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The Late Bronze Age 'metallurgists' graves' in south-western Poland. Tracing the provenance of the metal raw material using casting moulds

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ABSTRACT

A collection of objects associated with prehistoric metallurgy, including casting moulds, a casting core, and a fragment of a tuyere, were found in three metallurgists' graves in the Late Bronze Age cemetery in Legnica, south-west Poland. The finds from these graves presented an opportunity for a scientific investigation of several aspects of Bronze Age metallurgy in this region by applying various analytical procedures to characterise the remains of metals inside the casting moulds. We also analysed metal used for the repair of one of the moulds, and the razor from one of the graves that could have been cast in a mould discovered in another grave. One of the aims of this research project was to establish a possible provenance of the metal used by the population buried in these so-called metallurgists' graves using the chemical and lead isotope analysis. The casting moulds had clear wear marks providing proof of their use. In two cases, the moulds had thick greenish-black layers possibly representing remains of a corroded metal. The chemical compositions of these layers and metal from two other artefacts was investigated using ED XRF and SEM EDS. These analyses showed the diversity of the metals used for castings. Lead isotope analyses using MC ICP MS provided information about the possible origin of lead in the remains from the moulds. The most likely source of this lead is from the ores in the Erzgebirge, in eastern Germany, a few hundred kilometres south west from the site of the graves. The provenance of lead from the razor and from the repair of the mould can be either from the Erzgebirge or Slovak Ore Mountains, or a mixture of these ores.

1. Introduction

Graves with casting equipment or other artefacts related to metallurgical activities represent an interesting European phenomenon that has its origins in the Eneolithic (Bátora, 2003). Many authors have dealt with this subject, defining it in a variety of terms, including *smiths and founders graves or burials/graves of metallurgists and metalworkers* (German: Handwerkergräber, Schmiedegräber; Gräber von Metallgießern; Metallhandwerkergräber; Slovak: hroby remeslníkov-metalurgov; Polish: groby metalurgów, odlewników. See for example: Bátora, 2003; Dąbrowski, 1977; Jaeger and Olexa, 2014; Jockenhövel, 2019, 2018; Krzyszowski and Kowalski, 2019; Malinowski, 1982; Molloy and Mödlinger, 2020; Neipert, 2006; Nessel, 2013, 2012; Olexa, 1987; Pančíková, 2008). The history of research of this phenomenon and mentions of graves with metallurgy-related tools date back to the 18th century, and the subject literature is quite extensive. Detailed reviews of the research history have been published by several authors (Jockenhövel, 2019, pp. 9–42, 2018, pp. 223–225; Nessel, 2019, pp. 205–279). The authors of these publications distinguish different groups of grave offerings that should be considered as determinants of metallurgical activities. These include artefacts that represent the entire chain of activities of a prehistoric metallurgist, including mining, extracting metal from the ore, metal casting, as well as further processing.

However, while the determinants of metallurgy in graves and the issues of mortuary practices or the social status of the deceased are studied, the metallurgical tools deposited in the so-called metallurgists' graves are rarely studied in detail (apart from a few exceptions. See for example: Kowalski et al. 2021). This mainly concerns the casting

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moulds, which are most often discovered in these graves. The potential of using the residues of metal in the moulds found in graves to determine the provenance of the sources of metal used for casting, has rarely been expoited. The few published lead isotope analyses include the residue of copper from a casting mould for an LBA oxhide ingot found on the site in Ras-Ibn-Hani (Gale 1989) and for the slagged inner surfaces of the crucibles from the Bronze Age settlement site of Kastro-Palaia in Greece (Rehren et al., 2013). Several such analyses of metal residues in crucibles from the Minoan sites on Crete are listed on the OXALID database, but not of them published in papers (http://oxalid.arch.ox.ac.uk). So far there have been no such analyses of the metallurgical remains from the archaeological sites in Poland.

In the case of the cemetery in Spokojna Street, Legnica, we have a unique opportunity to examine the mould and the object that was made in it and compare the results. Namely, the razor deposited in grave no. 11 fits perfectly with the negative of the casting mould from grave no. 5. In addition, one of the moulds from grave no. 42 was repaired by pouring metal over the damaged area. This metal has also been tested to check its chemical composition and origin. Our research was therefore aimed at analysing the chemical and isotopic composition of the residue of the alloy poured into the moulds, the finished cast made in one of the moulds, and the metal associated with the repair of the casting mould. The results were compared with lead isotope data available for ores in Europe, Turkey and Iran.

2. Materials

2.1. The cemetery in Spokojna Street, Legnica. Archaeological context

The materials analysed for this research have been discovered in the Bronze Age cemetery in Legnica, in south-western Poland (Fig. 1). The site was located on the slope of a large hill (115 m above sea level), on the floodplain of the Kaczawa River, in the vicinity of the Kopanina Stream. The emergency excavations on this site, caused by construction works carried out at Spokojna Street in Legnica, were carried out in 1972–1973 and resulted in a discovery of 188 Late Bronze Age (LBA) graves. The typology of the finds from the graves indicated that the cemetery was used during the 4th and 5th periods of the Bronze Age (relative chronology: 1150/1000–800/750 BCE). Apart from determining the relative chronology of the grave inventories, two radiocarbon dates have been obtained from burned bone samples and determined the dating of the site to the Late Bronze Age, confirming the conclusions based on the typology of the artefacts (Goslar 2016; Nowak 2016).

Following this excavation, the inventory of the graves has been selectively presented in the literature and a comprehensive study of all was the obtained materials published in 2016 (Nowak and Stolarczyk, 2016). A year later, based on the finds from this cemetery, a reconstruction of the metal casting in a mould was published as a 3D visualization (Garbacz-Klempka et al., 2017). The cemetery in Legnica has been mentioned in the archaeological literature, mainly due to the presence of graves with equipment used in the casting of metal artefacts. Sparse information about this discovery has been included in monographic publications on individual categories of the equipment (*Prähistorische Bronzefunde* series; Gedl, 2009, 2004, 1995, 1981). In recent years, information about the graves with casting moulds from Legnica has been included in the articles and books by B. Nessel (2019, 2013, 2012), A. Jockenhövel (2018), and B. Molloy and M. Mödlinger (2020). Unfortunately, these publications contain erroneous information regarding both the number of graves with metallurgical equipment (e.g. Nessel, 2019, p. 263; Jockenhövel, 2018, pp. 250 and 259) and the number and types of metallurgy-related artefacts (Molloy and Mödlinger, 2020, p. 175).

2.2. 'Metallurgists' graves' – Archaeological and anthropological evidence

Three out of the 188 graves discovered in the Legnica cemetery (graves Nos. 5, 42, and 153) contained artefacts related to metal casting, such as moulds, a casting core, and a tuyere fragment (see details of the graves in Appendix A and Table 1). All casting moulds belong to the bivalve type of moulds and were used for gravity casting placed vertically. There was no clear pattern of deposition or arrangement of these graves in the cemetery (Fig. 2).

2.2.1. Grave 5

This grave represents an urn grave with cremated human remains that was damaged before its discovery. It contained three ceramic vessels, a large number of pottery fragments, a small clay bead, a bronze bracelet fragment, and ten items related to metallurgical activity (Fig. 3). The casting equipment discovered in grave 5 includes: casting moulds for sickles, razors, spearheads, socketed chisels, a casting core, and a tuyere fragment (Fig. 3.1-10). The discovered items were made of clay, and they were preserved whole, and in fragments.

2.2.2. Grave 42

An urn grave with the cremated human remains, found at the depth of 0.20–0.45 m below the arable layer. The grave was located on the N-S axis. Human bones were found in the urn, in the ceramic scoop vessel no.

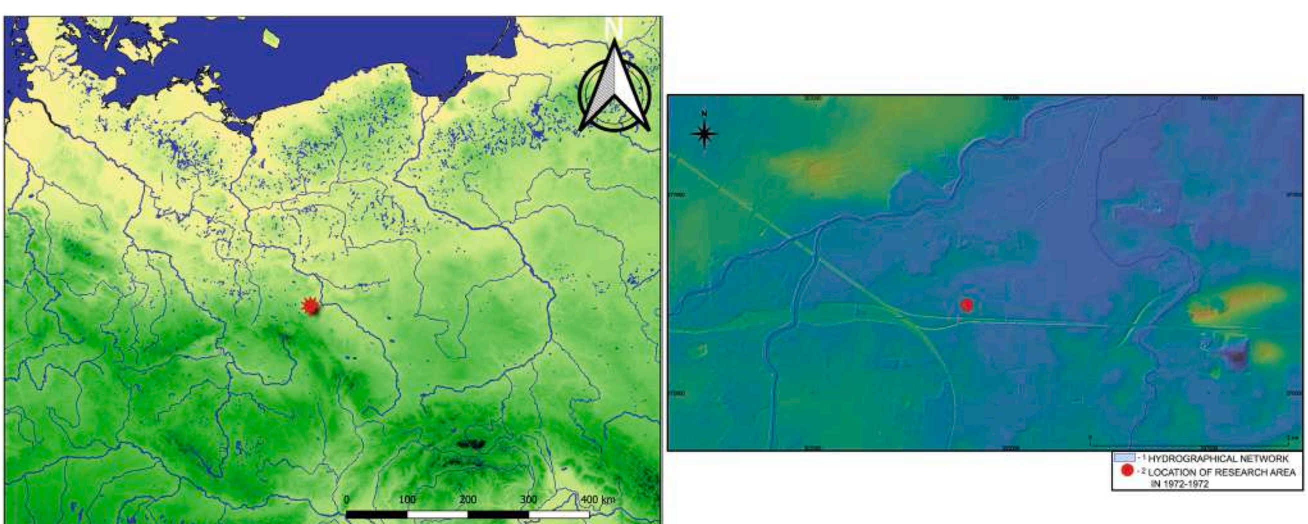

Fig. 1. Legnica, Lower Silesia, south-western Poland. Site location and area excavated in 1972–1973.

