/Abnutzungsspuren auf unkonservierten Beilen. a Kukleny, Beil-Nr. 79441; b Kukleny, Okr. Hradec Králové Beil-Nr. 79441 (REM); c Kukleny, Beil-Nr. 79462.*

preindustrial formulations for silvering can be found in A. Helmreich's *Kunstbüchlein* (Little Art Book), printed in Eisleben in 1563 (Helmreich 1563); the book's author was a mathematician and court clerk in Halle. On the second-to-last page of the work, which otherwise deals with the production of inks and pigments for manuscript illumination, there are two recipes for silvering copper. The first recipe uses (freshly precipitated) silver (or horn silver: which is not entirely clear), salt (natrium chloride), and cream of tartar. The paste is to be rubbed on the object to be silvered with the finger. The second recipe is somewhat unclear, using sal ammoniac (ammonium chloride), »galmei« (a zinc ore, not specified), cream of tartar, alum, silver powder, vinegar, and freshly deposited fine silver. The ingredients are briefly heated and applied.

The mechanism inherent in both recipes is that silver chloride (horn silver), initially formed by the action of acids (acetic acid, cream of tartar, alum) and the entry of oxygen, turns into soluble Ag-chloro complexes in the presence of an excess of chloride ions (from the abundantly added table salt). In both cases, there are aqueously dissolved silver ions. These ions deposit on the copper surface according to the principle of ›electroless plating‹, where the less noble copper passes into the solution, and the elemental silver is deposited. Similar formulations are essentially still used today, and corresponding commercial products are sold as ›rub-on silvering‹. Clear formulations can be found in practical textbooks from the 19th century. One frequently mentioned instruction is the »rub-on silvering according to Langbein« (Buchner 1891, 86) using 10 g of silver chloride, 20 g of cream of tartar, 20 g of table salt, and adding water to the consistency of dough. The paste is then applied to the workpiece.

Our experiments (Tab. 2) primarily tested the combination of silver chloride/cream of tartar/table salt, as well as silver chloride/table salt/acetic acid. All variations work and form a more or less dense, closed silver coating that can be polished to a high gloss with an agate afterwards (Fig. 22). The practical execution is surprisingly simple: Just a few drops of a silvering paste made of silver chloride, table salt, and organic acid are rubbed on the base metal surface with a brush or fingertip, and, within a few minutes, a bronze/copper metal is brilliantly silvered (Fig. 23).

Another ›chemical‹ likely used in the Early Bronze Age was fermented urine, possibly for patinating bronze surfaces (Berger 2012). Silver chloride is also soluble in weak ammoniacal solutions, forming silver diamine complexes. We conducted experiments in this direction as well, using ammonium carbonate instead of fermented urine. Although it is relatively easy to bring silver chloride into solution in this way, when these solutions are applied to the copper surface, only a colloidal, black precipitate of silver forms, and no usable metallic coating is produced. Thus, the system of

