Aldona Garbacz-Klempka · Jarosław Rola · Łukasz Kowalski
Małgorzata Perek-Nowak · Grażyna Szczepańska · Szymon Bednarz

A Hoard from Grabionna
New Information to Metalwork Production and Use in the Baltic Region

Abstract

In 2016, a metal hoard was unearthed during agrarian works in the village of Grabionna in north-western Poland. The hoard consists of over 100 bronze and iron artefacts dating back to the Early Iron Age, including body ornaments, a weapon, tools, horse gear items and other metal objects, which were wrapped in textile packing that had decayed, and represents an important archaeological heritage of the region. This paper presents and discusses the results of archaeological, metallographic and chemical investigations of the bronze and iron artefacts, aided by evidence of conservation issues and textile imprints on the metalwork, in order to add more details to the biography of the Grabionna hoard and to broaden our knowledge of the metallurgical activities and metal hoarding during the Early Iron Age in the Baltic region.

Keywords

Central Europe / Baltic region / Early Iron Age / metal hoards / bronze casting / iron blacksmithing / archaeometallurgy / non-destructive testing

The beginning of the Iron Age (8^{th} c. BC) was a time of increased mobility and connectivity in many parts of Europe, including the Baltic region that set the stage for different cultural traditions of the era to meet together and interact. These interactions are traceable through the bronze and iron traffic and the increasing interest in metal working in the Baltic region that has been observed in recent years (Čivilytė et al. 2017; 2023; Kowalski et al. 2019; 2020; Nowak/Gan 2023; Ling et al. 2014; 2019; Melheim et al. 2018; Nørgaard et al. 2019; 2021) may open a new perspective on Early Iron Age metalwork production and use. However, these issues have been investigated to greatly varying degrees across various regions of the Baltic area. In the last two decades in Poland there has been a growing interest in the importance of archaeometallurgical research and how it can improve the understanding of ancient metal working in both technological and socio-cultural dimensions (e. g. Baron et al. 2014; Gackowski et al. 2023; Gan/

Aldona Garbacz-Klempka, AGH University of Krakow, Faculty of Foundry Engineering, Historical Layers Research Centre, Reymonta 23, PL - 30-059 Kraków, agarbacz@agh.edu.pl, ORCID: 0000-0001-8417-6131

Jarosław Rola, Stanisław Staszic District Museum in Piła, Browarna 7, PL - 64-920 Piła, jrola@muzeum.pila.pl

Łukasz Kowalski (corresponding author), Nicolaus Copernicus University in Toruń, Institute of Archaeology, Centre for Applied Archaeology, Szosa Bydgoska 44/48, PL - 87-100 Toruń, lukasz.kowalski@umk.pl, ORCID: 0000-0003-0647-826X

Małgorzata Perek-Nowak, AGH University of Krakow, Faculty of Non-Ferrous Metals, Mickiewicza 30, PL - 30-059 Kraków, mperek@agh.edu.pl, ORCID: 0000-0003-0323-1624

Grażyna Szczepańska, Nicolaus Copernicus University in Toruń, Faculty of Fine Arts, Department of Conservation and Restoration of Architecture and Sculpture, Sienkiewicza 30/32, PL - 87-100 Toruń, grazyna.szczepanska@umk.pl, ORCID: 0000-0003-3313-7014

Szymon Bednarz, Museum of the Second World War, pl. Bartoszewskiego 1, PL - 80-862 Gdańsk, s.bednarz@muzeum1939.pl

Żukowski 2017; Garbacz-Klempka et al. 2016; 2017; 2018; Kowalski et al. 2021a; 2021b; Nowak et al. 2019; 2022). In a much broader chronological and geographical sense, archaeometallurgical research is becoming increasingly integral to interpretations of the material heritage of the region. It basically includes two lines of research: one concerning the movement and consumption of metal, with a special focus on the provenance of metal(work) through lead isotope and trace elemente analysis, and the other aiming to elucidate the manufacturing technology of metal objects and to zoom in on the strategies and organization of the casting workshop. These two metal-orientated approaches are mutual and involve the application of various analytical methods that combine archaeology, archaeometallurgy, metallography, materials engineering, casting technology, geology and chemistry. Recently, attempts have also been made to reveal technological and use-wear traces on metal objects (e. g. Baron et al. 2020; Sych et al. 2020).

We can also observe how archaeological interest in metal hoarding has grown significantly in recent years in the Baltic region (e. g. Čivilytė et al. 2017; 2023; Kowalski et al. 2019; 2020; Kaczmarek et al. 2022; Nowak/Gan 2023; Maciejewski/Nowak 2022; Sarauw 2015; Rundkvist 2023; Kristiansen 2019; Sperling 2016), and considerable attention has been paid to the multi-layered studies of metal hoards from the region dating back to the later Bronze Age and the Early Iron Age. These studies aim to explore in detail the context of metal production, use and deposition, which is in line with the general direction of metal hoarding observed elsewhere. This strong focus on bronze does not come as a surprise, especially in Poland, since the later Bronze Age and the Early Iron Age in this region saw the emergence of »smith's burials« (Kowalski et al. 2021b; Nowak et al. 2022; Stróżyk et al. 2023) and enjoyed the renaissance of bronze smithing, resulting in massive amounts of bronze objects usually buried or deposited in wet landscapes. The growing interest in bronze hoarding has also been fuelled by the increasing activity of metal detecting groups and treasure hunters in Poland and beyond (Makowska et al. 2016).

This paper examines bronze and iron objects hoarded at present-day Grabionna in north-western Poland, in order to determine their elemental composition and technological aspects and to provide a framework to discuss the patterns of production and use of these artefacts. The archaeometallurgical evidence from this study is complemented by conservation issues and textile analysis of the imprints on bronze and iron metalwork to add more details to the biography of the Grabionna hoard and provide new information on metallurgical activities and metal hoarding of the Early Iron Age in the Baltic region.

The Grabionna Hoard

The hoard was unearthed in winter 2016 during agrarian works in the village of Grabionna, near Miasteczko Krajeńskie (pow. Piła/PL) in the Noteć Valley of north-western Poland. Subsequent rescue excavations at the findspot by professional archaeologists from the Provincial Office for the Protection of Monuments in Poznań yielded over 100 artefacts made from bronze and iron (fig. 1). These included body ornaments, a weapon, tools, horse gear items and other metal objects and their destructs accompanied by badly preserved fragments of a ceramic vessel (see the list of finds). The rescue excavation did not result in any particular observations that could give a better insight into the context of the deposition and no trial trenches were made around the findspot to reveal possible traces of associated archaeological material or structures.

The hoard contains two massive bronze necklaces (MOP-1–2) that have almost identical dimensions and shapes, with engraved diagonal lines imitating the twisting of a bronze rod. They belong to the western (Pomeranian) type of *Halsringe mit Vogelkopfenden* (Hoffmann 2000) and are commonplace east of the Lower Vistula, while they can also be traced to the regions of Pomerania, Chełmno Land and Kuyavia in north-central Poland over an extended timespan from the Montelius IV period (1100–950/900 BC) to the early La Tène period (450–380 BC) in Europe (Hoffmann 2000; Blajer 2001); however, specimens decorated with very pronounced engravings are usually considered products of the Early Iron Age workshops.

There are two body ornaments made of iron: a twisted *Wendelring* (MOP-14) of Maszków type (Dzięgielewski et al. 2020) and a bracelet with overlapping endings (MOP-10) that dates back to the Early Iron Age in the Oder River Basin (Blajer 2001; Szczurek/Pudełko 2015). Twisted iron necklaces have their prototypes in bronze metalwork and are well attested in metal hoards of the era. However, the necklace from Grabionna is noticeable for having well-developed twists, which is a signature mark of the metal

Fig. 1 Metal hoard from Grabionna after the recovery (courtesy of the Stanisław Staszic District Museum in Piła). In the text, the objects are labelled with the sample ID. – (All figures and tables by the authors).

working of the later Hallstatt period (Szczurek/Pudełko 2015). A fragment of a non-decorated bronze bracelet (MOP-5) completes the body ornaments buried in Grabionna, although it is quite ordinary and a common product of the bronze smithing seen in the later Hallstatt period in Poland, and it shows little chronological and spatial relevance.

A laurel-shaped iron spearhead (MOP-13) is also part of the metal assemblage. The spearhead represents the XVIII B type, according to Fogel (1979), and signifies the weaponry of the Early Iron Age in Poland that can be found in the regions of Greater Poland, Silesia, Lesser Poland, Pomerania and Mazovia (Blajer 2001; Fogel 1979).

The tools buried in the hoard were forged from iron and consist of a socketed axe (MOP-12), a socketed chisel (MOP-7) and a sickle (MOP-8). The axe is characteristic of the iron axes of the A type, with a round socket and fan-shaped cutting edge, which are chiefly associated with the later stage of the Early Iron Age over a vast area of north-western Poland (Hoffmann 2000; Kostrzewski 1958). Socketed chisels are very rare in Polish metal inventories and have only been recorded in Pomerania (Kostrzewski 1958), Greater Poland and Lower Silesia (Blajer 2001). Iron sickles, on the contrary, have a wide distribution that covered a vast area of Poland during the Early Iron Age (Hoffmann 2000; Blajer 2001). It is difficult to provide precise typological information on the sickle from Grabionna due to the absence of the blade base, but it can be reasonably posited that the sickle suffered from mechanical damage before being deposited.

The hoard yielded a damaged iron single joint bit (MOP-9) that can only generally be assigned to the horse bit industry of the Hallstatt period. In Poland, single joint bits have most often been found in Greater Poland and Pomerania (Blajer 2001; Szczurek/Pudełko 2015; Kostrzewski 1958).

The most numerous group includes bronze buttons (*Zierknöpfe*), which consists of 67 conical buttons (MOP-6) and 19 flattened conical buttons (MOP-6). A survey of the bronze buttons in Europe shows that they were commonplace in the North European Bronze Age but also well attested in the regions of Pomerania, Saxony, Thuringia, Silesia and Greater Poland (Kostrzewski 1958; Rola 2011). It is widely accepted that bronze buttons were sewn onto clothes or were decorative elements of diadems and horse gear items (Dąbrowski 1993; Gackowski/Rosołowski 2020; Szydłowska 1963). There is also evidence from Poland that bronze buttons were sewn onto textile bags or containers – for example, metal objects found in Brudzyń (pow. Żnin/PL) may have been deposited in a flaxen bag decorated with bronze buttons (Gackowski/Rosołowski 2020). The conical buttons from Grabionna have a close match with the specimens from the famous Lusatian stronghold of Kamieniec (pow. Toruń/PL), near Toruń, dating to the Ha D (600–450 BC) period (Garbacz-Klempka et al. 2016; Bukowski 1960). Further comparisons provide a direct parallel that can be traced back to Malewo (pow. Sztum/PL), near Sztum in Pomezania, where 27 conical buttons were reported as a bog find (Šturms 1936).

In sum, typo-chronological evidence places the hoard event at Grabionna in the Ha C2–Ha D1 period (660–550/530 BC) and connects the hoard to the Pomeranian culture of northern Poland, which has its origins in the southern Baltic region.

Material and Methods

A total of 45 bronze and iron artefacts from the hoard were selected for archaeometallurgical investigation. The selection included a group of 30 bronze buttons.

Metal artefacts were first examined for casting defects as well as technological and use-wear traces using a Nikon SMZ 745Z stereoscopic microscope (OM) equipped with a Nikon Digital Sight DsFi1 microscope camera (magnification ×0.67–10). The selected bronze and iron artefacts were examined by X-ray radiography using an industrial X-ray radioscopy Y.MU2000-D (YXLON) system, comprising an X-ray tube (160 kV) coupled with a digital panel detector and the YXLON Image 2500/3500 system for data imaging. Surfaces of the bronze artefacts were prepared by mechanical removal of the corrosion products (exposing the metallic core) and followed by degreasing with acetone. Next, the artefacts were analysed for elemental concentrations using a Spectro Midex ED-XRF (energy dispersive X-ray fluorescence) spectrometer equipped with a molybdenum X-ray tube and a silicon Drift Detector (SDD), with a standardless mode using the fundamental parameters program (FP+) for correction of matrix effects. The analytical conditions used for ED-XRF were 44.6 kV, 5.9 mA, 180 s of live time. The detection limits were established at 0.01 % for Ni, Cu, As, and Bi; 0.02 % for Fe, Co, Ag, and Pb; and 0.05 % for Sn and Sb. The analytical error of ED-XRF for trace elements in copper-based alloys is usually 10–15 % (Lutz/Pernicka 1996), and the accuracy of fundamental parameter methods is hampered when undetectable low-Z elements (e. g. C, O) are present in the sample (Sitko 2007; 2008; Elam et al. 2004). Three measurements were taken in different areas to optimise the ED-XRF data reliability for each copper-based object. The selected bronze artefacts were additionally checked for elemental composition and microstructure by scanning electron microscopy (SEM) and energy dispersive X-ray spectroscopy (EDS) using a Hitachi S-3400N scanning electron microscopes coupled with a BSE (backscattered electrons) detector and an EDS NORAN 986B-1SPS spectrometer (Thermo Noran). Due to their general condition and active corrosion processes, the iron artefacts were examined macroscopically and without using sampling techniques that would require the internal structure of the objects. The corrosion products were carefully separated from the iron artefacts and analysed using a LEO 1430VP (Zeiss) coupled with the EDS spectrometer Quantax 200 with XFlash 4010 detector (Bruker AXS). The SEM-EDS investigations were conducted in a low-vacuum (50 Pa), semi-quantitative, surface and standardless mode using non-conducting material imaging. The analytical error of the standardless SEM-EDS analysis is usually below ± 25 % (Carlton et al. 2004; Goldstein et al. 2003).