Table 1
Equipment deposited in 'metallurgists' graves' from the cemetery in Legnica.

Number of the grave	Moulds number	Tuyere	Casting core	Number of ceramic vessels	Fragments of vessels	Metal items	Other items
5	Eight (three sets and two halves)	One fragment	One core in two fragments	Three (a cup, a pot, a dipper)	Minimum 13 (pots, a plate, vases, bowls)	Fragment of a bracelet	A small ceramic bead
42	Four (two sets)	–	–	Eight (a plate, six dippers, a vase	32 sherds (pots, a bowl, a dipper)	–	A stone axe, a small pebble
153	Two (one set)	–	–	Eight (two vases, a plate, a cup, two pots, a bowl, a dipper)	–	Fragment of an item	–

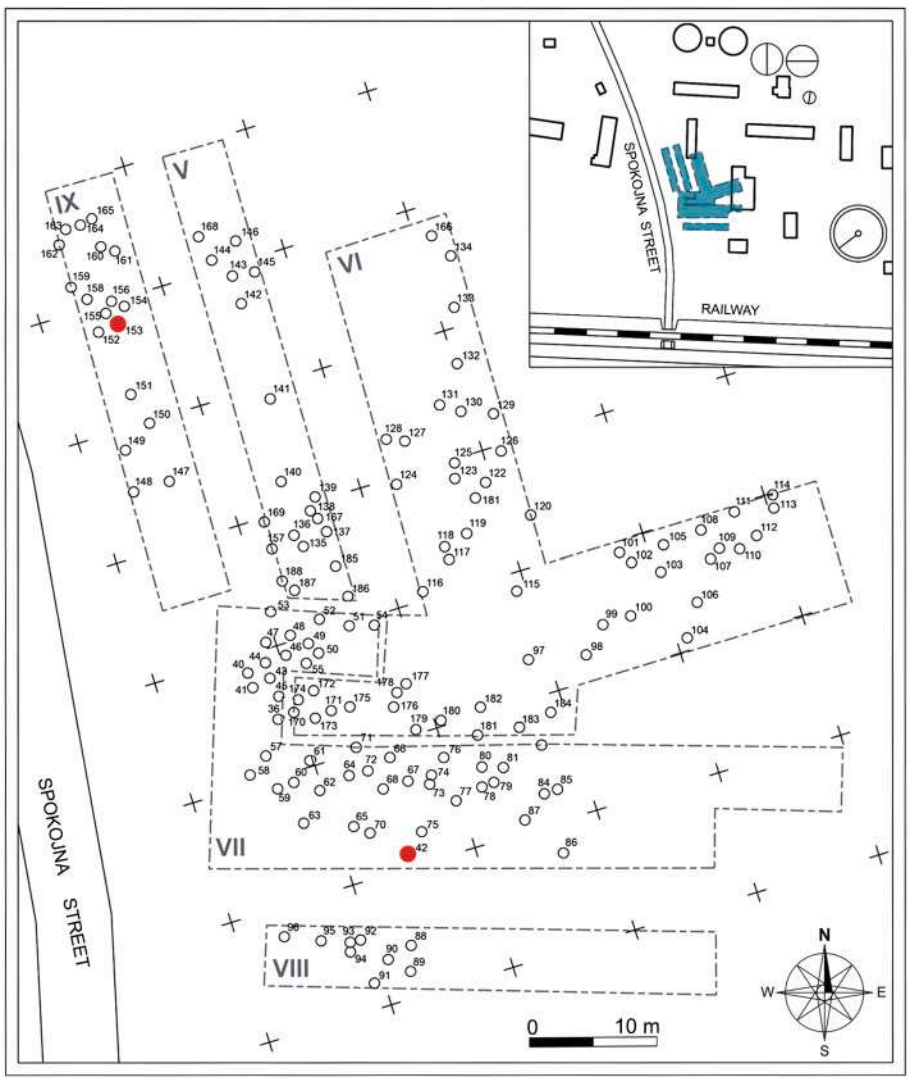

Fig. 2. Plan of the cemetery with marked graves (nos. 44–188). Graves 42 and 153 with metalworking tools are marked with red dots.

7, and next to the vessels (Fig. 4). Apart from the urn (not preserved), the grave included seven vessels, 32 pottery fragments, four stone moulds (Fig. 4.8–11), a stone axe (Fig. 4.12), and a stone pebble (Fig. 4.13). The moulds were deposited together in two sets.

2.2.3. Grave 153

This grave was discovered at a depth of 0.37 m and, at its lowest point, reached 0.56 m. The outlines of the vessels deposited in this grave were discovered below the arable layer, against the background of humus mixed with coarse gravel. Based on anthropological observations, the person buried in the grave was approximately 20–30 years old, most likely a male (Hałuszko and Łukowiak, 2016, p. 207). The finds in this grave included an urn and seven vessels, two damaged stone moulds (Fig. 5.9-10), and a fragment of a heavily corroded, undefined bronze artefact.

Casting moulds in graves 42 and 153 were used to produce socketed, Lusatian-type axes (referred to as the Czarków type, variant A). The Czarków type is one of the most common forms of socketed axes in Poland (Kuśnierz, 1998, p. 33).

2.3. A razor that fits the casting mould

The razor discovered in grave no. 11 (no. 11/9) fits the casting mould from grave no. 5 (Nos. 5/1–2; Fig. 3.19). Grave no. 11 was an urn grave, lying at a depth of 0.35–0.40 m. The grave contained an urn, seven vessels, a metal razor (lying between the vessels) and fragments of