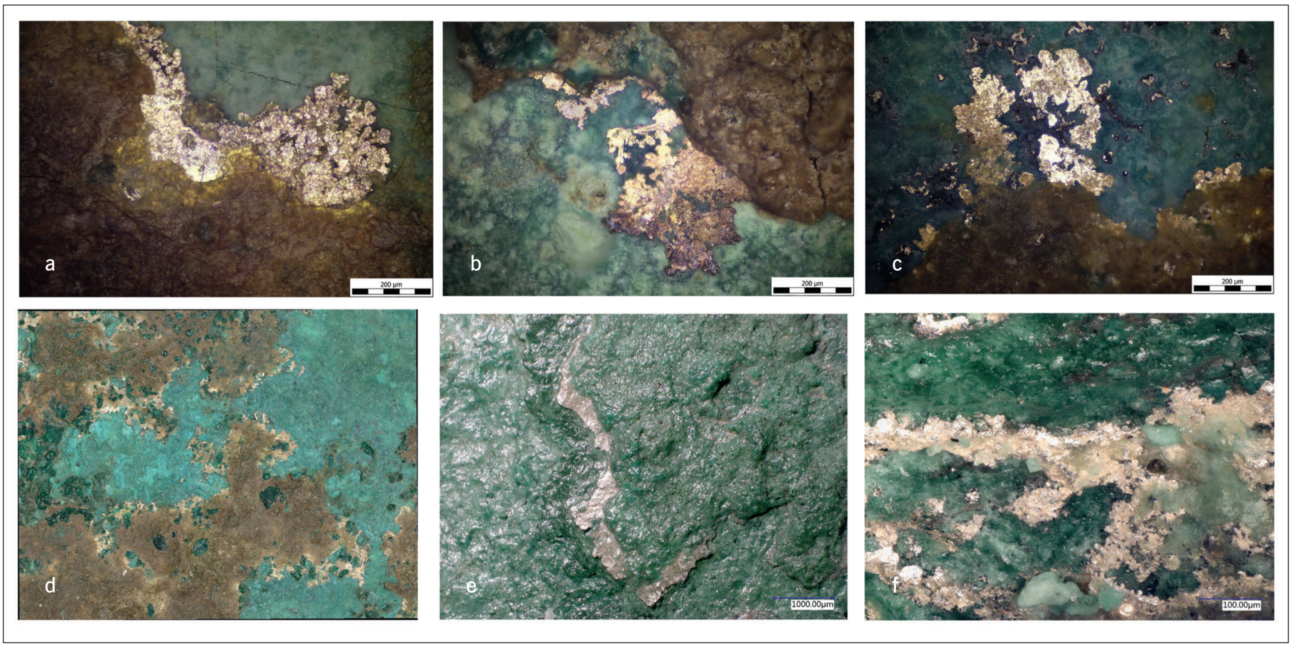

Fig. 20a–f Silver coating layers attached to the surface with calcified soil residues or copper corrosion. a Kukleny axe no. 79483; b Kukleny axe no. 79461; c Kukleny axe no. 79455; d Kukleny axe no. 79455; e Těchlovice axe no. 74800; f Těchlovice axe no. 74800.

Abb. 20a–f *Mit verkalkten Erdresten oder Kupferkorrosion an der Oberfläche anhaftende Silberbeschichtung. a Kukleny, Beil-Nr. 79483; b Kukleny, Beil-Nr. 79461; c Kukleny, Beil-Nr. 79455; d Kukleny, Beil-Nr. 79455; e Těchlovice, Beil-Nr. 74800; f Těchlovice, Beil-Nr. 74800.*

silver chloride/table salt in a slightly acidic medium (vinegar, fruit acids) works best and fastest. The question arises: Did the Únětice artisans in Bohemia have access to silver chloride or horn silver at all?

There is initially the theoretical possibility that artificially produced silver chloride from imported silver could have been used. The process involves a method similar to the so-called ›cementation‹ for purifying gold. Silver-rich gold (or pure silver) is heated with ceramic flour and table salt, producing silver chloride, which is absorbed by the ceramic flour and could then have been used for silvering. However, this technique was unknown in the Early Bronze Age (Wunderlich et al. 2014).

More likely, in the spirit of Occam's razor, it seems that there was no need to search long for silver chloride in Bohemia. It was simply lying around in some places in the form of the so-called ›horn ore‹. This ore is pure silver chloride. The term »horn ore« first appears in the Italian publication by M. A. Della Fratta Montalbano entitled *Pratica Minerale* (Montalbano 1678). There it says: »Ottima ancora è quella di color del corno, che chiamano i Tedeschi Hornerz, della qual fe ne caua nella Valle loachimia di Kutembergh«[9].