Results and Discussion

Elemental Composition

The results of ED-XRF analyses show that the level of impurities is significant amongst the bronze metalwork and controlled by antimony (0.92–5.5 %), arsenic (0.28–3.3 %) and nickel (0.12–1.2 %). This indicates that the bronze artefacts were made of copper smelted from fahlores (tab. 1) and provides further evidence for a substantial influx of fahlore copper in the Baltic region during the later Bronze Age and the beginning of the Iron Age (Čivilytė et al. 2017; 2023; Kowalski et al. 2019; 2020; Nowak/

sample ID	inv. no.	artefact	Fe	Co	Ni	Cu	As	Ag	Sn	Sb	Pb	Bi
MOP-1	MOP2016/129	necklace	< 0.02	0.06	0.71	88	2.5	1.3	< 0.05	3.8	4.2	0.07
MOP-2	MOP2016/130	necklace	0.08	0.06	0.72	90	1.8	0.95	< 0.05	2.6	4.2	0.06
MOP-3	MOP2016/133	bracelet (frag.)	0.04	0.06	1.1	85	1.5	1.0	1.9	3.4	5.8	0.06
MOP-4	MOP2016/141	casting drop	0.09	0.08	0.79	85	1.2	0.73	2.3	2.8	6.5	0.05
MOP-5a	MOP2016/139	conical button	0.12	0.10	1.2	87	1.2	1.6	5.1	2.9	0.40	0.04
MOP-5b	"	"	0.03	0.14	1.0	87	1.6	1.7	4.2	3.1	0.89	0.08
MOP-5c	"	"	0.27	0.09	0.80	88	0.93	0.52	6.9	1.1	0.83	0.03
MOP-5d	"	"	< 0.02	0.10	1.0	88	1.2	1.3	5.1	2.6	0.57	0.06
MOP-5e	"	"	0.78	0.08	0.60	80	1.9	1.0	12	2.0	2.5	0.06
MOP-5f	"	"	0.03	0.07	0.72	88	1.0	0.53	7.7	1.2	1.1	0.03
MOP-5g	"	"	1.6	0.11	0.45	80	2.9	1.9	6.9	4.2	1.5	0.06
MOP-5h	"	"	0.08	0.07	0.67	85	0.73	0.45	11	1.0	0.85	0.02
MOP-5i	"	"	0.13	0.07	0.68	88	1.2	0.61	7.6	1.5	1.3	0.04
MOP-5j	"	"	0.04	0.09	0.12	90	0.36	1.3	4.4	2.6	0.66	0.09
MOP-6a	MOP2016/139	conical button	0.26	0.08	0.32	75	0.55	0.74	12	1.8	3.0	0.07
MOP-6b	"	"	0.06	0.06	0.73	85	0.99	1.3	8.4	2.3	1.0	0.05
MOP-6c	"	"	1.3	0.08	0.42	80	1.3	0.94	10	1.9	3.4	0.10
MOP-6d	"	"	< 0.02	0.06	0.42	85	0.38	0.49	11	1.1	1.9	0.02
MOP-6e	"	"	0.08	0.06	0.65	87	0.79	1.0	7.6	2.1	1.0	0.04
MOP-6f	"	"	< 0.02	0.06	0.37	84	0.65	0.58	12	1.3	1.8	0.04
MOP-6g	"	"	0.41	0.07	0.77	75	3.2	2.5	11	5.5	2.2	0.18
MOP-6h	"	"	< 0.02	0.06	0.79	81	1.3	1.1	12	2.7	1.0	0.07
MOP-6i	"	"	0.25	0.06	0.42	84	0.55	0.53	12	1.3	2.3	0.04
MOP-6j	"	"	0.02	0.07	0.80	81	1.3	1.1	12	2.8	1.0	0.08
MOP-6k	"	"	0.10	0.06	0.84	79	2.0	1.6	12	3.5	1.7	0.12
MOP-6l	"	"	< 0.02	0.06	0.45	85	0.28	0.39	11	0.92	1.5	0.02
MOP-6m	"	"	0.05	0.07	0.81	82	1.8	1.4	11	3.3	1.4	0.11
MOP-6n	"	"	0.07	0.06	0.97	80	2.2	1.7	11	3.8	0.79	0.11
MOP-6o	"	"	0.31	0.07	0.82	78	2.2	2.1	12	4.6	2.2	0.15
MOP-6p	"	"	0.31	0.06	0.80	80	2.2	2.0	11	4.1	1.8	0.12
MOP-6q	"	"	0.07	0.07	0.41	86	0.50	0.50	10	1.1	1.8	0.04
MOP-6r	"	"	0.02	0.06	0.85	82	1.9	1.5	9.5	3.8	1.1	0.11
MOP-6s	"	"	0.21	0.06	0.87	76	3.3	2.2	11	5.2	2.0	0.19
MOP-6t	"	"	0.04	0.05	0.79	84	1.2	1.1	10	2.5	1.1	0.05

Tab. 1 The elemental composition of the bronze artefacts from the Grabionna hoard. The ED-XRF data are mean values of three measurements given in wt %.

Gan 2023; Ling et al. 2014; 2019; Melheim et al. 2018). To some extent this is observable through the SEM-EDS data as well. There, significant amounts of silver (2.7–88 %) were recorded in the EDS spectra (tab. 2; fig. 2) and elemental mapping (figs 3-5) for the selected bronze metalwork, accompanied by other elements typical of fahlore copper, such as arsenic (0.82–4.9 %), antimony (0.91–27 %) and nickel (0.78–8.3 %). The signal for sulphur in the bracelet MOP-3, making up to 10 %, may be a product of the thermal decomposition of tetrahedrite (Baláž 2000) during the roasting (oxidation) of fahlores to remove most of the sulphur (Pernicka 2014; Tylecote et al. 1977).

spot ID	inv. no.	artefact	O	S	Ni	Cu	As	Ag	Sn	Sb	Pb
MOP-3_pt1	MOP2016/133	bracelet (frag.)	...	10.02	...	89.98	...	...	...	...	...
MOP-3_pt2	"	"	...	...	...	34.21	...	20.46	...	...	45.33
MOP-3_pt3	"	"	...	...	1.11	94.83	2.19	...	...	1.87	...
MOP-3_pt4	"	"	...	...	8.29	60.55	3.77	...	...	27.39	...
MOP-3_pt5	"	"	...	...	...	16.77	...	56.46	...	...	26.76
MOP-3_pt6	"	"	...	...	...	28.08	4.97	12.05	...	...	54.90
MOP-3_pt7	"	"	...	...	...	8.92	...	81.76	...	...	9.33
MOP-4_pt1	MOP2016/141	casting drop	...	...	...	9.03	...	6.85	...	...	84.12
MOP-4_pt2	"	"	...	...	...	29.49	...	5.00	...	...	65.51
MOP-4_pt3	"	"	17.03	...	...	4.06	...	...	...	...	...
MOP-4_pt4	"	"	17.17	...	...	6.61	...	2.75	...	...	78.91
MOP-4_pt5	"	"	...	...	0.78	95.93	0.82	...	1.56	0.91	73.47
MOP-5i_pt1	MOP2016/139	conical button	...	...	...	5.53	...	...	...	...	94.47
MOP-5i_pt2	"	"	...	...	2.50	62.44	2.21	2.84	1.59	8.41	...
MOP-5i_pt3	"	"	...	...	...	5.09	...	...	...	...	94.91
MOP-5i_pt4	"	"	...	...	1.01	91.98	...	...	7.01	...	...
MOP-5i_pt5	"	"	...	...	...	89.90	2.05	...	8.05	...	...
MOP-6m_pt1	MOP2016/139	conical button	...	...	...	38.62	2.33	...	4.57	...	54.48
MOP-6m_pt2	"	"	...	...	...	26.89	0.93	...	9.68	4.99	57.52
MOP-6m_pt3	"	"	...	...	...	86.98	3.86	...	9.16	...	...
MOP-6m_pt4	"	"	...	...	...	94.53	...	...	5.47	...	...
MOP-6m_pt5	"	"	...	...	...	12.10	...	87.90	...	...	...
MOP-6m_pt6	"	"	...	...	1.28	80.31	1.57	4.27	12.57	...	...
MOP-6m_pt7	"	"	...	...	...	88.48	...	...	1.52	...	...
MOP-6m_pt8	"	"	...	...	...	94.24	...	...	5.76	...	...

Tab. 2 The results of the SEM-EDS analyses of selected bronze artefacts from the Grabionna hoard. The SEM-EDS data are normalised to 100 wt % (see fig. 2). »...« = no element was detected.

A closer look at the composition of the bronze buttons indicates that some of them show a diluted fahlore copper pattern. The contents of antimony (from 0.92 to 1.5 %) and silver (from 0.39 to 0.61 %) in these objects are much higher than expected for chalcopyrite, but clearly too low to be derived from copper smelted from fahlores (Grutsch et al. 2019). There are strong archaeometallurgical indications that during the later Bronze Age and the beginning Iron Age in the Alpine region, fahlore copper was mixed with copper smelted from chalcopyrite to reduce the disadvantages of high arsenic and antimony contents (Melheim et al. 2018; Grutsch et al. 2019; Lutz/Pernicka 2013). Similar evidence for the use of diluted fahlore copper was recently produced by the bronze hoard from Kaliska (pow. Szczecinek/PL) in northern Poland (Kowalski/Niedzielski 2021).

The signals for lead are significantly high for the body ornaments and the casting drop, with a variation of 4.2–6.5 %, suggesting the deliberate addition of lead (Liversage 2000). The same artefacts have the lowest tin content, and intentional alloying with lead may thus have been used to improve castability and workability of the castings, which was particularly true for the pseudo-twisted necklaces MOP-1 and MOP-2. The conical buttons mostly have a lead content of below 2 %, which may possibly indicate that the lead originated from the parent copper used for

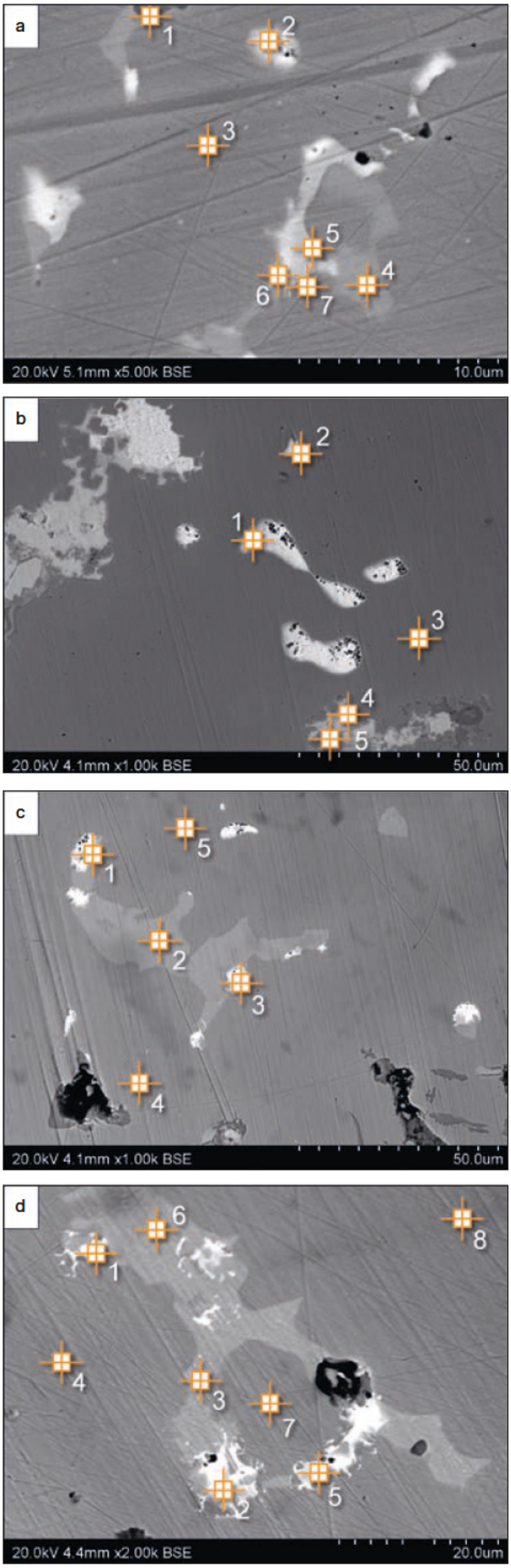


Fig. 2 SEM recordings of the bronze artefacts from Grabionna with EDS spots: **a** bracelet fragment MOP-3. – **b** casting drop MOP-4. – **c** conical button MOP-5i. – **d** conical button MOP-6m. The images were taken at a magnification of ×1.0–5.0 k under low-vacuum mode and with an accelerating voltage of 20 kV (see **tab. 2**).