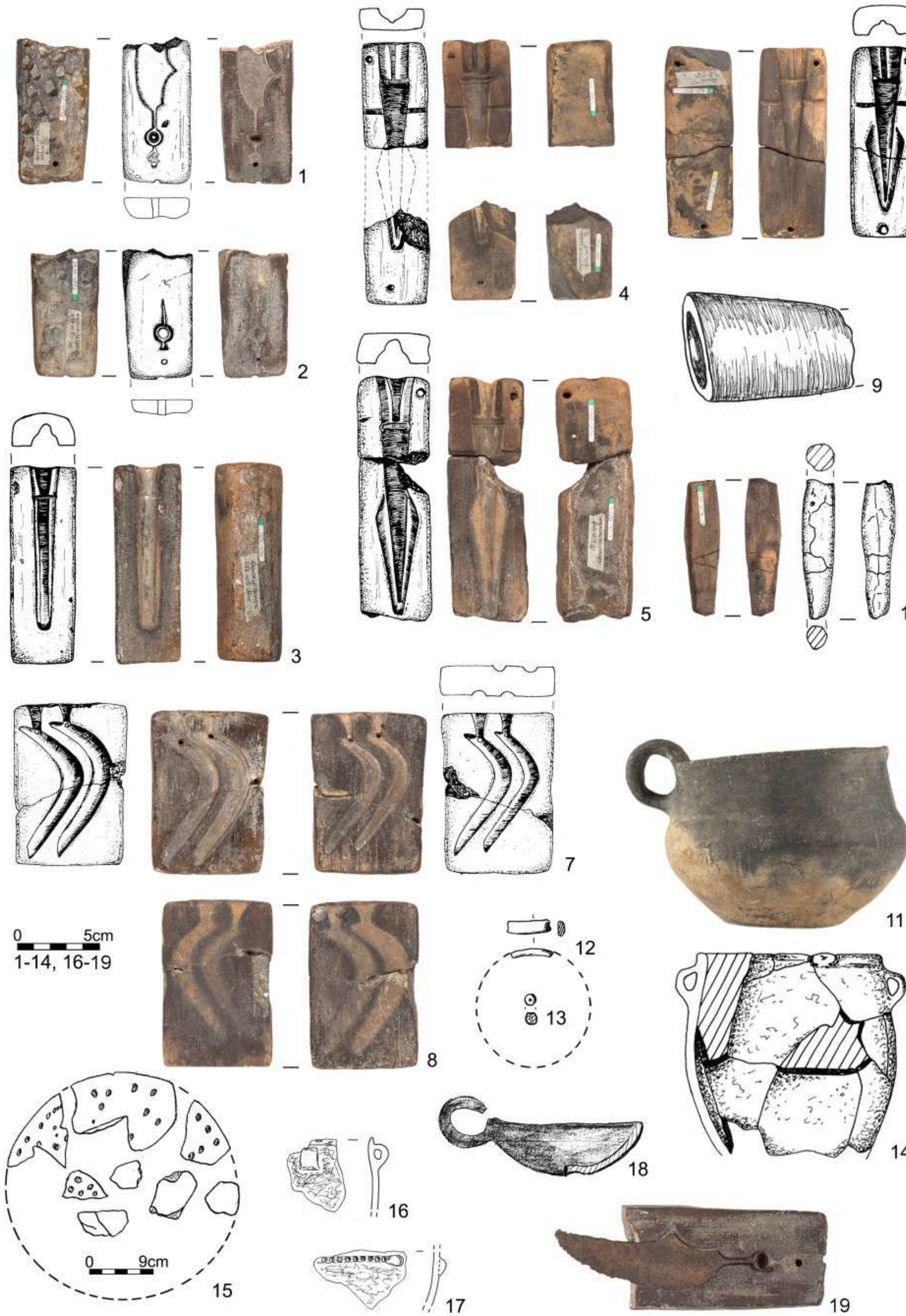

Fig. 3. Artefacts from grave 5 (1–10 – a set of metallurgical tools; 11, 13–18 – ceramics; 12 – a metal bracelet fragment). no. 19 – the razor from the grave 11 matching the negative of the casting mould. Photo and drawings: D. Berdys, M. Kiewra and Copper Museum in Legnica archive.

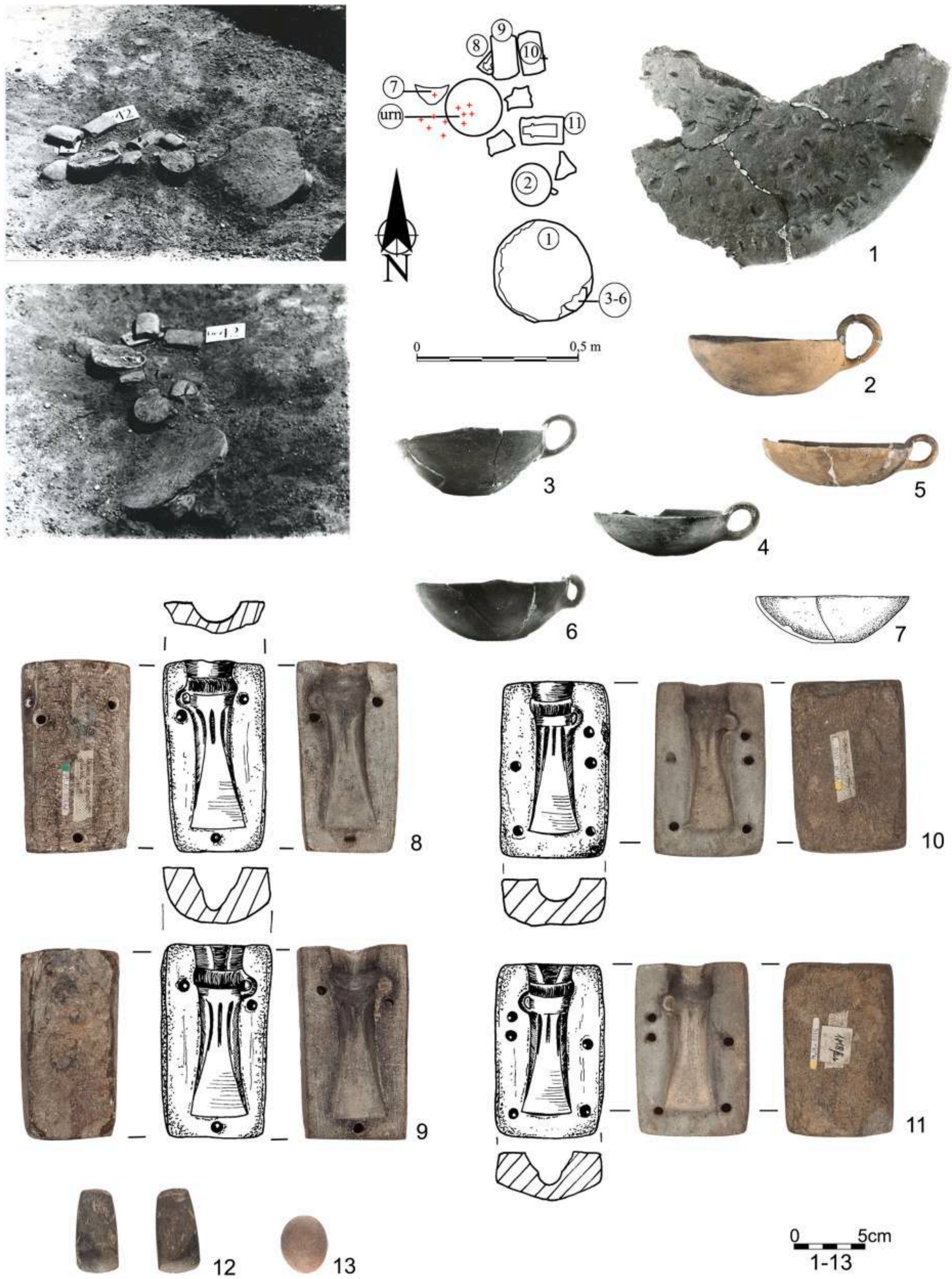

Fig. 4. Grave 42 – photographic and drawing plans, grave inventory (1–7 – ceramics; 8–11 – stone casting moulds; 12–13 – other stone artefacts). Photo and drawings: D. Berdys, M. Kiewra and Copper Museum in Legnica archive.

vessels. The human remains from the urn belong to the adult female (35–45 years old; Hałuszko, Łukowiak, 2016, 183). There were also animal remains in the urn. The razor from the grave no. 11 is a single-edged razor with a crescent-shaped blade and a handle. A. Jockenhövel describes it as the Herrnbaumgarten type (1971, 208) and M. Gedl distinguishes the Legnica variant (1988, 94). The discovery of a casting mould for the Herrnbaumgarten type razors in grave 5 and a finished cast in another grave indicates the local production of this type of grooming artefact. It is very likely that the razor was made in a casting mould discovered in the metallurgists' grave no. 5.