Although the Jáchymov (Joachimsthal) mine was only opened after 1516, it can be assumed that outcropping silver ores in the form of horn silver were known and available before this time, even if not used for silver production

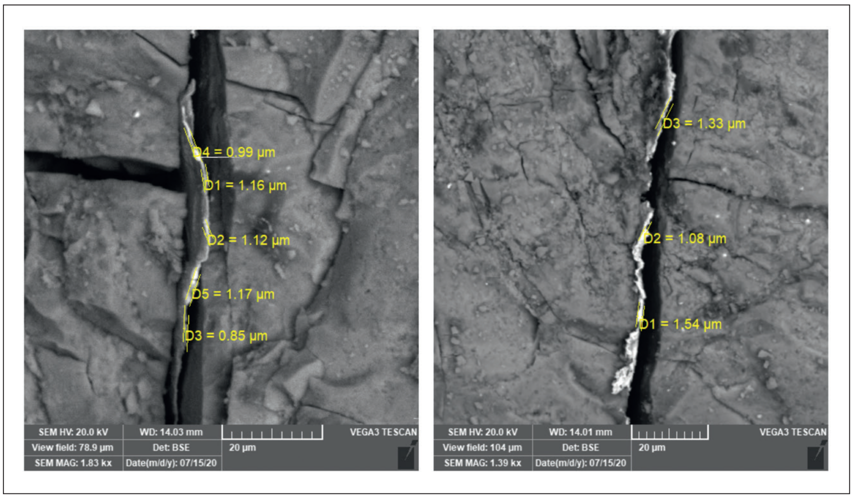

Fig. 21 Part of detached silver coating trapped between cracks in the copper corrosion layers (SEM).

Abb. 21 *Teil der abgelösten Silberbeschichtung in Rissen zwischen den Schichten der Kupferkorrosion (REM).*

9 Montalbano 1678, 96; »Excellent is also that horn-colored ore, which the Germans call ›Hornerz,‹ and is extracted in the Joachimsthal Valley near Kutná Hora«.

Experiments on »Bronze Age« Silvering
1. **Rub-in silvering, simple, with horn silver Silver chloride** 1 part Table salt 5 parts Mix with a little water. Rub on bare copper with a glass rod under light pressure, polishing at the same time. Result: It works, but there are slight defects. Copper chloride seems to form, which, due to the high pH, does not dissolve properly.
2. **Rub-in silvering** (»Anreibeversilberung nach Langbein« Buchner 1891, 86) Formulation as above, addition of ›cream of tartar‹ (potassium hydrogen tartrate) 100 mg silver chloride 200 mg cream of tartar 200 mg sodium chloride. Mix with a little water to form a paste, apply with a cloth. Works very well and, above all, very quickly. The paste can also be picked up with the finger and spread on the surface. Within a few minutes, a well-cleaned copper or bronze hatchet can be silvered.
3. **Silvering also succeeds if diluted acetic acid (5 %)** is used instead of cream of tartar.
4. **Silvering using ammonium carbonate and silver chloride** 100 mg silver chloride is rubbed into 100 mg ammonium carbonate in about 1 ml of water and applied to the copper surface. The solution turns slowly black (probably colloidal silver), but no closed silver surface is formed.

Tab. 2 Recipes of possible silver coating methods verified experimentally.

Tab. 2 *Rezepte denkbarer Silberbeschichtungsmethoden, experimentell überprüft.*

(Lommer 1776, 26). C. H. Lommer reports that horn silver is mainly found »in upper, insignificant depths«, meaning at or near the Earth's surface. He states that horn silver appeared »three to four ells under the turf and surface of the earth« during the reopening of a shaft in the »Gotthelf Schallerer Berggebäude«[10]. Other locations mentioned for horn silver are Marienberg, Schneeberg, Annaberg, all Erzgebirgskreis district, and Jáchymov, Karlovy Vary district, in Bohemia. In light of this, it seems entirely probable that Únětice metalworkers had access to silver chloride in the form of naturally occurring horn silver, even without the need for extensive silver mining. Additionally, the required quantities were small. Only a few milligrams of horn silver were needed to completely silver an axe.

Internal structure of the axes

The study of the internal structure of axes was conducted with X-ray and tomographic scanning. While axes from copper and its alloys appear to be well cast, their inner structure often shows frequent casting defects. The casting defects were originated during the cooling of the melt in the casting molds. The most common were closed cavities in the alloy. This type of casting defect is caused by the changing solubility of gases in the melt during cooling and the insufficient deaerating of casting molds (Atkins 2006).