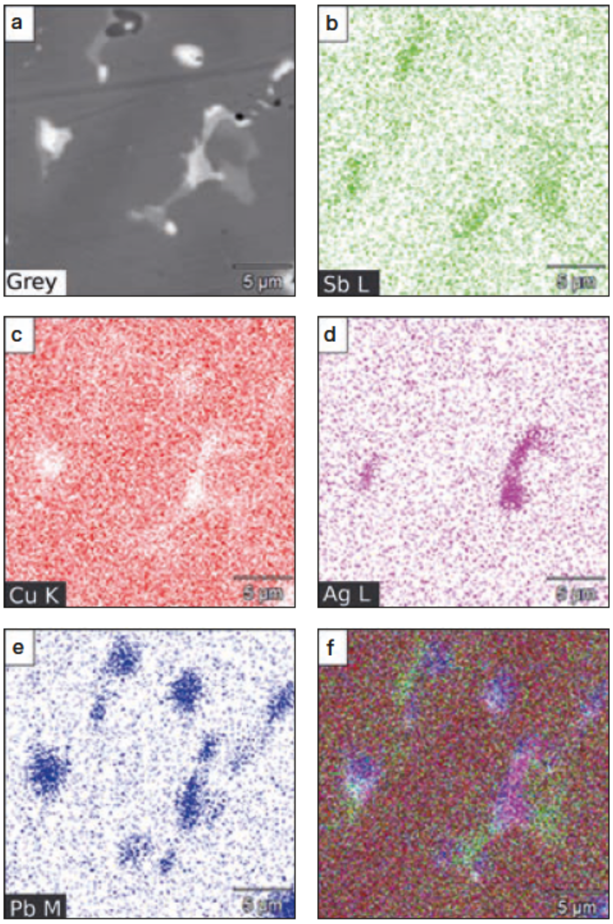


Fig. 3 SEM-EDS elemental mapping of the bracelet fragment MOP-3. The images were taken at a magnification of ×5.0 k under low-vacuum mode and an accelerating voltage of 20.0 kV.

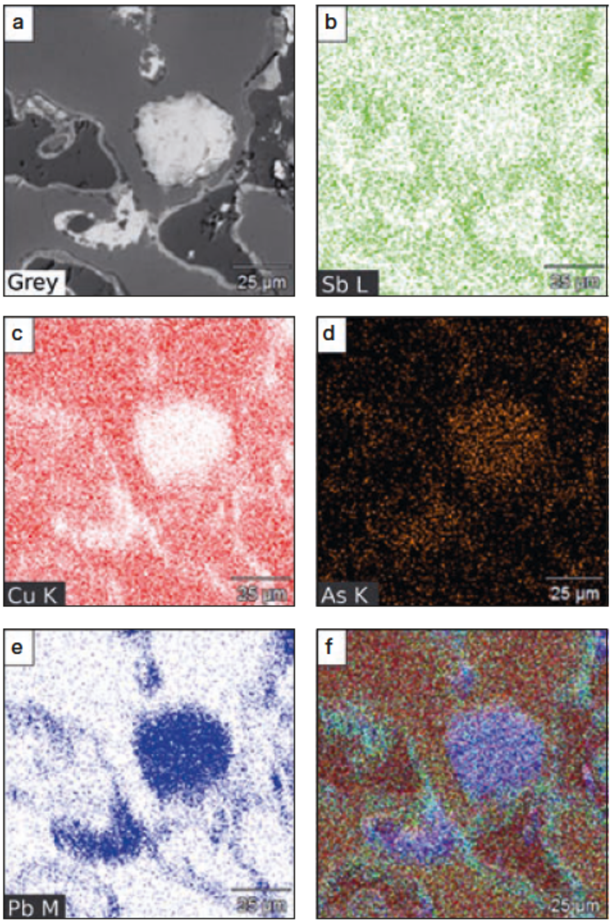


Fig. 4 SEM-EDS elemental mapping of the casting drop MOP-4. The images were taken at a magnification of ×1.0 k under low-vacuum mode and an accelerating voltage of 20.0 kV.

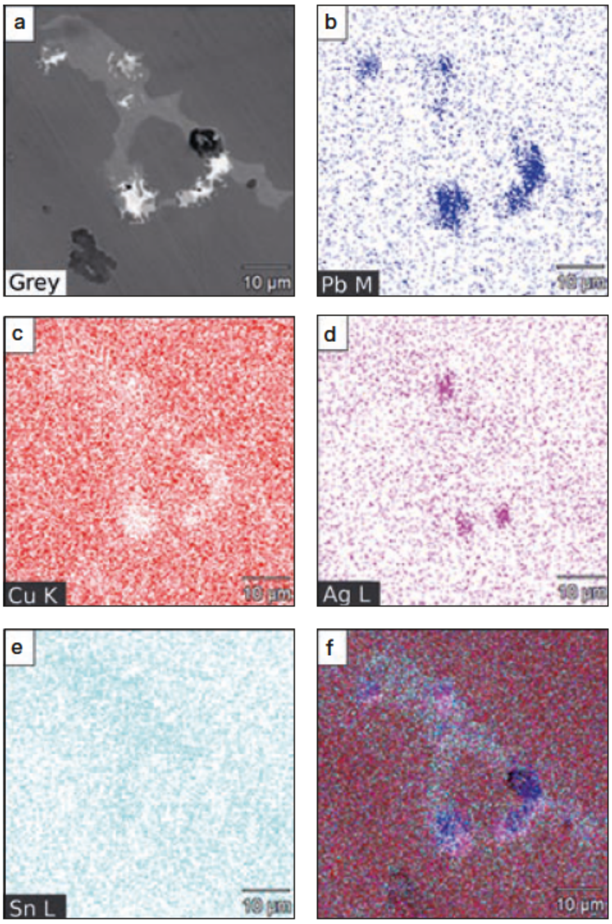


Fig. 5 SEM-EDS elemental mapping of the conical button MOP-6m. The images were taken at a magnification of ×2.0 k under low-vacuum mode and an accelerating voltage of 20.0 kV.

their production. However, when comparing the antimony and lead content in the buttons (fig. 6), a relationship between these two elements was not conclusive enough to prove that lead had come into these objects together with the fahlore copper. On the other hand, the positive correlation between tin and lead shown in figure 6 seems to depict another potential source of lead, which could be tin diluted with lead (Grutsch et al. 2019). In Poland, the use of diluted tin–lead alloys can be traced, for example, to the Lusatian cemetery at Wartosław (pow. Szamotuły/PL), dating back to 1100–900 BC, which yielded a casting mould that was clogged with pewter (Sn = 96 %, Pb = 2.7 %) (Kowalski et al. 2021b). Here, it should also be noted that the bronze metalwork from Grabionna contains considerably higher concentrations of lead than contemporary metals from some other Baltic regions, e. g. artefacts from Sweden and Denmark, which have lead contents mostly below 0.5 % (Ling et al. 2014; Liversage 2000). Elevated lead content is often observed in bronze artefacts from Late Bronze and Early Iron Age Poland (Kowalski et al. 2019; 2020; Baron et al. 2014; 2016; Kowalski/Niedzielski 2021), and this feature may indicate different metal trade routes that secured the flow of metal to the Baltic region, or may indicate different metallurgical practices in these regions.

The groups of buttons MOP-6d, 6f, 6i, 6l and 6q, MOP-6 g, 6o, 6p and 6s as well as MOP-6b, 6h, 6j and 6t have identical chemical compositions within the analytical errors, indicating the possibility that they could have been cast from the same alloy and using a permanent mould for the simultaneous production of four or more castings of the same form. The moulds of such type are known from the Lusatian sites of Gogolin-Strzebniów (pow. Krapkowice/PL; Garbacz-Klempka/Dzięgielewski 2021) and Bieszków (pow. Żary/PL; Orlicka-Jasnoch 2013) in western Poland (see below). The tin content of MOP-5b is slightly less than that of the MOP-5a and 5d buttons, but it could still be within the range of the same bronze alloy due to the compositional variation resulting from surface enrichment or corrosion that may have limited the accuracy of the ED-XRF (Pollard/Heron 1996; Scott 1991).

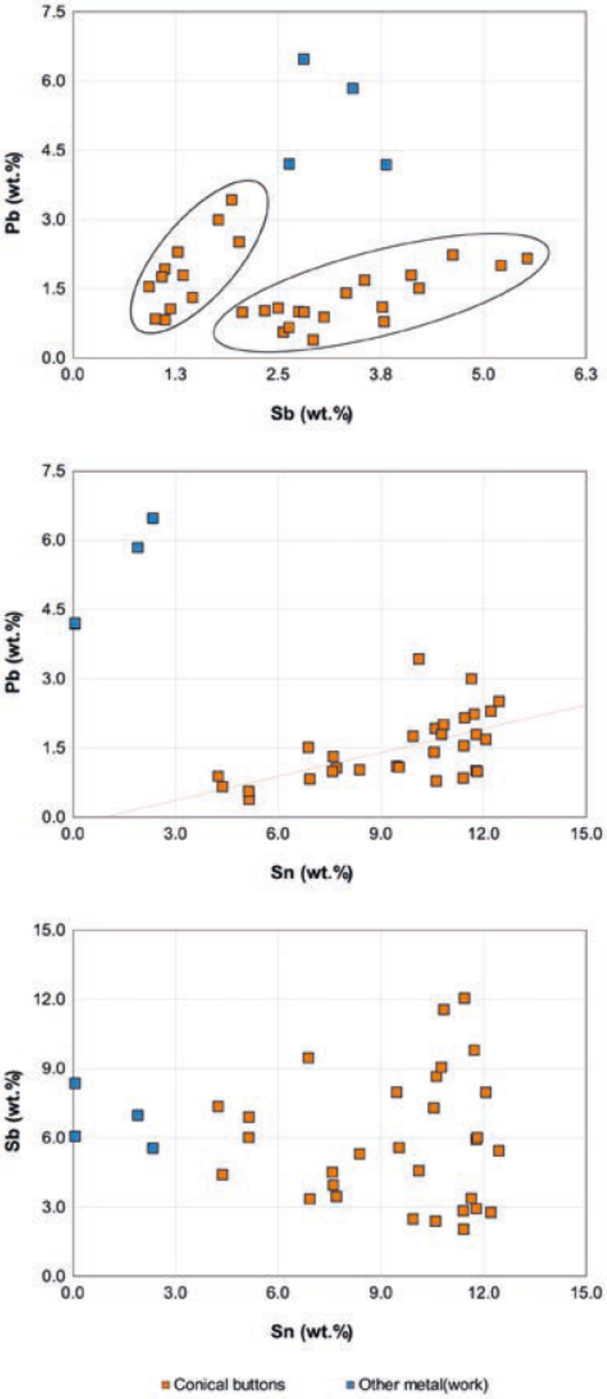


Fig. 6 The elemental diagrams for the bronze metalwork from Grabionna (see text for further details).

Fig. 7 Necklace from Kamieniec (pow. Toruń/PL) near Toruń, which is a typological and chemical sibling of the pseudo-twisted necklaces MOP-1 and MOP-2 from the Grabionna hoard (courtesy of the District Museum in Toruń). – Scale 1:3.