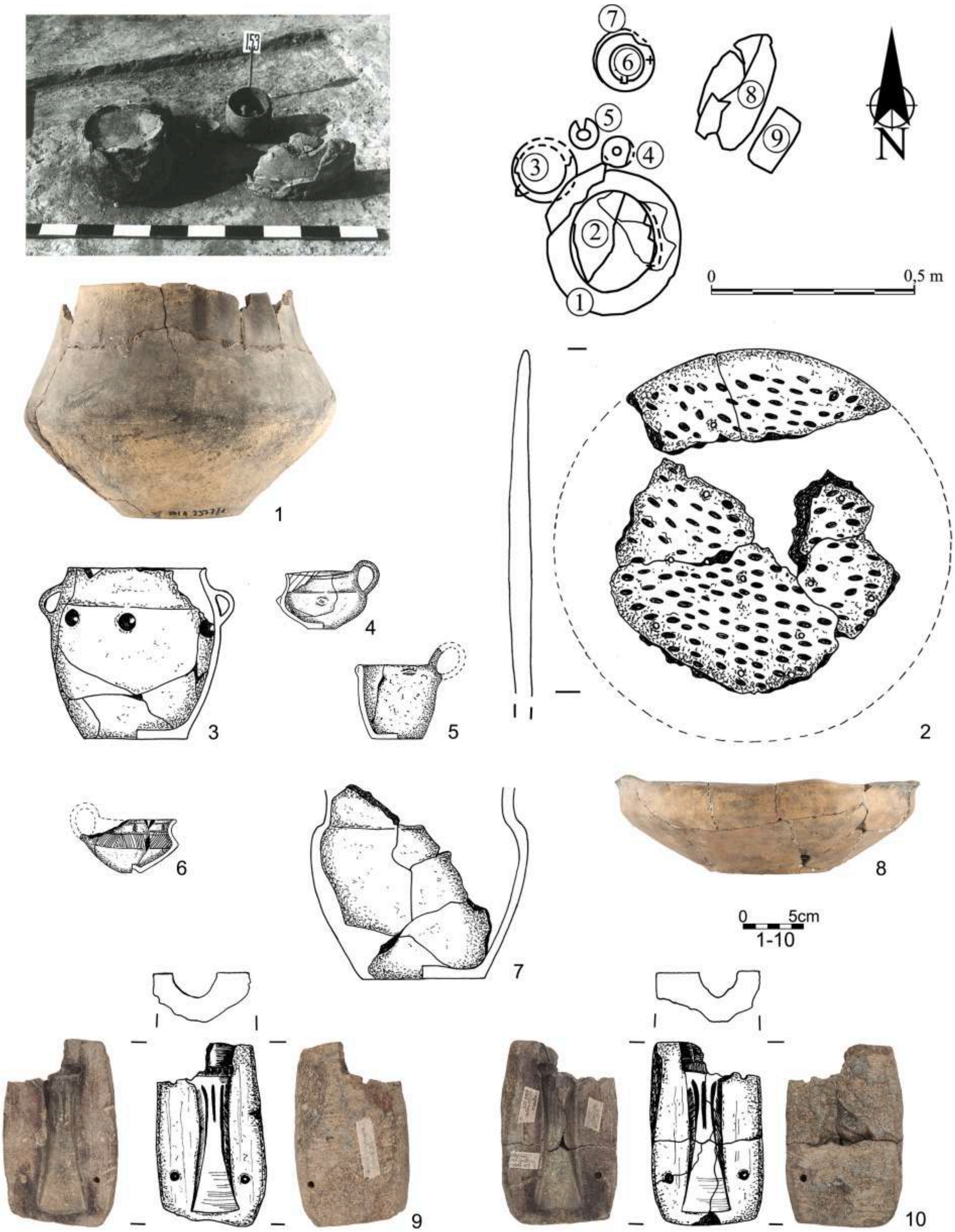

Fig. 5. Grave 153 – photographic and drawing plans, grave inventory (1–8 – ceramics; 9–10 – damaged stone casting mould). Photo and drawings: D. Berdys, M. Kiewra and Copper Museum in Legnica archive.

2.4. Metallurgical equipment deposited in graves 5, 42, 153

In all cases, the casting moulds were deposited in urn graves, not distinguished by their structure or depth. In the case of grave 5, the moulds were at least partially placed in the urn, a pot or a larger cup. In grave 42, two mould sets were deposited right next to the urn (a large vessel, most likely a vase), and the burnt remains were also found scattered between the vessels and in a ceramic scoop adjacent to the urn. The mould in grave 153 was placed next to a vessel accompanying the urn. Thus, no clear model of mould deposition in the grave could be distinguished.

The graves were equipped with ceramic vessels as well as metal and

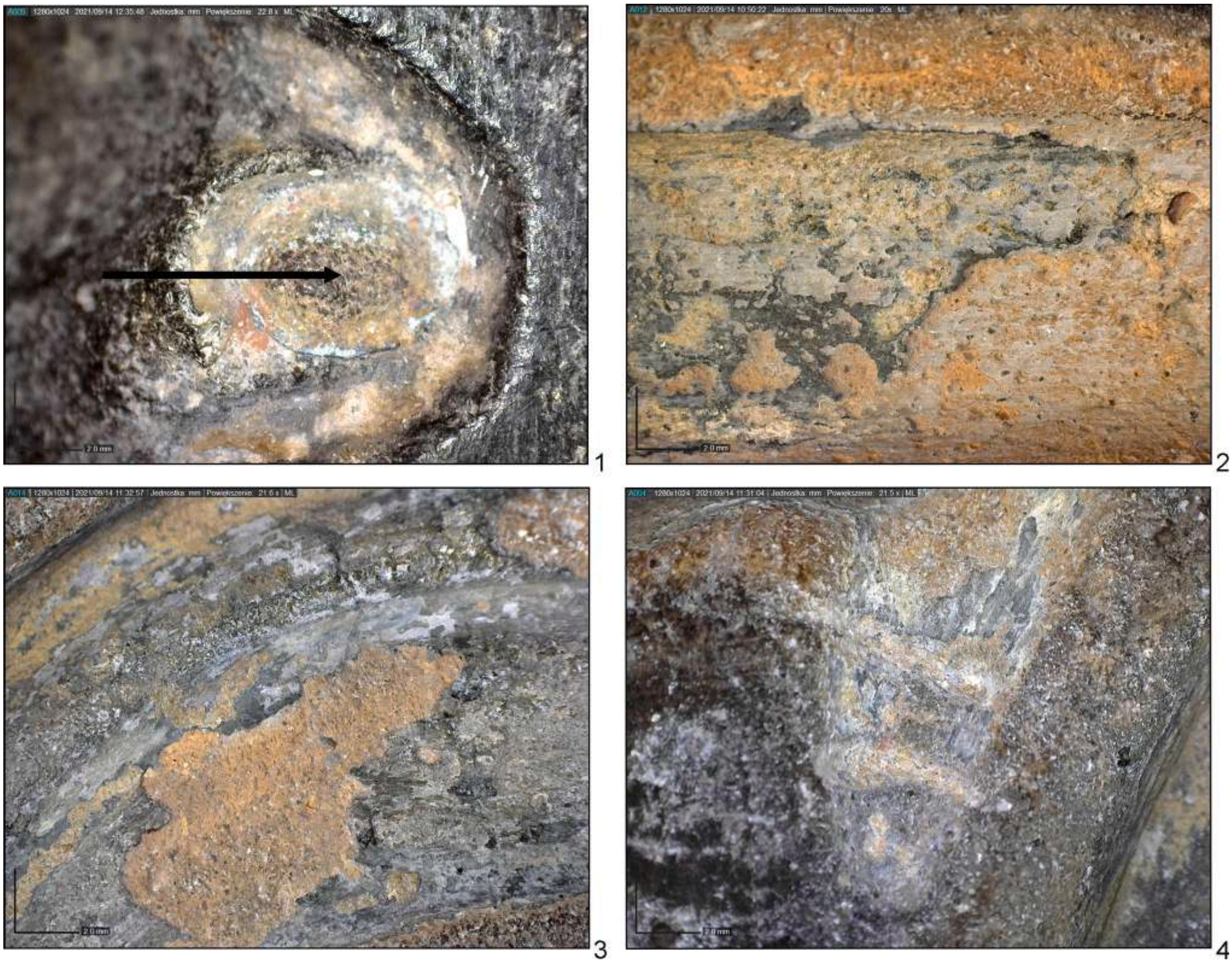

Fig. 6. Use wear and repair traces. 1 – trace of the repair on the stone casting moulds no. 42/2. 2–4 – the layers in cavities-negatives in the ceramic casting moulds no. 5/3 and no. 5/7.

stone artefacts (Table 1). The content of the grave 42 is quite distinctive: it contained 8 vessels including 6 ceramic scoops stacked on top of one another and covered with a ceramic plate. In addition, a stone axe and a stone pebble were placed in the grave. Polished stone pebbles of various dimensions, including one with an incised 'X' sign, were discovered in a 'metallurgist's grave' in Wartosław, Wielkopolska Province (Krzyszowski and Kowalski, 2019, p. 80, fig. 27). As suggested by the authors, they could have been used for smoothing and polishing surfaces of the casts. Another interpretation suggests that such pebbles were used as weights (cf. e.g. Ialongo, 2019; Ialongo and Rahmstorf, 2019). Adopting this interpretation, both casting tools and an item related to trade or exchange of the manufactured casts have been deposited in grave 42.

Casting moulds have been found in various states of preservation. In grave 5, only the chisel mould was well-preserved. The other ones, as well as the tuyere and casting core, were discovered in fragments. In grave 42, stone moulds were in good condition. In the case of the mould no. 42/1–2 one half was damaged and repaired near the negative of the axe ear. The bivalve stone mould from grave 153 is broken. This damage may have happened during the pouring of the metal into the mould, perhaps caused by the wear and tear from previous castings.

The moulds show many traces of manufacture and use. The inner surfaces of the ceramic and stone casting moulds showed the presence of regular, vertical scratches. Such traces were recorded on all stone casting moulds and are exceptionally well visible on mould no. 153/2 and mould no. 42/1. The outer surfaces of the moulds are usually less carefully prepared and are uneven and rough. In the case of the mould 42/2, there are drilling marks at the drilled hole for the centering pins. As describe above, this half has been damaged and repaired. Repairs were made by pouring metal into a specially drilled hole (marked with red circle on the fig. 4.9 and with black arrow on the fig. 6.1).

Traces associated with the pyrotechnical use of stone casting moulds include grey-black and greenish patches on the surface of the mould concavity, near the concavity, and in one case, on the outer surface (no. 42/2). The most important traces associated with the use of the moulds are thick green-black layers visible in the concavities of ceramic moulds for chisels (Fig. 6.2) and sickles (Fig. 6.3-4).