Other casting defects were open shrinkages which were observed in the butt of some axes. The open shrinkages were formed in the places where the melt was solidified last. The formation of open shrinkages was caused by the insufficient height of the risers and by the improper location of the gating system in the casting molds used. The location of these shrinkages in the butt of the axes suggests casting into probably closed molds that were in perpendicular position (with the edge at the bottom of the mold). The inner shrinkages and the shrinkage porosity (Fig. 24) were also observed in some axes. The uneven cooling of the bronze melt in the casting molds, the improper location of the gating system, and the improper construction of the casting molds used were the main reasons for these defects. Very often, significant damages of the blades by corrosion were observed.

Discussion

The majority of axes from eastern Bohemia come from only one hoard containing 57 artefacts from the total of 111 axes. Only one axe comes from a grave, two fragments come from stratified settlement features, and the remaining 25 come from unspecified contexts. One of the two axe-shaped hammers comes from a hoard and the other was found in the 19th century under unknown circumstances. This proves that, as in other groups of the Únětice Culture, axes are most frequent in hoards. The phenomenon has been interpreted in many different ways, yet it shows a clear inclination towards accumulating axes in hoards rather than displaying them in graves as a symbol of individual status (see Meller 2017). The one axe from a grave is also consistent with this theory. The fragments from settlement contexts are very important because they indicate that metal axes were used alongside stone axes, which were still frequent at Early Bronze Age settlements. The low frequency in settlement contexts could be connected to the reuse of the metal after the axe was damaged and not suitable for use anymore. Many axes might had been reutilised, and their original number must have been much higher. Four of the hoards were stored in a ceramic vessel, which is a common feature of hoards in Central Germany. In this context, the hoard from Dermsdorf is very unique, as it was found during the excavation of the site. Here, 98 axes and two unfinished halberd cast blanks were buried by the side of a long house (Küßner/Wechler 2019; Meller 2019a).

10 Johanngeorgenstadt, Erzgebirgskreis district, today Saxony, on the border with the Czech Republic.

Fig. 22 Experiments of silver coating with silver chloride, sodium chloride, and cream of tartar.

Abb. 22 *Versuche zur Silberbeschichtung mit Silberchlorid, Natriumchlorid und Weinstein.*

Results of the elemental composition of the axes show that the majority of them were made from bronze with different amounts of tin. Some specimens were made from fahlore copper (Junk et al. 2011; Lutz/Pernicka 2013). The majority of them also showed the intentional addition of tin.

The comparison between the elemental compositon of axes from hoards from eastern Bohemia and Central Germany shows that, in the latter area, axes were made predominantly from copper (see Meller 2019; Meller 2019a). By contrast, in eastern Bohemia the axes were made mainly from bronze.