The two massive necklaces MOP-1 and MOP-2 are separated from the other metals by the amount of tin below 0.05 %. The ED-XRF results further indicate that the same artefacts have identical chemical compositions within the analytical errors, suggesting the use of the same alloy for their production. There was little difference in the arsenic and antimony content of these two artefacts, but their As/Sb (0.66 and 0.67) and Ag/Sb (0.35 and 0.36) ratios indicate that they could have been cast from the same alloy. The necklaces from Grabionna have nearly exact chemical siblings among a contemporary necklace of the same type from the Lusatian stronghold of Kamieniec (fig. 7), near Toruń (Garbacz-Klempka 2016). Furthermore, the tin content in the MOP-1 and MOP-2 necklaces shows no correlation with the antimony (fig. 6), and there is no reason to assume that there was selective alloying to save tin when working with fahlore copper, which was naturally enriched with antimony and arsenic (Grutsch et al. 2019). Moreover, the high content of antimony (2.6–3.8 %) and arsenic (1.8–2.5 %) in the Grabionna necklaces was rather disadvantageous in mould casting and could have led to a reduction in the elastic modulus of the necklaces, so that there is hardly any technological rationale for the tin depletion in the analysed objects. Also, it is interesting to see these results in connection with a group of ring ornaments that may have been intended to serve as semi-products or used as commodity money (*Gerätegeld*). Bronze sickle hoards of the Late Bronze Age seem to provide evidence to support a shift from luxury to commodity in the European Bronze Age metal trade network (Pare 2013; Sommerfeld 1994), and the supporting evidence comes from the deposits of D-shaped bronze ingots that are known chiefly from the Lusatian metal industry in northern Poland (Kowalski et al. 2020). Ongoing lead isotope analysis of *Halsringe mit Vogelkopfenden* will help to determine the origin of metal used for their production and identify the trading networks that

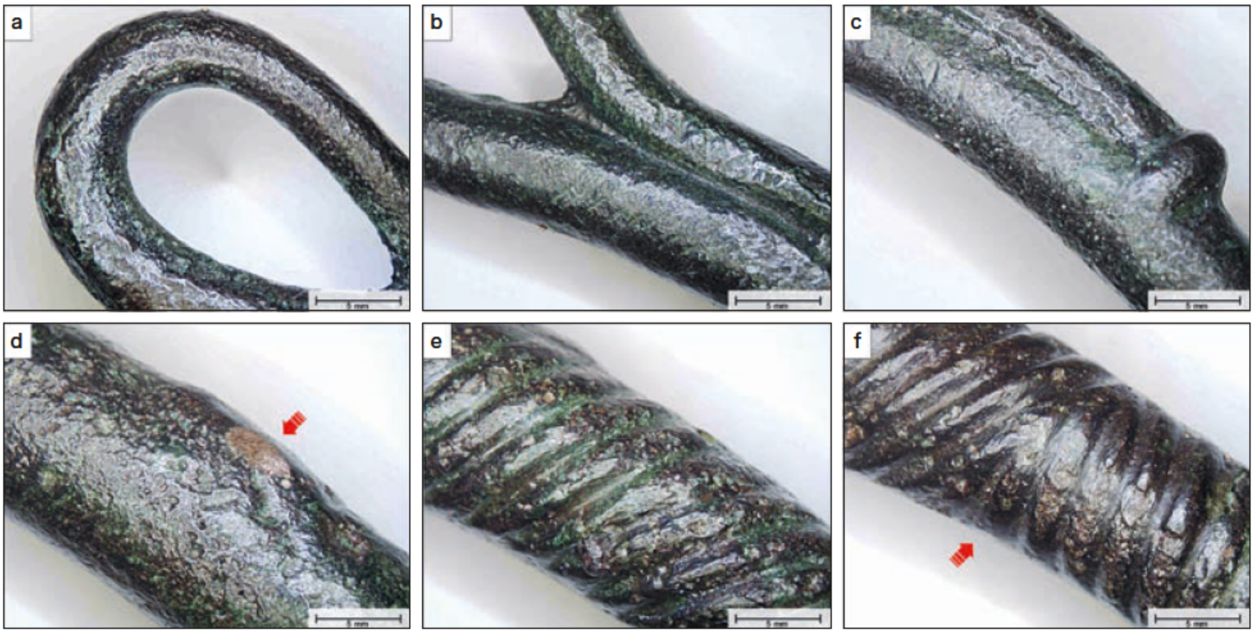


Fig. 8 Photomacrographs of the necklace MOP-1 showing the presence of macrostructures typical of lost-wax casting. The arrows indicate (**d**) not completely removed casting jet and (**f**) grooves modelled in wax and refined after casting by chiselling.

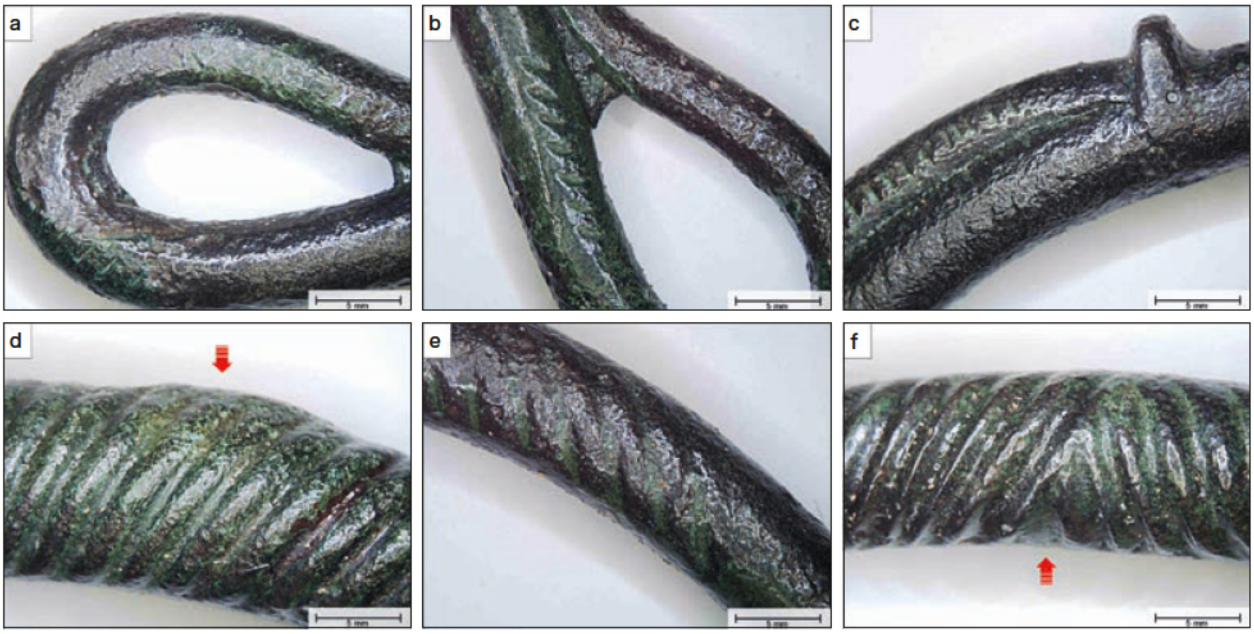


Fig. 9 Photomacrographs of the necklace MOP-2 showing the presence of macrostructures typical of lost-wax casting. The arrows indicate (**d**) not completely removed casting jet and (**f**) grooves modelled in wax and refined after casting by chiselling.

safeguarded the metal supply to Lusatian and Pomeranian clients in northern Poland.

Technological Characterisation

Photomacrographs confirm that the two massive bronze necklaces MOP-1 and MOP-2 were cast using the lost-wax casting technique. This is well evidenced by the presence of casting jets that were not trimmed and were completely removed (figs 8d; 9d). Also, X-ray recordings identified the porosity near the endings (fig. 10a-b), which is due to the gaseous melt that was used for casting. The grooves imitating the twisting of a bronze rod that are visible in the artefacts were modelled in wax and refined by chiselling after casting. The relatively high lead content (4.2 %) in the alloy used for the necklaces had a

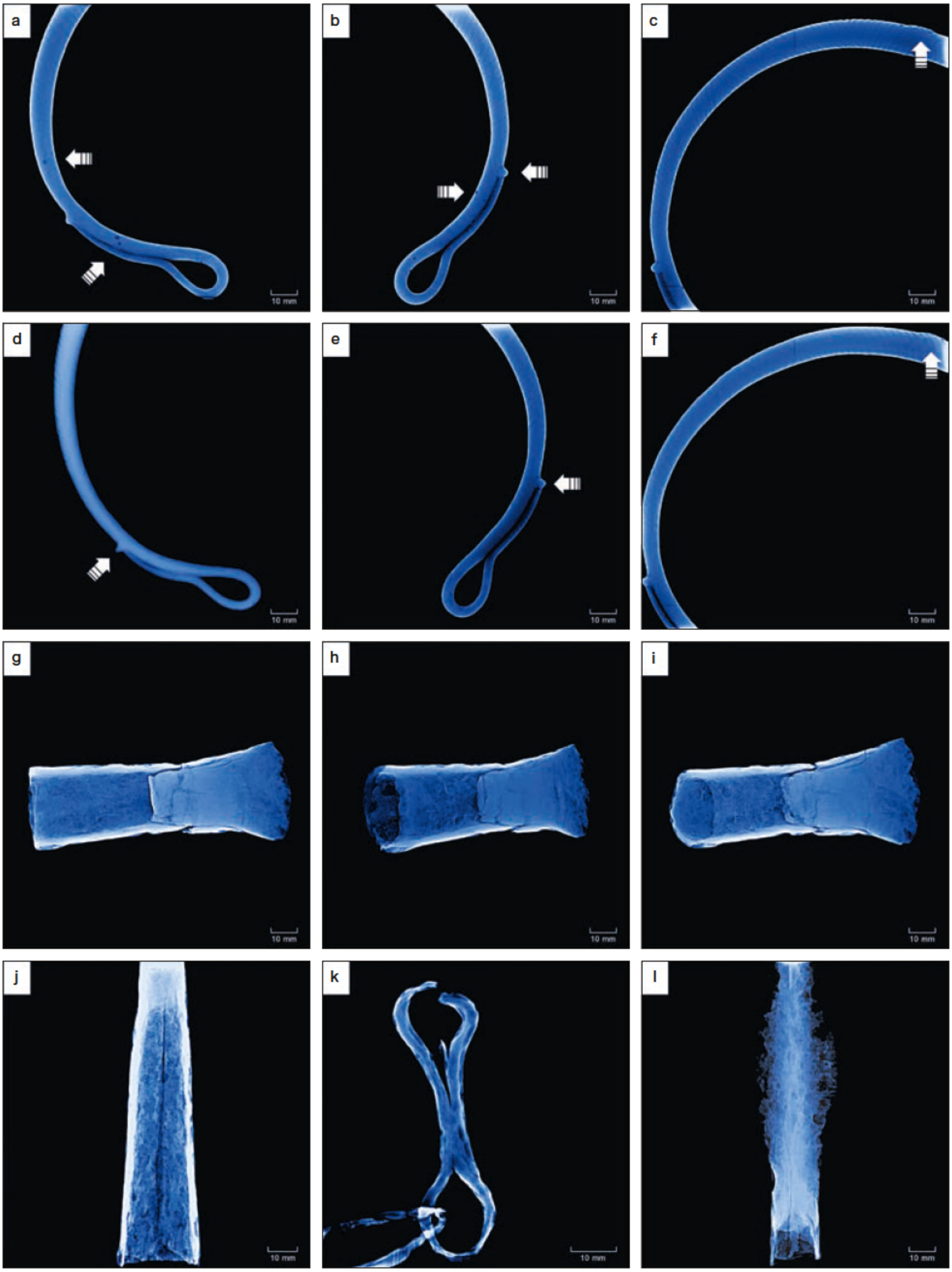


Fig. 10 X-ray recordings of the bronze and iron metalwork from the Grabionna hoard: **a-c** bronze necklace MOP-1. – **d-f** bronze necklace MOP-2. – **g-i** iron socketed axe MOP-12. – **j** iron chisel. – **k** iron joint bit fragment. – **l** iron spearhead. – The arrows indicate macrostructures observed on the bronze necklaces that are typical of mould casting.

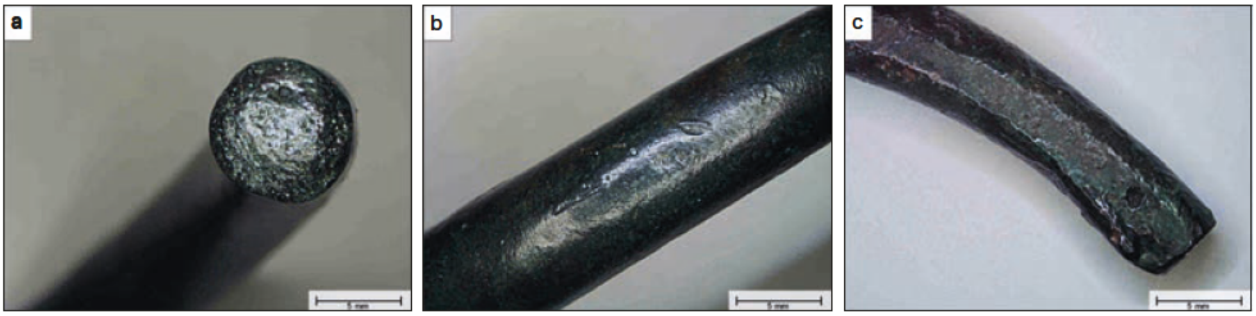


Fig. 11 Photomacrographs of the bracelet fragment MOP-3 showing the presence of macrostructures typical of casting and plastic forming.