Analysis of the construction of these casting moulds allows the deduction of the methods of fixing casting cores during the production of socketed items. Moulds for the manufacturing of chisels, spearheads and axes have channels in the upper part of the negative, above the socket edge. The casting core was placed between the mould halves and stabilized by putting the halves together. Its upper part could have channels through which metal was poured, as in the case of casting cores from Ķivutkalns in Latvia (Podėnas and Čivilytė, 2019, Fig. 2) or Castro da Senhora da Guia de Baiões in Portugal (Senna-Martinez et al., 2020, Fig. 4.f). The use of such a casting core causes the presence of characteristic 'knobs' on the socket edge of the finished casts. We can notice that in the case of the mould for spearheads, the channel in one of the halves is funnel-shaped (no. 5/5; Fig. 3.5) while the second is straight and served as a gas vent (no. 5/4; Fig. 3.4). We do not observe such a solution in the case of axe moulds, because all the analysed stone moulds have a funnel-shaped pouring channel only in one half of the mould. Casting moulds for making both types of spearheads have additional transversely cut grooves that extend crosswise in the upper part of the socket, indicating a casting core mounting system for forming the socket (Bingelli, 2011; Trommer and Bader, 2013).

The ceramic casting mould for the production of the knobbed sickles consists of two parts. One of them has the negatives of two sickles on both sides, while the other is flat on all sides. The flat part served as a cover during the casting of two sickles, as evidenced by visible black deposit in the shape of sickles (a result of high temperature). The construction of the sickle mould indicates the possibility of its multiple use, at least twice. It is worth noting that in the case of four sickles negatives, one of them has so-called casting marks on the base (Fig. 6.4).

3. Analytical methods

3.1. Analyses of the metals and metal remains in the casting moulds

The monographic publication of materials from the cemetery in Spokojna Street, Legnica (Nowak, Stolarczyk 2016) includes a wide range of analyses of stone and ceramic csting moulds from the graves nos. 5, 42 and 153 (Garbacz-Klempka et al. 2016; Gunia 2016a; Gunia 2016b; Miazga 2016). The results already published provide large amount of information related to the identification of the type of raw material used for manufacturing casting moulds, as well as the technology of their manufacturing and use.

The discovery of such a numerous set of items related to bronze metallurgy provides a considerable body of material for further analyses (listed in Table 2). In the present article, we focus the anlysis of metal residues inside casting moulds (Fig. 6.2-3) in order to identify the type and provenance of the metal used in them. We also tested a droplet of metal from mould 42 (Fig. 6.1) and a razor made in one of the moulds (Fig. 3.19).

3.1.1. XRF analyses

Samples from the metal droplet poured into the mould no. 42/2 and from the metal razor were taken by drilling with a 1.6 mm diameter HSS steel drill. In addition, ceramic and stone casting moulds and the ceramic casting core were analysed only to show whether the surfaces of the casting tool kit were in contact with the casting alloy. We selected three different parts of the casting moulds for analysis:

- The outer part of the mould was analysed to provide information about the chemical composition of the background, that is, the metals present in the raw material from which the moulds had been made.
- The inner, flat contact surfaces between the two parts of the mould were analysed, to identify the expected remains of the metal poured into the mould.
- The third analysed surface was in the cavity - negative of the artefact to be cast - where, if the mould had been used for casting, there should also be traces of the metal.

The analyses were performed using a Spectro Midex table spectrometer, with an X-ray tube with a molybdenum anode and a silicon drift detector (SDD) with Peltier effect cooling. The measuring system was equipped with an imaging system (a CCD camera with 20 magnification), enabling analysis of a precisely selected area of approx. 0.7 mm in diameter. The sample chamber with the maximum dimensions of 52 × 31 × 16 cm allowed analyses of the whole artefacts.

3.1.2. SEM EDS analyses

Two samples from the residues in the inner hollows, negatives of the shape of artefacts, were scraped off the mould from grave no. 5 (Nos. 5/3 and 5/7). Metal samples were prepared in the same way as for XRF analysis.

Several analyses using SEM-EDS were undertaken. Tests of samples were carried out with an EDS spectrometer (Oxford Instruments) coupled with a Hitachi Tabletop TM4000 Scanning Electron Microscope, using 15 kV excitation energy and selecting test sites using from × 30 to × 300 magnification of the samples. The research was carried out in the Laboratory of Archaeometry and Conservation of Archaeological

Table 2
Metallurgy-related items from the Legnica cemetery. Mus. Inv. Nos. – inventory numbers in the Copper Museum in Legnica; Nos. – numbers in the text; L – length; W – width; T – thickness; Di – diameter.

Grave	Mus.Inv. Nos.	Nos. in text	Item related to casting	Casting shape	Dimensions	Figure	Analysis
5	ML/A –1081/1a	5/1	Mould, half	Razor	L: 11 cm, W: 5.5–6 cm, T: 1.5–2.2 cm	3.1	ED-XRF
5	ML/ A – 1081/1b	5/2	Mould, half	Razor	L: 11 cm, W: 5.5–6 cm, T: 1.5–2.2 cm	3.2	ED-XRF
5	ML/A – 1081/2	5/3	Mould, half	Chisel	L: 16.6 cm, W: 5.7 cm, T: 3 cm	3.3	ED-XRF, SEM-EDS, MC ICP MS
5	ML/A – 1081/3a	5/4	Mould, half	Spearhead	L: 26 cm, W: 6.2 cm, T: 2,5 cm	3.4	ED-XRF
5	ML/A – 1081/3b	5/5	Mould, half	Spearhead	L: 26 cm, W: 6.2 cm, T: 2.5 cm	3.5	ED-XRF
5	ML/A – 1081/4	5/6	Mould, half	Spearhead	L: 17.2 cm, W: 6 cm, T: 2.5 cm	3.6	ED-XRF
5	ML/A 1081/5a	5/7	Mould, half	Two sickles	L: 14.4 cm, W: 9.6 cm, T: 2.7 cm	3.7	ED-XRF, SEM-EDS, MC ICP MS
5	ML/A – 1081/5b	5/8	Mould. half(a „lid")	Two shapes of sickles	L: 14.7 cm, W: 9,5 cm, T: 2,6 cm	3.8	ED-XRF
5	ML/A – 1081/6	5/9	Casting tuyere	–	L: 10 cm, Di: 4.5–6.5 cm, wall T: 1.3 cm	3.9	–
5	ML/A – 1081/7	5/10	Casting core	–	L: 8.3 cm, Di: 2.1–3.2 cm	3.10	ED-XRF
42	ML/A – 1118/1	42/1	Mould, half	Socketed axe	L: 13.5 cm, W: 7.6 cm, T: 6.4 cm	4.8	ED-XRF
42	ML/A – 1118/2	42/2	Mould, half	Socketed axe	L: 13.5 cm, W: 7.6 cm, T: 6.4 cm	4.9	ED-XRF, SEM-EDS, MC ICP MS
42	ML/A – 1118/3	42/3	Mould, half	Socketed axe	L: 12.1 cm, W: 7.7 cm, T: 6.8	4.10	ED-XRF
42	ML/A – 1118/4	42/4	Mould, half	Socketed axe	L: 12.1 cm, W: 7.7 cm, T: 6.8	4.11	ED-XRF
153	ML/A – 2377/9	153/1	Mould, half	Socketed axe	L: 15 cm, W: 9.5 cm, T: 7.5 cm	5.9	ED-XRF
153	ML/A – 2377/10	153/2	Mould, half	Socketed axe	L: 15 cm, W: 9.5 cm, T: 7.5 cm	5.10	ED-XRF
11	ML/A – 1087/9	11/9	–	Razor	L: 13.8 cm, W (max): 3.4 cm, T: 0.1 cm	3.19	ED-XRF, SEM-EDS, MC ICP MS

Artefacts of the Institute of Archaeology at the University of Wrocław.

3.1.3. Lead isotope analyses (LIA)

Samples of the metal residues from the moulds Nos. 5/3, 5/7, of metal from mould no. 42/2, and razor no. 11/9 taken for the SEM EDS analyses were sent for the lead isotope analysis to the Isotope Laboratory, School of Earth Sciences, University of Melbourne. The lead isotope ratios were measured using a Multicollector-Inductively Coupled Plasma Mass Spectrometer (MC ICP MS). Powdered samples and metal drillings, as supplied, were weighed into 12 mL Savillex beakers and reacted with 2 mL of hot 7 M HNO_3 overnight. The solutions (with occasional undissolved specks) were dried in HEPA-filtered air. Lead was extracted using a single pass on a 0.2 mL bed of AG1-X8 (100–200 mesh) anion resin with the HBr-HCl technique.

After strong dilution, lead isotope ratios were measured on a Nu Plasma MC ICP MS over the course of 2 separate sessions, using thallium doping to correct for instrumental mass bias (Woodhead, 2002). The thallium doping technique is expected to yield $iPb/^{204}Pb$ results that have an external precision of 0.04–0.08 % (2std dev). This is confirmed by the results for the SRM 981 Pb standard, analysed in the same sessions. Seven analyses of lead extracted from the BCR-2 reference basalt show greater variability, but the average is in excellent agreement with the GeoREM-preferred compositions (http://georem.mpch-mainz.gwdg.de) and is consistent with the long-term laboratory average and with TIMS reference data. Estimated lead concentrations (ppm Pb*) are based on sample weights, dilutions, and signals in the mass spectrometer. They are minimum values (some lead was lost during processing) and of low precision (R. Maas and J. Woodhead, University of Melbourne, personal communication).