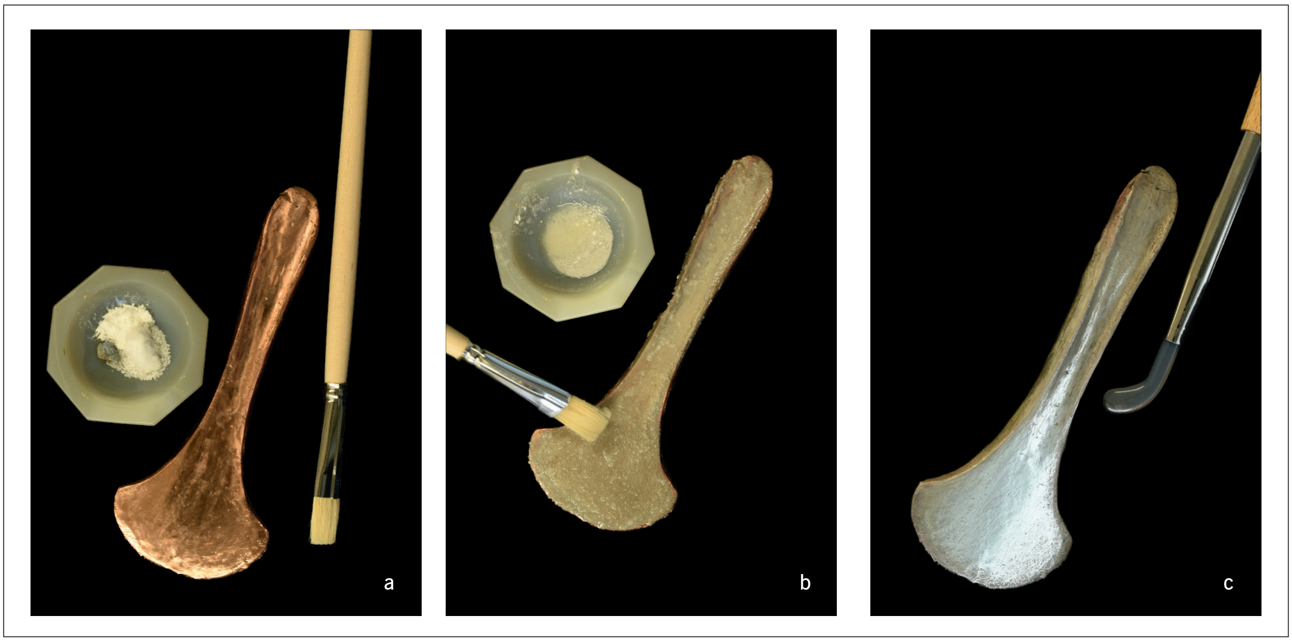

Fig. 23a–c Results of silver coating experiments. a silver chloride; b sodium chloride; c cream of tartar.

Abb. 23a–c *Ergebnisse der Silberbeschichtungsversuche. a Silberchlorid; b Natriumchlorid; c Weinstein.*

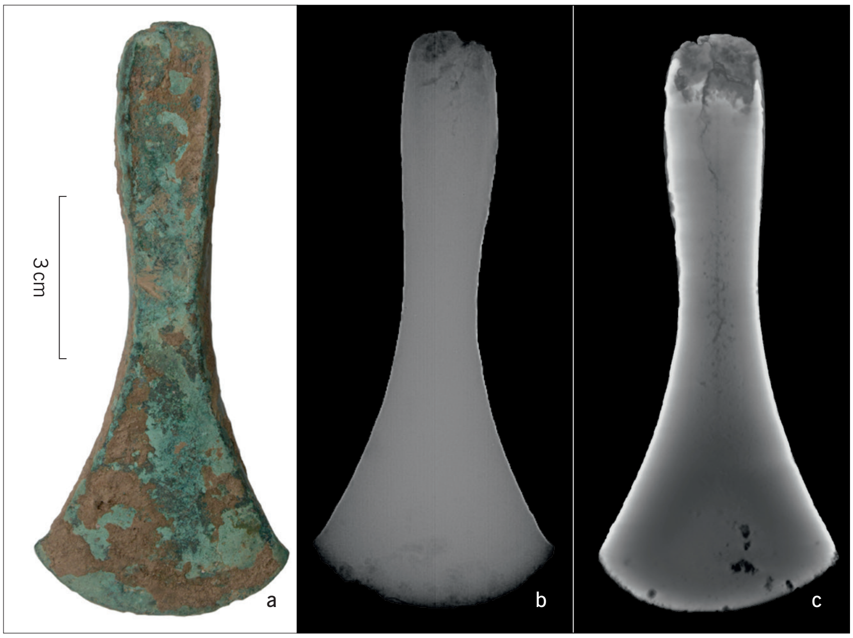

Fig. 24a–c Documentation of an open shrinkage with photography (a), X-ray (b; 200 kV, 180 uA) and CT (c).