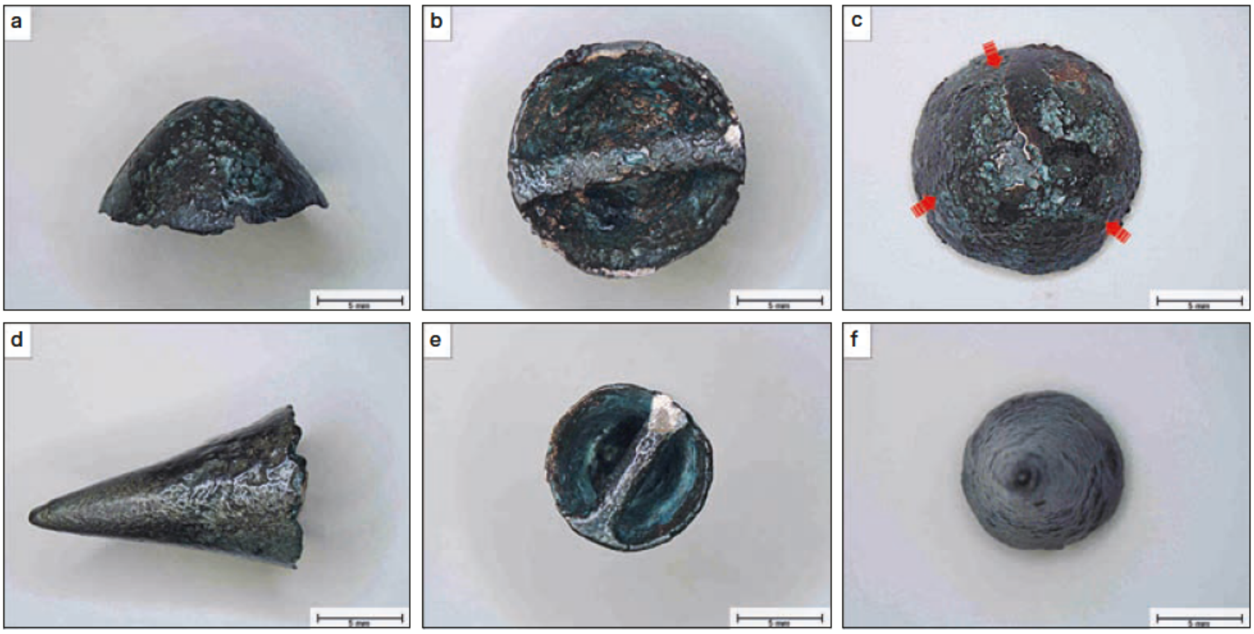


Fig. 12 Photomacrographs of conical buttons: **a-c** button MOP-5a. – **d-f** button MOP-6a. – The arrows indicate the parting lines on the dome of the MOP-5a button, which are indicative of the use of a three-part mould.

positive effect on the castability of these decorative elements, compensating for the absence of tin minerals in the melt.

A closer look at the bracelet MOP-3 shows that it went through a *chaîne opératoire* that involved casting and plastic forming (fig. 11). To some extent, this could be seen in the scanning microscopy image and showed an as-cast structure and intermetallic compound infill between the dendrite arms (fig. 2a).

Macroscopic observations show that mould casting was used for the conical buttons (fig. 12), and their geometry and casting defects point to one-piece casting in a split mould. As can be seen in figures 13a-b and 13f, the casting flashes at the base of the buttons were not removed. The buttons also have blowholes caused by gas from the melt or mould used. Figures 12c and 13m-o show the presence of the parting lines on the domes of the buttons, which are indicative of the use of two- or three-part permanent moulds. The SEM images revealed a continuity of the microstructure in the joint area between the transverse bars and domes of the buttons, which point to one-piece casting (fig. 14a-f). These recordings also show the as-cast structure with dendrites and intermetallic compound infill, which indicate no plastic forming after casting.

The chisel MOP-7 (fig. 15) and the sickle MOP-8 (fig. 16) were forged from a single piece of iron without welding. As the X-ray recording (fig. 10j) shows, the edges of the chisel socket had been formed tightly one to another with no joint, which is also visible on the photomacrographs (see fig. 15a-b). These photomacrographs also suggest that the cutting edge has no use-wear traces or clear grinding striations to indicate its preparation for use. The socketed axe MOP-12, which completed the list of tools from Grabionna, had been forged from two separate parts that included the socket and the blade part (figs 10g-i; 17).

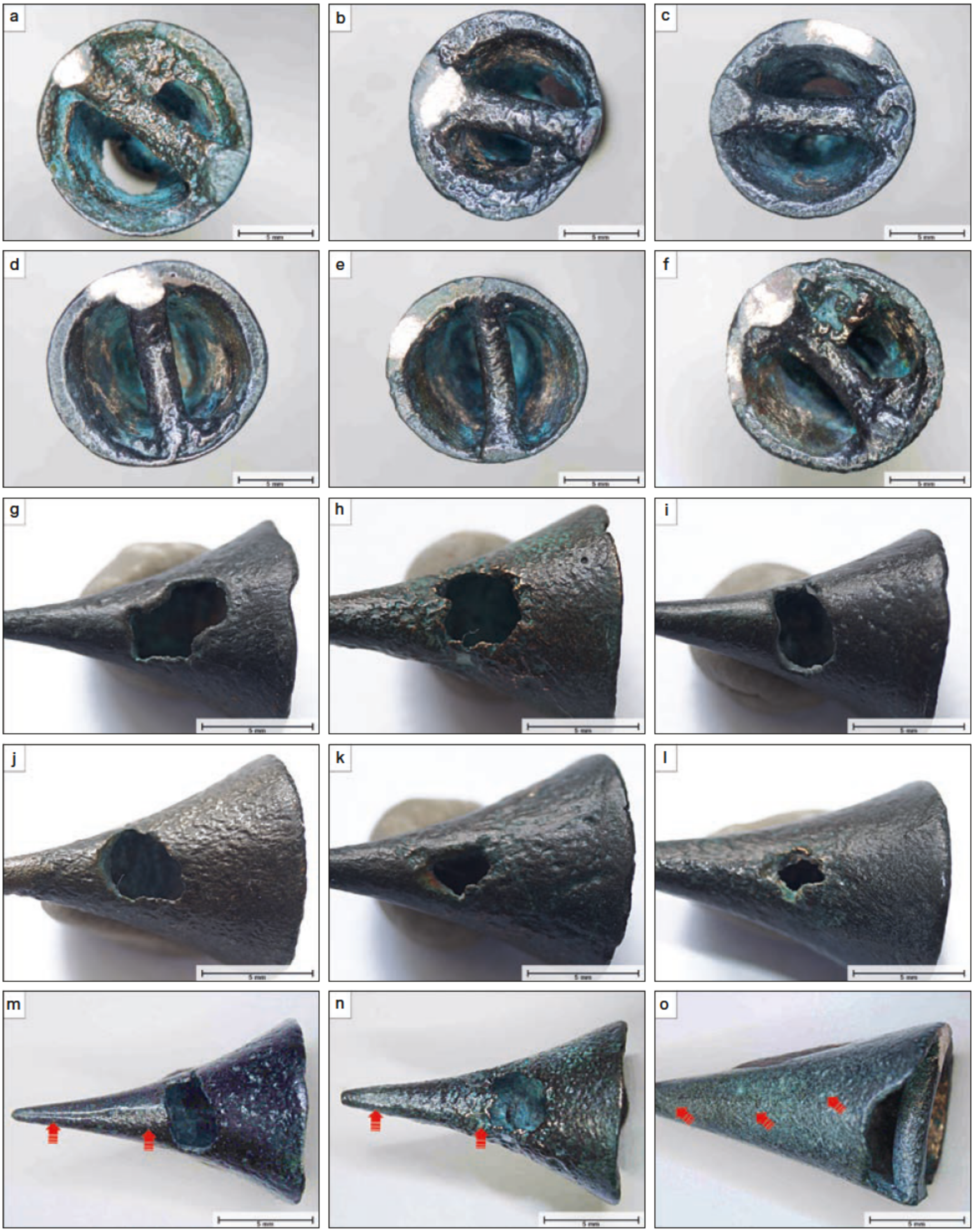


Fig. 13 Casting defects on conical buttons showing the presence of flashes and blowholes: **a. h. n** MOP-6b. – **b. g** MOP-6h. – **c. l. m** MOP-6j. – **d** MOP-6m. – **e** MOP-6o. – **f** MOP-6r. – **j** MOP-6n. – **k** MOP-6s. – **l** MOP-6k. – **o** MOP-6d. – The arrows indicate the parting lines on the domes of the buttons, which are indicative of the use of two- or three-part moulds.

However, these parts had been imperfectly connected, possibly due to forge welding at too low a temperature or the use of too little welding flux. Further macroscopic observations of the axe identified the presence of areas with the remnants of slag removed in the purification process of iron blooms from a slag pit furnace, as can be seen in figure 17c. This can also be observed on the X-ray recordings (fig. 10g-i).

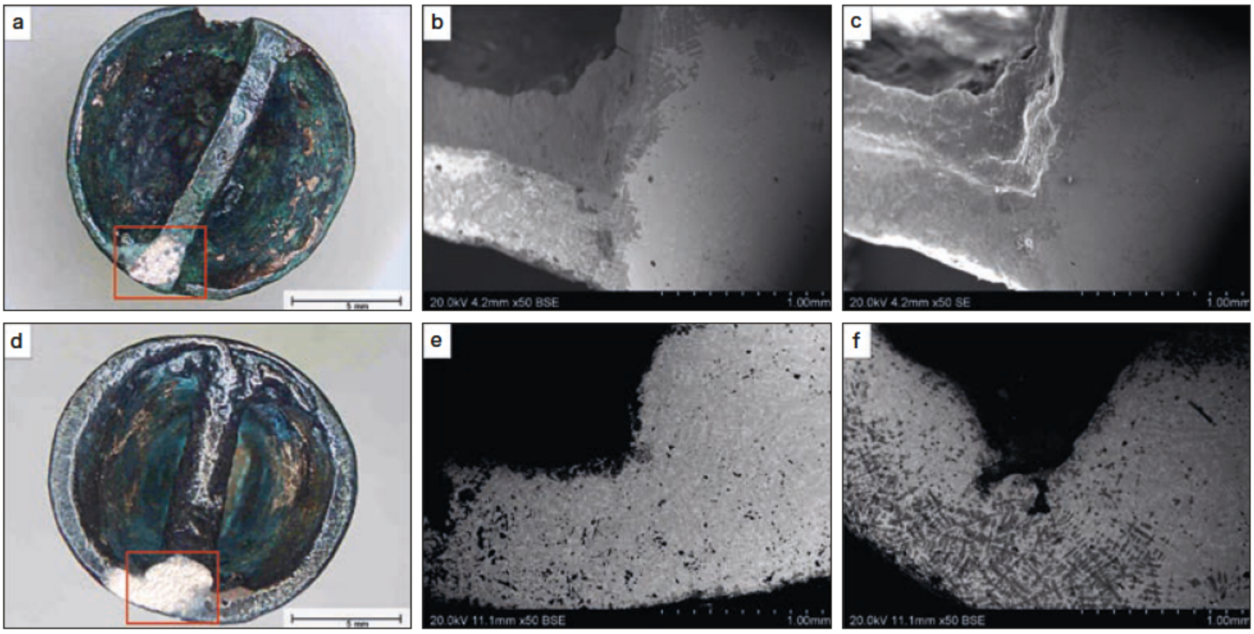


Fig. 14 Photomacrographs of the conical buttons with SEM recordings indicative of one-piece casting: **a-c** button MOP-5i. – **d-f** button MOP-6m. – The SEM images were taken at a magnification of ×200–2.0k under low-vacuum mode and an accelerating voltage of 20.0 kV.