4. Results

4.1. Results of the XRF analyses of the casting moulds and the razor

The grey-black or greenish patches and thick green-black layers on the surface of the ceramic and stone moulds were analysed non-destructively using ED XRF. The considerable depth of the negatives of tool shapes makes it difficult to see the exact positions of the irradiated areas. Despite these difficulties, the differences in the intensities of the X-ray lines of copper, tin and lead peaks allowed comparisons in the quantity of these metals present in the three analysed parts of the moulds (outer surface, flat inner surface, and mould cavity).

This procedure enabled the detection of higher quantities of metals than in the body of the material not only inside the negative cavities, but also on the contact surfaces of all the moulds, indicating the penetration of metals into the mould structure. In the case of stone mould no. 42/2, an increased presence of copper was also identified on its outer surface.

The casting core is the only item analysed in which the ED XRF has not detected any metals above the background level found in its ceramic body.

Greenish compact layers identified inside the negative cavities of the chisel moulds (no. 5/3; Fig. 6.2) and the sickle moulds (no. 5/7; Fig. 6.3, 4) were also analysed. In the case of the former, in the analysed micro-area the lead peaks significantly exceeded the intensity of copper (Fig. 7.1). The analyses of the dark green layer in the sickle negatives also showed the presence of extremely high peaks of lead, significantly

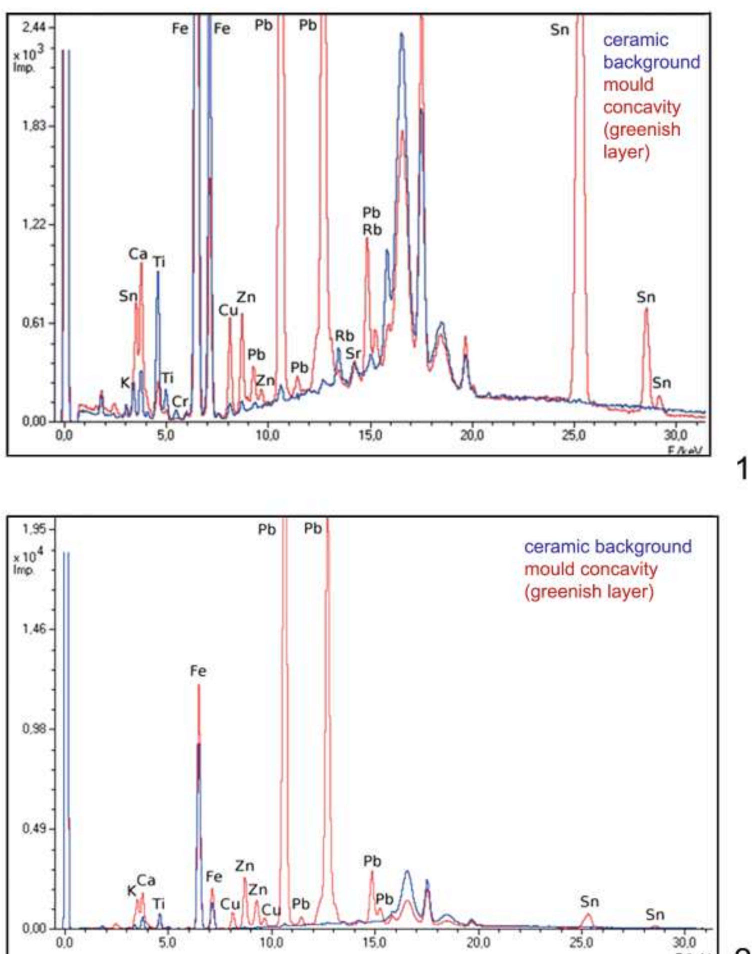

Fig. 7. ED XRF spectra showing elevated signals, e.g. for Pb in the layers inside the casting moulds negatives. 1 – chisel mould (no. 5/3); 2 – sickle mould (no. 5/7)

Table 3
Results of the analyses (SEM-EDS) of chemical compositions of the samples taken from the metal residues (R) found in the chisel (no. 5/3) and sickle (no. 5/7) casting moulds' negatives (values in %wt).

Sample no.	CuO	SnO_2	MnO	FeO	ZnO	As_2O_3	Ag_2O	Sb_2O_3	PbO	SO_2	MgO	Al_2O_3	SiO_2	P_2O_5	K_2O	TiO_2	Na_2O	CaO
5/3 R	0.5	14.2	1.1	4.8	0.7	0.80	0.9	2.6	3.0	1.3	1.3	19.8	43.6	0.5	2.2	0.8	1.1	0.8
5/7 R	1.0	27.9	0.5	7.7	1.0	0.3	0.5	1.9	5.4	5.3	0.8	12.9	25.5	0.4	1.9	1.1	0.7	5.2

Table 4
Results of the analyses (SEM-EDS) of chemical compositions of the metal samples taken from the mould no. 42/2 (metal droplet inside the mould) and from the bronze razor from the grave 11 (values in %wt).

Sample no.	Cu	Sn	Mn	Fe	Zn	As	Ag	Sb	Pb	S	Co	Ni	Te	Au	Bi
42/2	92.2	0.4	0.1	0.3	0.0	0.6	0.8	1.7	1.0	0.2	0.2	0.6	0.6	<0.4	<0.4
11/9	89.7	5.7	0.2	0.2	0.1	0.2	0.3	0.6	0.4	0.2	0.2	0.6	0.1	<0.4	<0.4

higher than the peaks of copper (Fig. 7.2). This effect has been most likely created by a significant ability of copper to form soluble compounds during the deposition, that have been leaching away reducing the apparent amount of this metal.

In the case of the metal droplet from the mould no. 42/2 and the metal from the razor no. 11/9, it was possible to obtain semi-quantitative results. The metal from the mould contains 92% of copper, 2.2% of lead, 1.4% of antimony, 0.6% of silver, and 0.2% of tin. The razor was made of bronze, containing 91% of copper, 5% of tin, and small amounts of lead (0.5%) and antimony (0.5%).

4.2. Results of the SEM EDS analysis

The SEM EDS analyses were aimed at quantifying the composition of the layers inside the casting moulds for sickles and chisels, the metal droplet from the casting mould no. 42/2 and the metal from the razor no. 11/9. The analytical results are semi-quantitative because the very small size of the drillings prevented their suitable positioning in the resin block to obtain uniformly flat surfaces. The results are presented in Tables 3 and 4.

The SEM EDS analysis of the metal sample from the mould no. 42/2 shows a high content of copper at 92.2%, as well as the presence of some tin at 0.4% and comparatively high lead at 1%, The analysis of the razor no. 11/9 gave the result as 89.7 % copper and 5.7 % of tin. The lead content in this artefact is about 0. 4%.

The lead contents in the samples taken for analyses from scrapings from the moulds (5/3 and 5/7) have been also analysed in the Department of Geology at the University of Melbourne, by isotope dilution when dissolving the aliquots for lead isotope analyses. The lead contents measured by this method were 0.8% for sample 5/3 and 5.8% for sample 5/7. These results compare quite well with the semi-quantitative SEM analyses that gave 3% and 5.4% respectively. The lead content in the samples of metals measured by the isotope dilution was approximately 0.8% for the metal droplet no. 42/2 as compared with 1% by SEM, while for the razor (no. 11/9) isotope dilution gave a lead concentration of 0.24% and SEM about 0.4%. (Tables 3 and 4). Other significant minor elements found in the analysed samples of copper-based metal include arsenic, antimony, silver and nickel.

4.3. Results of the lead isotope analyses (LIA)

Four samples of metal used by the Bronze Age metallurgists from the cemetery in Legnica were analysed for their lead isotope compositions. They included scrapings of the metal residues from two moulds from the Grave 5 (Nos. 5/3, 5/7) and the droplet of metal inside the mould from the Grave 42 (no. 42/2). Additionally, a sample of metal from the bronze razor with the looped handle from Grave 11 (no. 11/9) was also analysed. The results of lead isotope analyses in these samples are presented in Table 5.