Abb. 24a–c *Dokumentation einer offenen Schrumpfung mittels Fotografie (a), Röntgen (b; 200 kV, 180 uA) und Computertomografie (c).*

Based on use-wear analysis, we can argue that the axes primarily served for woodworking, while we lack enough data to conclusively identify traces from combat activities. Surprisingly, wear traces also appear on axes with a surface application of precious metal. Regarding the silver coating of the entire surface, the question arises whether it occurred before or after the axe was hafted. Since silver residues are present on all parts of axes, including the hafted sections, it is challenging to draw a definitive conclusion. The evidence supports both possibilities Conducting experiments with siver-coated axes could help determine the stability of the silver layer and possibly clarify the timeline of these modifications.

Current experiments are focused on axes as tools. The axe is a versatile object that can be used both as a tool and as a weapon, as evidenced by, among other things, iconographic sources (e.g., Horn 2023). There are quite a few specimens with typical signs of wood processing, including tree-felling (Dolfini/Crellin 2016; Dolfini et al. 2023). Without sufficient experimental data, traces of combat that would prove the use of axes as weapons are still difficult to confirm.

The definitive confirmation of silver coating could radically change the current view on Early Bronze Age metallurgy. Aside from the Iberian Peninsula, where silver was used in large scale to manufacture jewellery or the silver rivets of daggers (Lull et al. 2014; Delgado-Raack et al. 2016), in Central Europe silver had been absent since the Late Neolithic, where it occasionally appears in Bell Beaker contexts (Moucha 1971; Peška 2016). But thereafter, suddenly, silver seems not to have been used throughout the entire Bronze Age. There is only one recent example of artefacts made from silver, namely, the four silver rings from an Early Bronze Age cemetery in Erding, Bavaria (Biermeier et al. 2022). Our research on axes from eastern Bohemia shows that silver was present in a different way – in the form of coating. Coating with another metal – gold, electrum, or, in rare cases, tin – has been observed already[11]. From the Czech Republic, examples of silver coating have been published, such as a bronze ornaments from Moravská Nová Ves, Břeclav district, and from Mikulovice (Ptáčková/Ustohal 1996; Ernée et al. 2020). The hoard found in Sýčina, Mladá Boleslav district, is probably the best-preserved example with the thickest and most extent layer of silver present on the surface (Šteffl et al. 2017). There are many questions connected to this phenomenon, the first being the reason for such practice. So far, we have not been able to propose any functional or technological advantage that would change the quality of the particular tool/weapon. The most likely explanation is for aesthetic or symbolic reasons. There are strong indications that the colour of the final product was important and that Early Bronze Age metallurgists were intentionally altering the colour through the casting process. H. Meller proposed this theory when considering the weapons of the Únětice Culture in Central Germany. His studies concluded that colour mattered to such degree that it distinguished different ranks in the organised military society (Meller 2019; Meller 2019a). The composition of the metal is one way to influence the final colour of the artefact. In the most simple way, copper artefacts have a reddish colour, but by adding tin it is possible to alter the colour towards a more golden, and by arsenic towards a more silvery hue (e.g., Mödlinger et al. 2017; Radivojević et al. 2018). Coating metal with a

11 E.g., Berger et al. 2010; Berger et al. 2019; Rožnovský 2015; Kinnes et al. 1979; Meeks 1986.

layer of another metal shows another step that could allow even more possibilities involving not only the change of colour but perhaps also decorative features. All this is, however, hard to prove because the corrosion processes damage the coated surface to a level where its original extent is impossible to reconstruct. From the entire collection, the coating was present on almost 38 % of the axes[12]. The remains of the silver layers were observed on the entire surface, including the parts that were hafted. Further research will be necessary in order to ascertain the specific technology or technologies used for the coating. Moreover, even though we were able to confirm, that the layers were not caused by corrosion from the matrix, more experiments are necessary to exclude any possibility of the silvery layers to be result of a reaction with the environment of any kind. However, we can see a certain preference for silvery-coloured metal artefacts in Bohemia, as has already been observed by D. Berger (2018). In this context, it is also interesting to mention the hoard from Dolany, which, in addition to an axe probably coated with silver, also contained bracelets with a shiny, greyish silvery surface that strongly resemble similar bracelets from Thuringia (where, according to other artefacts found with them, a Bohemian origin is also considered). With their high content of tin (up to 20 %), the silvery surface of these Thuringian bracelets was most probably caused by inverse segregation (so-called tin sweat), and, although the intentionality of this phenomenon could not be confirmed, as it is a result of casting process, it neverthless indicates the preference for a silvery surface in Bohemia (Berger 2018).