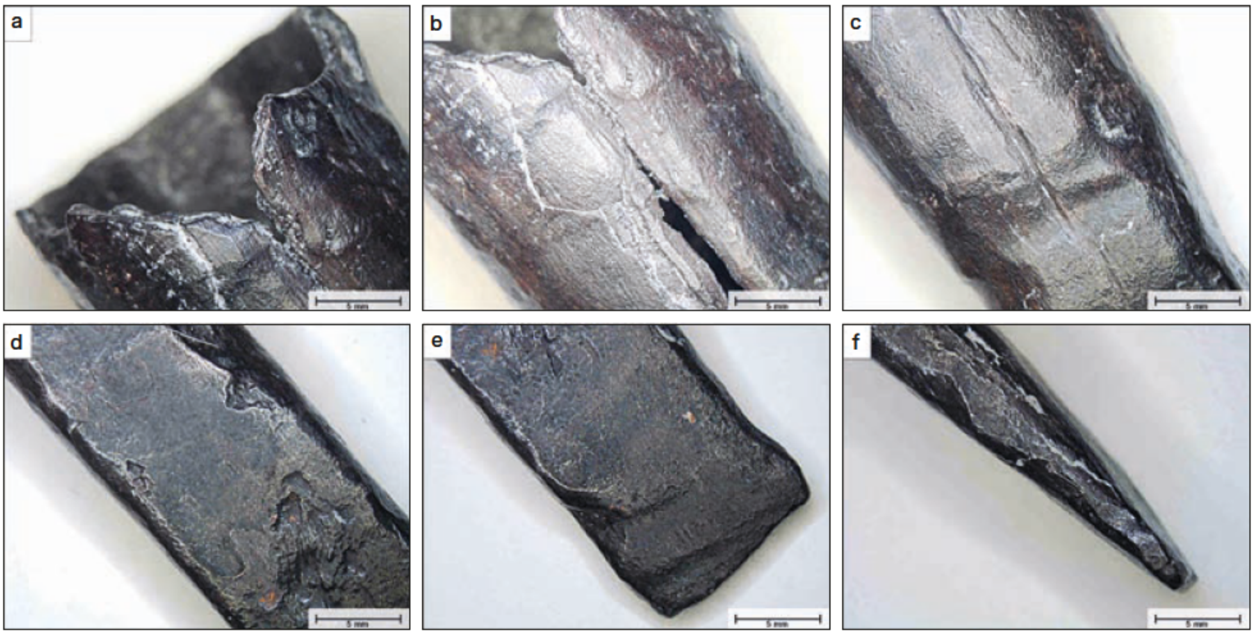


Fig. 15 Photomacrographs of the iron chisel MOP-7. Note (**b**) the gap between the edges of the chisel socket, which had been formed tightly one to another with no joint.

There is some evidence of plastic forming, which is evident at the blade part.

The starting material used for the iron body ornaments, consisting of the bracelet MOP-10 (fig. 18) and the necklace MOP-14 (fig. 19), was an iron rod with a square cross-section. The rod used for the necklace displays four changes of a twisting direction and originally terminated with two looped and flat endings. It can be concluded from the iron delamination visible in figure 19b that it resulted from insufficient treatment of the metal in the post-smelting stages, which included the forging and twisting of the iron rod.

The iron bit MOP-9 was forged from a single piece of metal that had been formed into a rod with a square cross-section. After forging, the rod had been pierced and then stretched with a round punch to form two 8-shaped apertures that once formed a joint bit (figs 20a; 10k). One of the apertures had been cut before being threaded through the other

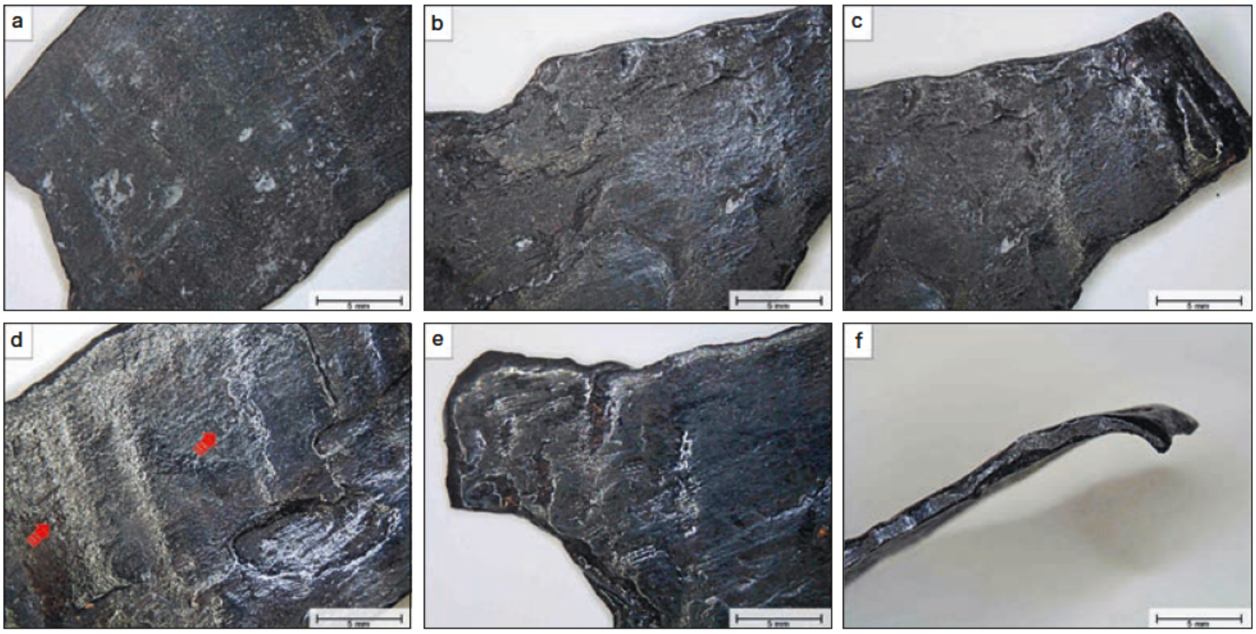


Fig. 16 Photomacrographs of the iron sickle MOP-8. The arrows indicate right-skewed grooves, which are the result of forging and may indicate that the craftsperson was left-handed.

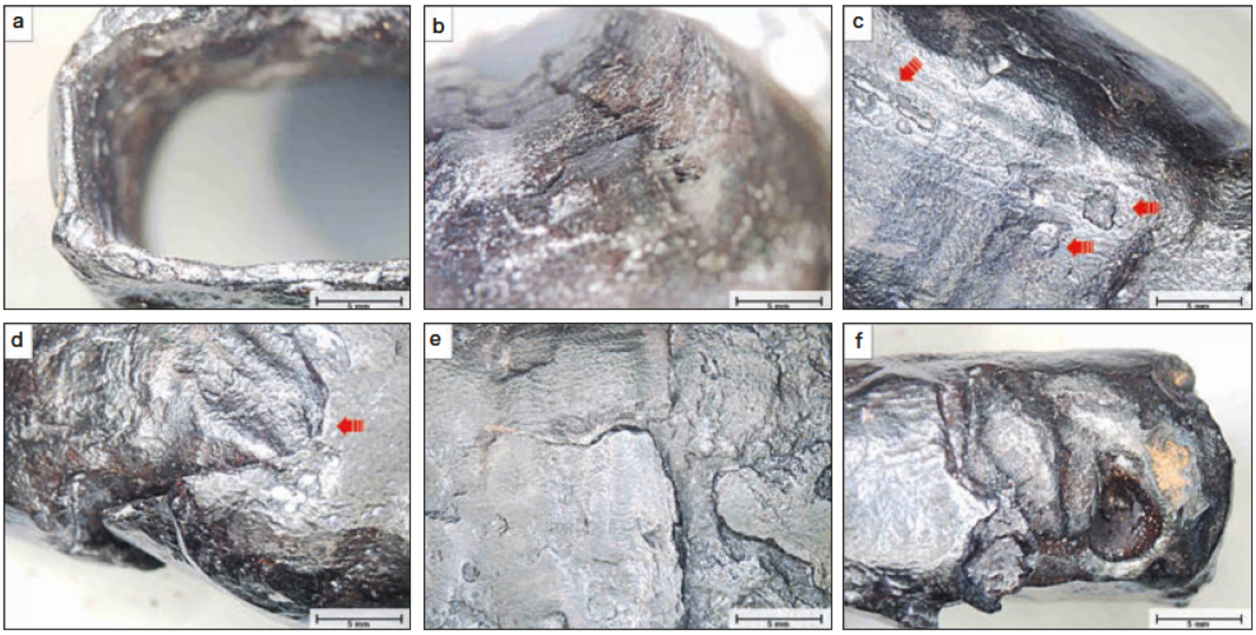


Fig. 17 Photomacrographs of the iron socketed axe MOP-12. The arrows indicate (**c**) the remnants of slag removed in the purification process of iron blooms from a slag pit furnace and (**d**) an imperfect connection of the socket and the blade part, possibly due to forge welding at too low a temperature or using too little welding flux.

and then re-joined by heating to a high temperature and hammering.

Similar to the chisel, the spearhead MOP-13 was made from a single piece of iron, and the edges of the spearhead socket had been formed tightly one to the other without forge welding (fig. 21e). A radiographic examination confirms this observation (fig. 10l) and also revealed that this metallic structure is best preserved in the central part of the spearhead, while the blade edges displayed many pores and gaps and had been strongly affected by the corrosion process. The presence of the remnants of slag removed during the purification process of iron blooms from a slag pit furnace was also identified on the surface of the spearhead, as can be seen in figure 21a.

Noteworthy are grooves that can be observed on the chisel (fig. 15c), the sickle (fig. 16d) and the

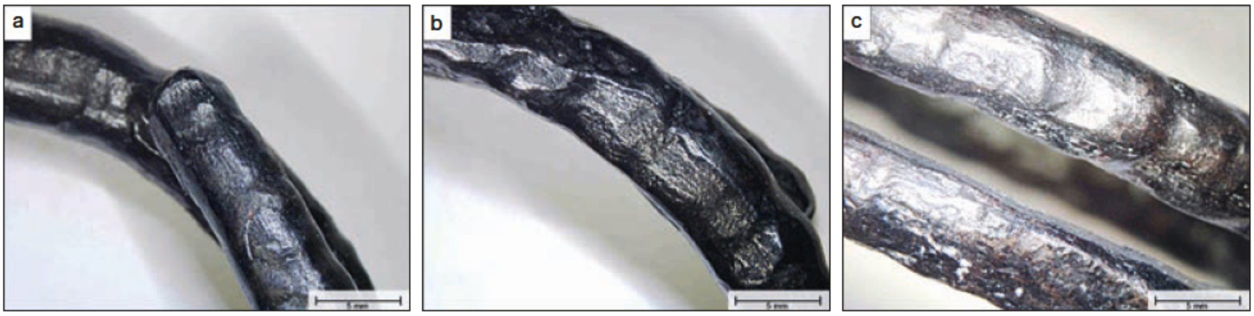


Fig. 18 Photomacrographs of the iron bracelet MOP-10.

Fig. 19 Photomacrographs of the iron necklace MOP-14. The arrows indicate (**b**) iron delamination resulted from insufficient treatment of the metal in the post-smelting stages and (**c**) an area with a change of the twisting direction of the iron rod.

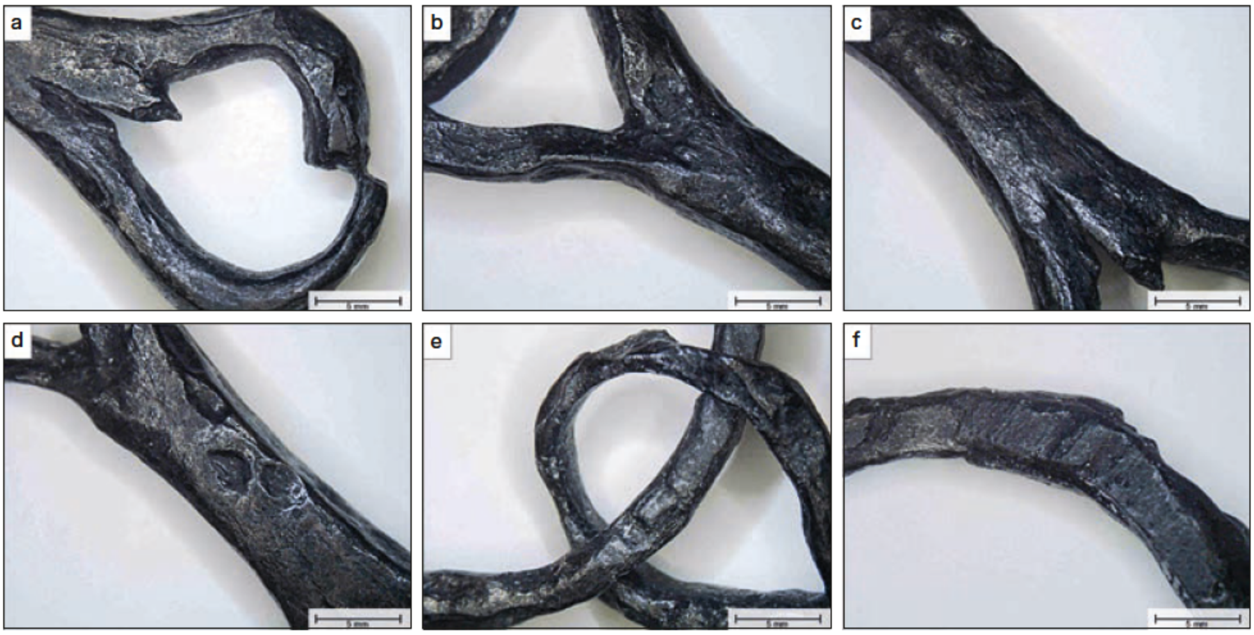


Fig. 20 Photomacrographs of the iron joint bit fragment MOP-9.

bracelet (fig. 18). These structures are the result of forging techniques aimed at extending the length of the metal, and may have been due to an uneven anvil face or the blacksmith's custom, and there was no technological justification for these dealings. The grooves are right-skewed, possibly indicating that the craftsperson was left-handed.