To identify possible ore deposits that might have supplied copper for metallurgical activities on this site these lead isotope ratios were compared with the database of all published data for the European ore deposits (about 9000 sets of ratios). In view of the chemical compositions of these metals and metal remains, the ore deposits that can be considered, not only must contain copper and lead ores consistent with their lead isotope ratios, but also some of the ores must have been of the Fahlerz type, containing arsenic, antimony and silver. Two deposits that fulfil these qualifications are the ones near Freiberg and Zschopau in the Erzgebirge (Niederschlag et al. 2003; Bielicki and Tischendorf, 1990) and in the Slovak Ore Mountains (Schreiner 2007) (Figs 8.1 and 8.2). Additionally, the lead isotope compositions of these four samples are also consistent with the ores from the Inn Valley in North Tyrol (Höppner et al. 2005) (Fig. 8.3). However, this Fahlerz ore deposit seems less likely as a source of the metals cast in Legnica, because of a considerably lower lead content (<0.1%) in all analysed prehistoric artefacts consistent with the origin from these ores (Höppner et al. 2005. Tab. 1, p. 295–6). Also, as can be seen on the $^{208}Pb/^{206}Pb$ plot on Fig. 8.3 only one of the analysed samples has lead isotope ratios fully consistent with the Fahlerz ores from the Inn Valley. It should be mentioned that the lead found in the two moulds from Grave 5 is also isotopically similar to the ores from the Massif Central in southern France (Brevart et al. 1982; Baron et al. 2006) and the Jaen area in southern Spain (Stos-Gale

Table 5
Lead isotope data for lead in the metal residues found in the casting moulds from the cemetery in Legnica, from the metal droplet inside the mould 42/2 and from the razor with a handle (no. 11/9). The concentrations of lead in the analysed samples were measured using the isotope dilution method (1 ppm = 0.0001%).

Sample no.	Lead (ppm)	$^{208}Pb/^{206}Pb$	$^{207}Pb/^{206}Pb$	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb$	$^{208}Pb/^{204}Pb$
5/3 R	7989	2.0985	0.8524	18.347	15.640	38.500
5/7 R	58,722	2.1020	0.8545	18.305	15.642	38.478
42/2	7769	2.09411	0.85239	18.357	15.648	38.442
11/9	2416	2.08903	0.84938	18.425	15.650	38.489

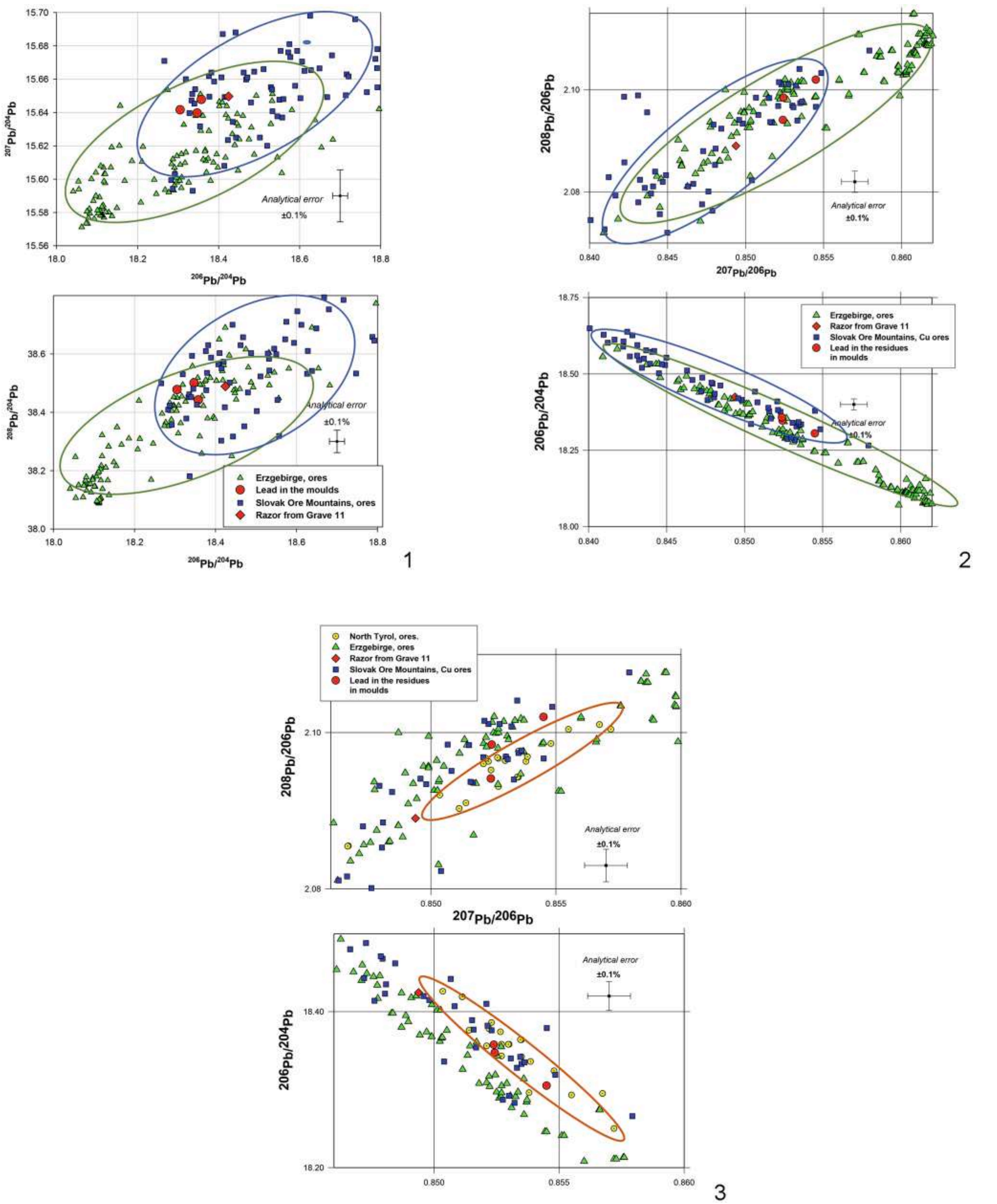

Fig. 8. Lead isotope data for Erzgebirge, the Slovak Ore Mountains and the North Tyrol compared with lead from the residues in the three casting moulds and a razor, a from the LBA Legnica cemetery.

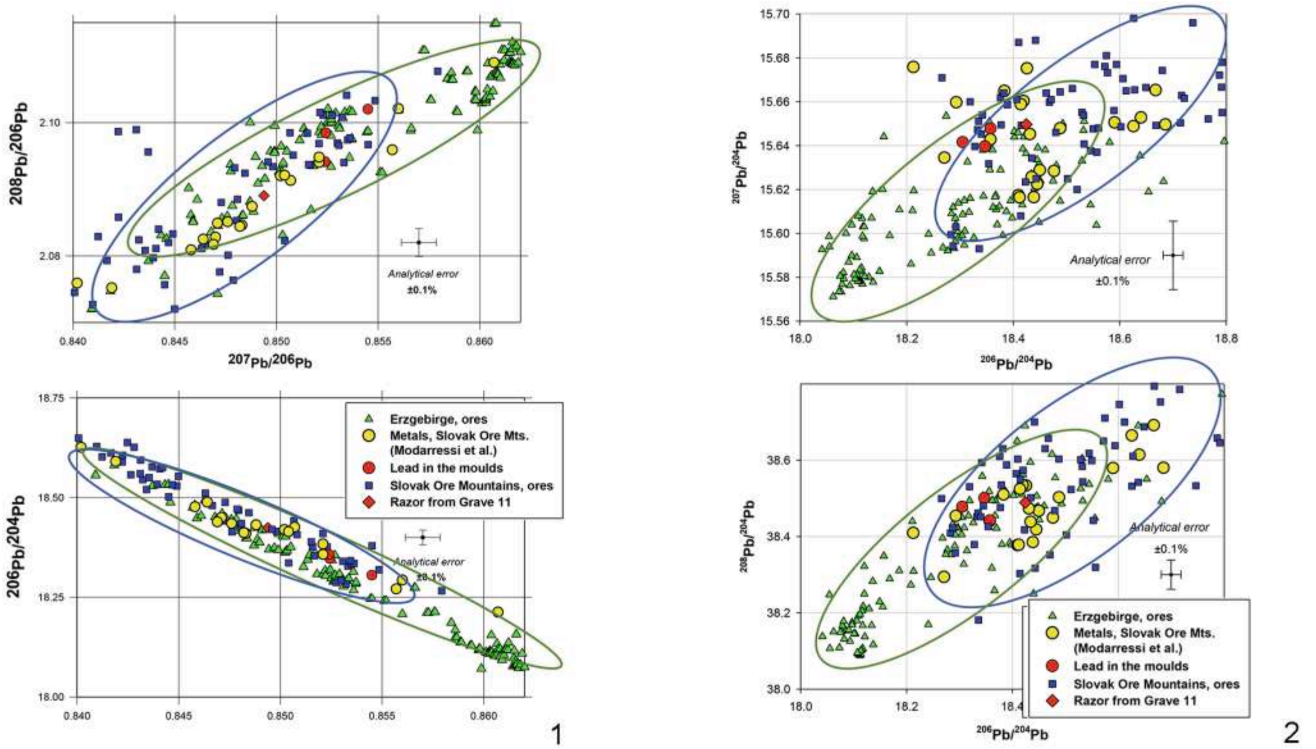

Fig. 9. Comparisons of lead isotope data of the copper-based ingots and bars from the survey in the Slovak Ore Mountains (Modarressi et al., 2016) with those in the moulds and the bronze razor from the LBA cemetery in Legnica.

et al. 1995). The bronze razor is also isotopically consistent with the ores from Le Valais in Switzerland (Cattin et al. 2011). The ore deposits in the Massif Central contain lead ores, antimony minerals, and copper, but there is no documented evidence of copper exploitation in the Late Bronze Age. The same can be said about the deposits in Le Valais. The lead isotope compositions of the ores from southern Spain are only consistent with the lead in mould scrapings from Grave 5, and since all four lead isotope ratios measured for the metals from this cemetery seem to form a group, the Spanish origin of only two of them seems unlikely.