Another interesting question concerns the geographical and chronological occurrence of silver coating. So far, it has been observed only on Early Bronze Age artefacts from Bohemia and on one artefact from Moravia (Ptáčková/Ustohal 1996; Ernée 2020; Šteffl et al. 2017)[13]. An interesting observation has been provided by the investigation of the cemetery at Mikulovice. In graves 12 and 13, two women were buried who, among other artefacts, had stone tools with traces of gold and silver. The woman buried in grave 13 also had jewellery that was coated with silver (Ernée et al. 2020). These two women were presumably working with precious metals, and, since we have no silver artefacts from that period, they may also have been specialised in coating with silver. The cemetery of Mikulovice also lies less than 30 km away from the largest hoard of axes at Kukleny.

The inner structure of the axes could clarify the actual process of casting. No stone moulds have been found in Central Europe, which means they were made from non-durable materials such as clay or sand and are therefore very hard – or, in case of sand moulds, nearly impossible – to detect. The position of casting defects such as open shrinkages, which were present specifically on the butts of axes, show that this part of an axe solidified last. This tells us that one casting method could employ a closed mould in a perpendicular position with the edge at the bottom and the butt at the top. Although such casting defects were quite frequent, there were definitely axes that were cast quite well. However, due to their similar shape, we can assume that this method was quite frequent. Another option could be casting into flat open moulds, which would be harder to prove as most of the irregularities could have been smoothened by forging and hammering.

Conclusion

The coating of copper and bronze artefacts with silver in the Únětice Culture has so far been observed only in Bohemia. Our investigation has proven that this phenomenon may be more common than previously assumed, since 38 % of the studied axes from eastern Bohemia were definitely covered with layers of silver. Poor preservation probably explains why many cases remained undetected until now. Corrosion processes of copper can destroy the coating layers, leading to their detachment and eventually to their complete loss.

The observed layers were very thin and could have been obtained with a method of electroless plating. Using chemical methods for coating with precious metals requires deep knowledge and skill. The exact technique needs to be further tested experimentally to determine the potential thickness and durability during use, but our experimental work has proven that the effect is very prominent. The coating of copper and bronze axes with such a thin silver layer can only imply an intention to change the visual appearance of the artefacts. In Central Germany, a similar optical effect seems to have been achieved by selecting specific metal compositions to enhance the outer appearance of the axes. In this sense, the findings from eastern Bohemia contribute to the hypothesis that colour was important among metal artefacts. The proposed coating technique changes the colour so radically that, after polishing the surface, it resembles pure silver. Such an effect would be very hard to achieve by mixing alloys.

While the stability of the layer needs to be tested experimentally, its reapplication is so fast and simple that it would probably not be considered a demanding and time-consuming activity. In principle, all the required ingredients (silver chloride, salt, acid) could have been obtained from local sources. More complex is the technical knowledge applied, indicating that metal axes were a rare and highly valued commodity. It seems that most of them ended up being deposited in hoards, whereas the axes from settlement and funeral contexts seem to lack silver coating. Further investigations, especially on non-conservated axes, are necessary in order to determine whether coating with silver was specific to Bohemia or was also known in other regions of the Únětice Culture. Experiments also need to be carried out in order to exclude confusion with other processes and to sort the different appearences of silver on the artefact surfaces.

12 If the ones with silver residues observed only by SEM are also included, the percentage rises to 87 %. But in these cases we cannot exclude that some small silver particles could occur naturally through corrosion processes.

13 It was presumably observed once in Sweden, but in this case the authors themselves doubt whether the silver is a result of a corrosion process or an intentional coating (Brink et al. 2016).

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