Textile Evidence

Microscopic examinations of corrosion products on the bronze (MOP-3) and iron artefacts (MOP-7 and MOP-13) revealed the presence of ephemeral textile imprints (fig. 22a-c). After the corrosion crust had been removed from the destructs of iron metal-

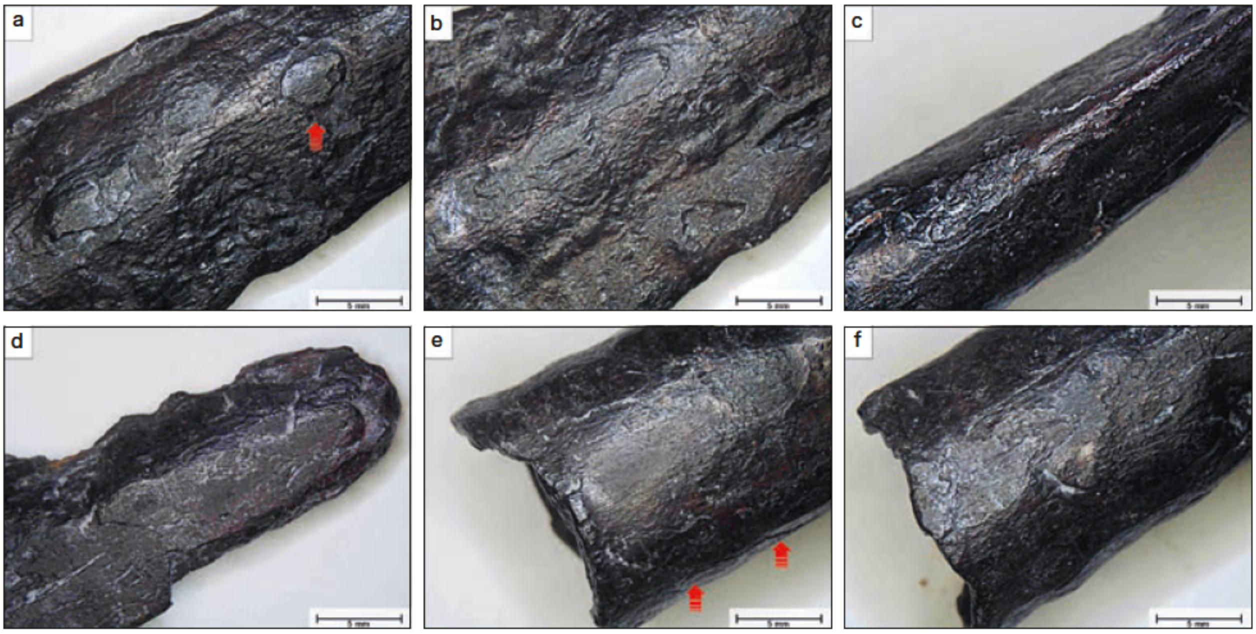


Fig. 21 Photomacrographs of the iron spearhead MOP-13. The arrows indicate (**a**) the remnants of slag removed in the purification process of iron blooms from a slag pit furnace and (**e**) the gap between the edges of the spearhead socket, which had been formed tightly one to another with no joint.

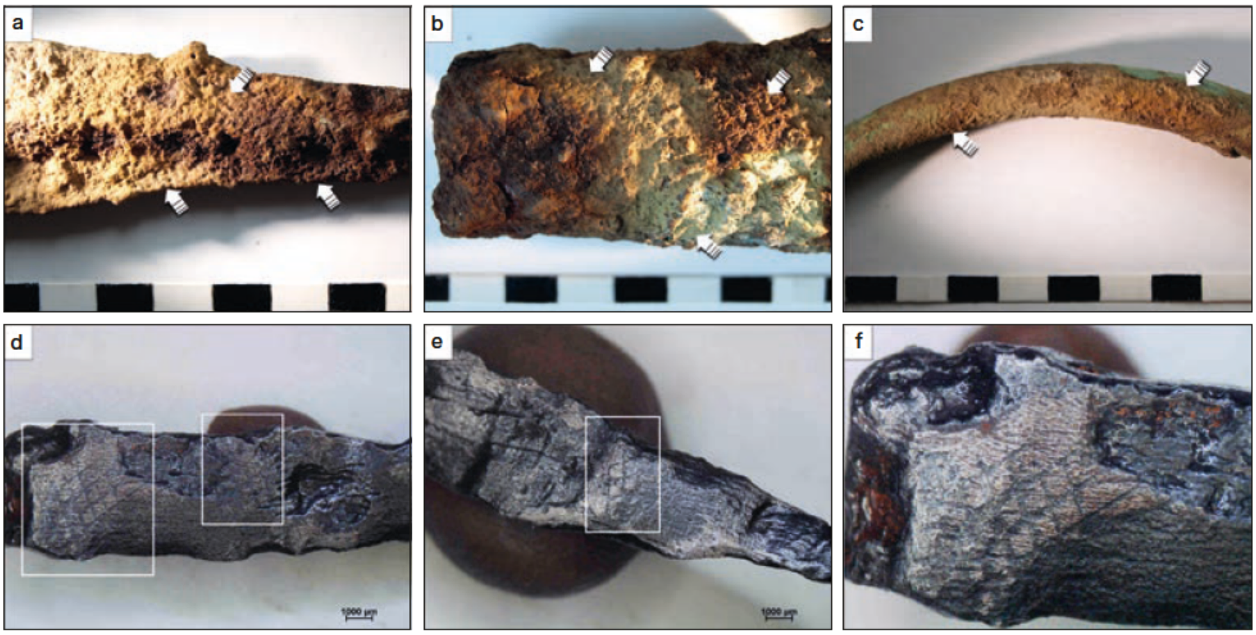


Fig. 22 Photomacrographs of bronze and iron metalwork from Grabionna showing the presence of textile imprints (indicated by the arrows and frames), suggesting that the metal artefacts were buried in textile wrapping: **a** iron spearhead MOP-13. – **b** iron chisel MOP-7. – **c** bracelet fragment MOP-3. – **d-f** destructs of iron metalwork.

work, some ghost textile surfaces also became visible, forming a pattern of dark grey diamond shapes in the metal surface (Davis/Harris 2023). As can be seen in figure 22d-f, the binding points were preserved, but with no remnants of fibre or textile. The identified imprints were not formed during the production process, for example as a result of a moulding procedure using a ceramic mould or the lost-wax technique, allowing the confident interpretation that the metal artefacts had been wrapped in textile packing prior to burial. There are known examples from northern Poland of the practice of wrapping metal objects that have a similar chronology to the Grabionna hoard, such as metal deposits from

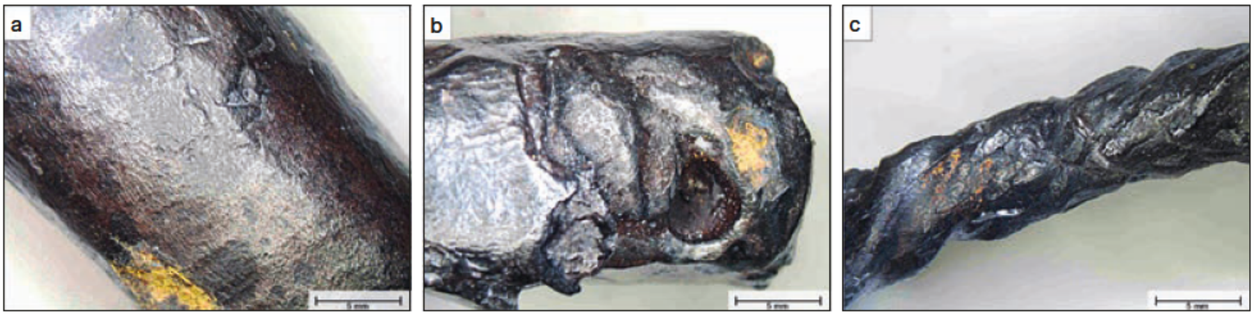
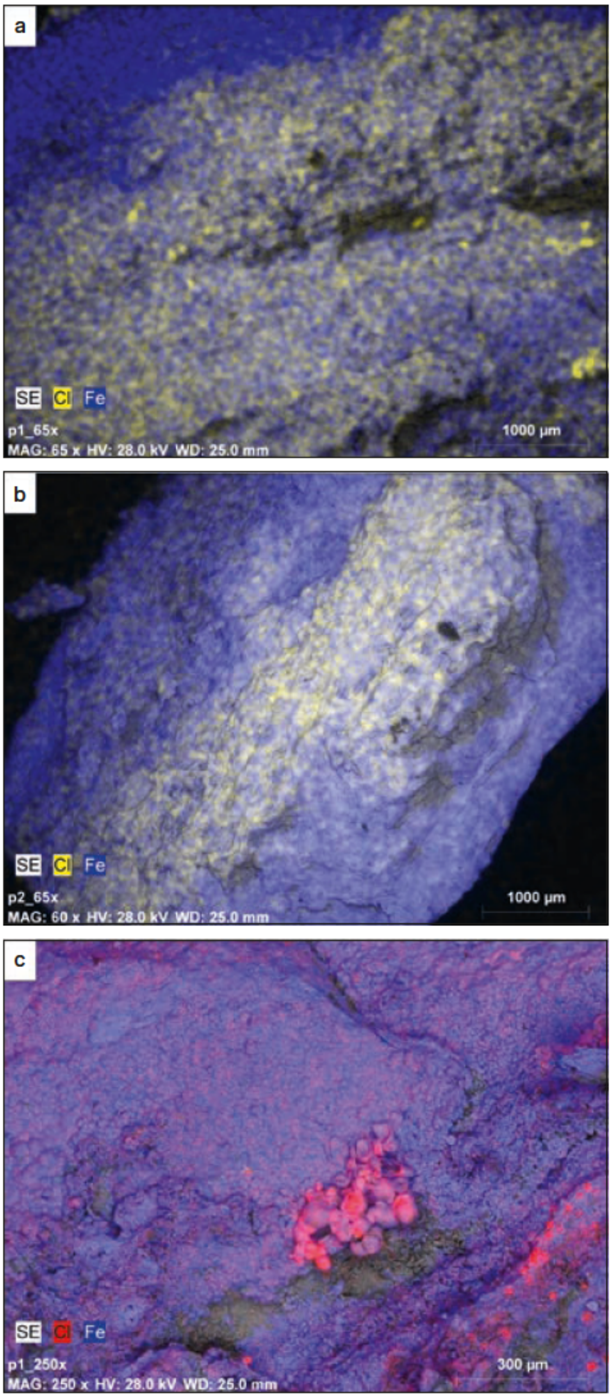


Fig. 23 Photomacrographs of iron metalwork from the Grabionna hoard showing the presence of yellow corrosion products that are associated with the weeping iron condition: **a** chisel MOP-7. – **b** socketed axe MOP-12. – **c** necklace MOP-14.



Brudzyń (Przymorska-Sztuczka 2022), Rosko (pow. Czarnków-Trzcianka/PL; Sikorski 2006) and Cierpice (pow. Toruń/PL; Gackowski et al. 2023).

The estimated thread diameter on the iron destructs from Grabionna ranges between 0.1 and 0.2 mm (fig. 22d-f), yet it seems to correspond with textile evidence from other parts of Early Iron Age Europe indicating the use of yarns with a diameter between 0.1 and 0.2 mm (Grömer/Rösel-Mautendorfer 2013). Similar examples are also known from the region. For instance, a textile imprint with a thread diameter of 0.12–0.17 mm preserved on a ceramic vessel from Kałdus (pow. Chełmno/PL) in northern Poland, and similar evidence comes from the Lusatian cemetery at Konin-Grójec (pow. Konin/PL) in central Poland, where textile imprints identified on bronze metalwork indicate a textile type with a thread diameter ranging from 0.15 to 0.3 mm, with a few examples between 0.050 and 0.075 mm (Przymorska-Sztuczka 2022).

Deposition Context Evidence

Visual examinations revealed that the iron artefacts went through various corrosion processes and were strongly deteriorated. The corrosion layer is rough and composed of different corrosion products of grey, orange and brownish colours that were mixed with soil deposits. These products include swilling, exfoliation and pitting effects and indicate the aggressive conditions of the burial environment. Features of mechanical damage are also evident in the iron

Fig. 24 SEM recordings of the corroding iron socketed axe MOP-12 with EDS elemental mapping showing the significant amount chlorine and (**c**) the hollow shells characteristic of the weeping iron condition (see text for further details). The SEM images were taken at a magnification of ×65–250 under low-vacuum mode and an accelerating voltage of 28.0 kV.

spot ID	C	O	Na	Mg	Al	Si	S	Cl	Ca	Fe	Cu
31721	4.34	28.74	…	…	…	…	…	0.56	…	66.36	…
31725	5.77	32.22	…	…	…	…	…	0.58	…	61.43	…
31719	8.39	39.59	1.50	8.63	2.29	3.26	…	2.44	6.87	27.03	…
31726	3.58	31.34	…	…	…	…	…	5.14	…	59.94	…
31723	2.38	32.04	…	…	…	…	…	6.74	…	58.84	…
31724	2.47	31.38	…	…	…	…	…	6.80	…	59.35	…
31716	2.37	30.60	…	…	…	…	…	7.32	…	59.70	…
31717	2.38	27.25	…	…	…	…	…	7.71	…	62.66	…
31720	2.80	25.17	…	…	…	…	…	8.30	…	63.72	…
31718	2.81	25.35	…	…	…	…	…	8.53	…	63.30	…
31722	3.28	29.11	…	…	…	…	0.81	13.04	…	50.39	3.38

Tab. 3 Results of the SEM-EDS analyses of the corroding iron socketed axe MOP-12 after the first washing (ethylenediamine). The SEM-EDS data are not normalised and given in wt % (see fig. 24). »…« = no element was detected.

artefacts due to their use in the past and subsequent interaction with the burial environment.

The conservation treatment for the iron metalwork employed two washing techniques to remove the corrosion-promoting chlorides, which were also the main factors responsible for the corrosion on the bronze artefacts from the hoard. The first desalination method used ethylenediamine solution (5 %, deionised water) (Argo 1982; Selwyn/Argyropoulos 2005). After nine cycles of washing and the application of corrosion inhibitor (tannin) and protective coating systems (10 % Paraloid B-72 in toluene and Cosmoloid 80 H in white spirit), the chlorides had not been fully complexed and were still accelerating corrosion reactions in the iron objects (fig. 23). Accordingly, an alkaline sulphite washing (0.5 M NaOH/0.5 M Na_2SO_3 in stirred deionized water at 60°C) (North/Pearson 1975) was used to diffuse enormous amounts of chlorides from the iron objects. The treatment was repeatedly applied over a period of 1.5 months.

Control SEM-EDS investigations were carried out for the corroding iron socketed axe (MOP-12) after the first washing (ethylenediamine), confirming that the corrosion products that had developed on the artefact contain significant amounts of chlorine, which covered a large part of the surface of the corroding iron (fig. 24a-b). The SEM recordings also revealed the presence of hollow beads in the corroded surfaces, which indicates a »weeping iron« condition, as can be seen in figure 24c (Réguer et al. 2007; Salem et al. 2019; Selwyn et al. 1999; Watkinson et al. 2019). The weeping is attributed to the hygroscopic nature of iron chloride salts and depends on the relative humidity (Selwyn 2004), and signals that the iron metal work suffered a progressive stage of corrosion due to the chloride contamination (Salem et al. 2019; Selwyn et al. 1999).

Table 3 lists the major elemental compositions of the corroding iron axe MOP-12. Apart from oxygen, the chemistry of the corrosion products is directly controlled by iron and chlorine content ranging from 27–66 % and 0.6–13 %, respectively. Noticeable amounts of aluminium and silicon and elevated calcium content amounting to 6.9 % may point to the corrosion products that had been mixed with the remnants of the burial context with some clay minerals.

As a postscript to the depositional context, the enormous amounts of chlorides in the iron objects from Grabionna identified during the conservation treatment and SEM-EDS investigations may raise the question of whether the metals could have been deliberately buried with salt, and it would be interesting to pose this question in the light of the preliminary archaeological evidence for salt production in the Bay of Puck in northern Poland during the Early Iron Age (Bukowski 1985; Mazur/Dzięgielewski 2021). Future research on metal deposits should include methods for testing the possibility of intentional salt co-deposition, including salinity testing of soils and the accompanying ceramic materials (Horiuchi et al. 2011), as this could add an interesting point of view for research on prehistoric metal hoarding in the region of modern Poland and beyond.

Conclusions

The results of the analyses add more details to the biography of the Grabionna hoard and increase our knowledge of the metal production and use in the region during the later Bronze Age and the Early Iron Age. Based on ED-XRF and SEM-EDS analyses, the bronze artefacts were chemically determined, and optical microscopy examinations allowed us to zoom in on some aspects of the technology used for the production of the bronze and iron metalwork. The recognized production patterns enabled us to conclude that the bronze buttons were cast in a multiple casting mould, while the iron metalwork was personalized and produced by one and the same craftsperson. Furthermore, textile imprints on the metalwork indicated that prior to burial, the metal artefacts had been wrapped in textile packing.

The find from Grabionna is the first metal hoard from the Early Iron Age reported in the basin of Middle Noteć since World War II, and is an example of the important archaeological heritage of the region. The recovered bronze and iron metalwork are typical products of the workshops operating in north-western Poland in the later Bronze Age and the beginning of the Iron Age. The metal assemblage from Grabionna adds to the archaeological evidence for the widespread metal trade network that extended through the North European Plain and well attests to the active role of the Noteć Valley as a contact zone between the Baltic area and the more southerly regions of Early Iron Age Poland (Kaczmarek 2019). The content of the hoard and its context of disposition are equally important. Here, the co-deposition of the female-gendered ornaments and the iron horse bit (accompanied by iron tools and bronze waste) adds to a growing body of evidence from southern Scandinavia and the South Baltic coast that horse-related accessories and female ornaments were used for ritual and social events, including metal hoarding (Sarauw 2015; Gackowski et al. 2023; 2024). A similar pattern of metal deposition can be traced to Brudzyń, which is 60 km south of Grabionna, where horse bridle elements were found assisted by bronze ornaments and tools (Gackowski/Rosołowski 2020). Notably, some of the metal objects had already been damaged or fragmented before burial. Likewise to be mentioned is the topography around the findspot, indicating that the hoard was deposited at the edge of a small valley, at the interface between wet and dry environments, in line with other geographical locations identified for metal hoards of the North European Bronze Age. Finally, the archaeological evidence from the region can also be used to suggest that the Grabionna hoard marks the border of the local group territory and that the hoarding event took place near the passage through the valley, which may have been an important local communication node during the Late Bronze Age and later.

List of Finds

Body Ornaments

1 Cast bronze necklace with engraved diagonal lines imitating the twisting of a bronze rod. The endings are topped with protuberances and decorated with transverse and slightly diagonal engraved lines. Visible green and light green patina. Size: ∅ 18.0 cm × 16.5 cm; max. width 1.0 cm; weight 270 g. Inv. no. MOP2016/129. Sample ID: MOP-1.

2 Cast bronze necklace with engraved diagonal lines imitating the twisting of a bronze rod. The endings are topped with protuberances and decorated with transverse and slightly diagonal engraved lines. Visible green and light green patina. Size: ∅ 17.5 cm × 15.7 cm; max. width 1.0 cm; weight 248 g. Inv. no. MOP2016/130. Sample ID: MOP-2.

3 Iron necklace made of a twisted rod, with looped and flat endings. Only one loop is preserved. Visible corrosion through pits. Size: ∅ 18.7 cm × 17.5 cm; rod width 0.7 cm; weight 88 g. Inv. no. MOP2016/131. Sample ID: MOP-14.

4 Iron bracelet with overlapping endings, made of a rod with a round cross-section. Size: ∅ 7 cm; weight 69 g. Inv. No. MOP2016/132. Sample ID: MOP-10.

5 Cast bronze bracelet (fragment) made of a non-decorated, narrowing rod. Visible green patina. Size: ∅ 0.8 cm (ca. 9.5 cm after reconstruction); weight 32 g. Inv. no. MOP2016/133. Sample ID: MOP-3.

Weapon

6 Iron spearhead. Visible damage of the socket base and blade tip. Size: length 15.2 cm; socket ∅ 1.5 cm × 15.7 cm; max. blade width 2.8 cm; weight 74 g. Inv. no. MOP2016/134. Sample ID: MOP-13.

Tools

7 Iron socketed axe with fan-shaped cutting edge. Socket is round in cross-section. The axe is preserved in two parts. Size: length 13 cm; socket ∅ 2.1 cm; cutting edge width 4.2 cm; weight 215 g. Inv. no. MOP2016/135. Sample ID: MOP-12.

8 Iron socketed chisel. Size: length 12.7 cm; blade width 1.8 cm; socket ∅ 2.5 cm; max. width 1.0 cm; weight 77 g. Inv. no. MOP2016/136. Sample ID: MOP-7.

9 Iron sickle. The blade base has not been preserved. Size: length 11.7 cm; max. width 2.7 cm; weight 15 g. Inv. no. MOP2016/137. Sample ID: MOP-8.

Horse-gear Items

10 Iron single joint bit (fragment). Mouthpiece has a diamond-shaped cross-section. Size: length 6.7 cm. Terret ring is oval-shaped. Size: ∅ 5.3 cm × 4.4 cm. Total weight 18 g. Inv. no. MOP2016/138. Sample ID: MOP-9.

Bronze Buttons

11-77 67 conical buttons with a transverse bar. Size: ∅ 1.0–1.2 cm; height 1.5–1.8 cm; weight 0.56–1.72 g. Inv. nos MOP2016/139. Sample ID: MOP-6.

78-96 19 flattened conical buttons with a transverse bar. Size: ∅ 1.3–1.4 cm; height 0.70–0.80 cm; weight 0.83–1.82 g. Inv. nos MOP2016/140. Sample ID: MOP-5.

Metal Waste

97 Bronze casting drop. Weight 3.2 g. Inv. no. MOP2016/141. Sample ID: MOP-4.

98-103 Six small fragments of iron metalwork.

Pottery

104 More than ten badly preserved and fragile fragments of a ceramic vessel.

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Zusammenfassung
Résumé

Ein Hort aus Grabionna. Neue Informationen zur Herstellung und Verwendung von Metallarbeiten im Baltikum

Im Jahr 2016 wurde bei landwirtschaftlichen Arbeiten im Dorf Grabionna im Nordwesten Polens ein Metallhort ausgegraben. Der Hort besteht aus über 100 Bronze- und Eisenartefakten aus der frühen Eisenzeit, darunter Körperschmuck, eine Waffe, Werkzeuge, Pferdegeschirr und andere Metallgegenstände, die in zerfallene Textilverpackungen eingewickelt waren, und stellt ein wichtiges archäologisches Erbe der Region dar. In diesem Beitrag werden die Ergebnisse archäologischer, metallografischer und chemischer Untersuchungen der Bronze- und Eisenartefakte vorgestellt und diskutiert, die durch Hinweise auf Konservierungsprobleme und Textilabdrücke auf den Metallgegenständen untermauert werden, um die Biografie des Grabionna-Hortes zu ergänzen und unser Wissen über die metallurgischen Aktivitäten und die Metallhortung während der frühen Eisenzeit im Baltikum zu erweitern.

Un magot de Grabionna. Nouvelles informations sur la production et l'utilisation des métaux dans la région de la Baltique

En 2016, un trésor métallique a été mis au jour lors de travaux agricoles dans le village de Grabionna, dans le nord-ouest de la Pologne. Le trésor se compose de plus de 100 artefacts en bronze et en fer datant du premier âge du Fer, y compris des ornements corporels, une arme, des outils, des articles d'équipement pour chevaux et d'autres objets métalliques, qui étaient enveloppés dans un emballage textile qui s'était décomposé, et représente un patrimoine archéologique important de la région. Cet article présente et discute les résultats des recherches archéologiques, métallographiques et chimiques des artefacts en bronze et en fer, aidés par les preuves des problèmes de conservation et des empreintes textiles sur le travail du métal, afin d'ajouter plus de détails à la biographie du magot de Grabionna et d'élargir nos connaissances sur les activités métallurgiques et la thésaurisation des métaux au cours du premier âge du Fer dans la région de la Baltique.

Schlüsselwörter
Mots-clés

Mitteleuropa / Baltikum / frühe Eisenzeit / Metallhort / Bronzeguss / Eisenschmiedekunst / Archäometallurgie / zerstörungsfreie Analyse
Europe centrale / région de la Baltique / premier âge du Fer / dépôts métalliques / fonte du bronze / forge du fer / archéométallurgie / analyse non destructive