5. Discussion

5.1. Using the metallurgical toolkit

Casting moulds bear traces of their production and use-wear. Use-wear traces visible on the ceramic and stone moulds are different. Traces of use on the stone ones are grey-black and greenish patches in the area of negatives of the shape of artefacts. In the case of ceramic casting moulds, there are thick green-black layers. These are the remains of the metal poured into the mould, which has reacted with the silica from the clay (Kearns et al. 2010, 51–52). These layers are best preserved on moulds 5/3 and 5/7 (Fig. 6.2-4).

The casting core is the only item analysed in which ED XRF has not detected any metals above the background level found in the ceramic body of this artefact. Therefore, the analyses could not prove its use in a metallurgical process. Most likely, this was a semi-finished product that had been deposited in the grave. The crack in this object indicates that it was damaged during the firing (for information on the production of clay cores, see Drescher, 1957, pp. 63–65).

The observed traces are not only related to the use, but also to the repair of the casting moulds. In the case of no. 42/2, it was a repair of the damaged part forming the loop in the casting. The metal poured was almost pure copper with a slight contamination of tin and lead. Contamination with antimony, arsenic and silver are also visible. Lead, along with tin, improves the hardness of the copper alloy, but it lowers its melting point. If we decided that the repair was supposed to allow the mould to continue to be used, then the use of tin–lead bronze was not the best choice. We can also assume that lead and tin were naturally occurring impurities in copper. In this case, the metallurgist using it might not have known about the contaminants that worsened its properties.

Such repairs of the casting moulds are known, but are still a relatively rare phenomenon. They were most often made with metal clamps bonding the damaged elements, as was the case with moulds for axes from the stone casting mould hoards from Pobit Kamak in Northeast Bulgaria (Leschtakow, 2016, Fig. 41.2–3), or from Želiezovce in Slovakia (Novotná, 1970, 101, fig. 45.847–848). Two parts of a mould for a knife from the hoard from Waldsieversdorf in eastern Germany were broken in three parts and subsequently repaired with a liquid metal that held together the broken parts (Götze, 1920, p. 70, Fig. 2.3-4; Sprockhoff, 1937, fig. 27.7, 10; 28.9, 11). Interestingly, the repairs done on the mould no. 42/2 are similar to the repairs on the stone mould discovered in a similarly dated grave in the cemetery in Piekary, Lower Silesia, located 30 km away (Seger, 1909, pp. 17–18). It is possible that the moulds were used by a group that knew each other, originated and functioned in a similar tradition (casting tradition?) and had knowledge of such remedial activities.

5.2. Identification oft he the metal used in the casting moulds

Kearns et al. (2010, pp. 55–56) showed experimentally that thanks to the XRF analysis of the mould negatives, it is not possible to determine the exact alloy poured into the casting mould. In case of the artefacts from the Legnica cemetery, ED XRF analysis confirmed the usage of the casting moulds,but we can only conclude qualitatively that the alloying constituents, copper, tin and lead are present.

The thick green-black layers inside the cavities – negatives of the moulds no. 5/3 and 5/7 were additionally sampled and tested with the

SEM EDS in order to check their elemental composition. In both cases, a very low content of copper (0.5–1.0%) is observed, and the tin and lead levels are high. It has been proven experimentally that when using tin bronze, copper contamination is visible and the tin is almost undetectable. This is combined with the low reactivity of silica from the ceramic mass with tin oxide (Kearns et al. 2010, 54). In our case, there is a high amount of tin and very little copper. According to the cited authors 'an explanation for this may lie in the ability of lead oxide to promote the oxidation of other base metals and to form fusible compounds with them. Furthermore, the lead oxide is likely to form a viscous glass phase which may facilitate the mechanical retention of tin oxide' (Kearns et al. 2010, 55). It follows that tin–lead bronze was cast in the analysed moulds, possibly from the same crucible charge. The addition of lead in the casting alloy binds the tin. Therefore, both tin and lead are strongly represented in moulds. The lack of copper should be explained by its chemical activity, strong corrosion, and washing out while the moulds remain in the soil.

The discovery of a casting mould (no. 5/1–2) and a finished object probably cast in it (no. 11/9) in two separate graves in one cemetery is an exceptional phenomenon in the Late Bronze Age. The analysis of the finished cast and residues from the casting moulds, which could be filled with the same crucible charge, allows for comparisons. But we have to be careful with such comparisons according to the above mentioned differences in the chemical composition of the original alloy poured into the mould and the composition of the layers from the casting mould negatives.

The elemental composition of the residues from the casting mould negatives no. 5/3 and 5/7 and the razor no. 11/9 shows that a different type of casting alloy was used. It is clearly most visible from the lead content, which in the razor is in trace amounts. If a tin–lead alloy was used, both tin and lead would be present in high concentrations. For this reason it can be assumed that the razor was made of tin bronze. This is in contrast to the casting moulds where high tin and lead content indicates the use of tin–lead bronze.

5.3. Origin of the metal

The residues identified inside the moulds for chisels (no. 5/3) and sickles (no. 5/7) as well the metal samples from the mould 42/2 and the razor 11/9 were used to determine the provenance of the metal poured into the moulds.

On the grounds of elemental and lead isotope compositions, these four samples are consistent with the origin from the ores in the deposits in the Slovak Ore Mountains and/or the Erzgebirge. All analysed samples contain tin, a mineral which is not very common in European ore deposits. The most significant deposits of tin ores in Europe are in Cornwall, the Iberian Massif, and the Erzgebirge (Brügmann et al. 2017, Fig. 1, p. 104). The first two were most certainly exploited in the Bronze Age. So far, it is not clear when and to what extent the polymetallic deposits in Erzgebirge were mined (Niederschlag et al., 2003), although it is increasingly thought that tin has been extracted there since the Bronze Age (Nessel et al., 2018). This theory has been strongly supported by the evidence of the extraction of tin ore in placer mining at Schellerhau in the Erzgebirge. ^{14}C dating of charcoal from this site has revealed the presence of human activity in this area in the Early and the Late Bronze Age (Tolksdorf et al., 2020). Besides lead and tin, the Erzgebirge deposit also contains copper and silver ores. Minerals containing antimony are not common in the Erzgebirge, but amongst the analyses of copper ore samples published by Niederschlag (et al. 2003, Table 7, p. 91) there are two specimens (nos. 222 and 225) that contain several per cent of antimony, as well as significant amounts of lead and silver.

As can be seen in Figures 8.1 and 8.2, the lead isotope ratios of the analysed copper ores from the Slovak Ore Mountains to a large degree overlap with a part of the range of lead isotope ratios published for the lead and copper ores from the Erzgebirge. The three analysed remnants of metals from the moulds from the LBA cemetery in Legnica fall closely together on the upper edge of the range for the ores from Slovakia and in the middle of the range for the ores from the Erzgebirge. Two of them have very high lead and tin content and no other high impurities, and therefore seem chemically consistent with the ores from the Erzgebirge. The mould for a socketed axe from grave 42 contains very little tin, but an large amount of antimony and also some lead. This chemical composition can represent either of these two ore deposits but can also be a result of a mixture of the ores from both regions since lead is not a common impurity in the ores from the Slovak Ore Mountains and antimony is not so common in the Erzgebirge.

The ore deposits in the Slovak Ore Mountains are generally regarded as the major copper ore deposits exploited in Central Europe in prehistoric times. The periods of ore exploitation in the Slovak Ore Mountains are not clearly defined yet; it is certain that the copper ores there were exploited since the 5th millennium BC and in the Late Bronze Age, but copper production there in the later periods is still a topic of research (Modarressi-Tehrani et al. 2016, 110).

Unfortunately, there are few published analyses of LBA bronzes from central Europe, but in Figures 9.1 and 9.2, the lead isotope compositions of the metals from Legnica are compared with a group of copper-based metal bars and ingots found during the surveys in the mountains north of the Hron in Slovakia (Modarressi-Tehrani et al. 2016). From the lead isotope plots it seems possible that all of the analysed artefacts from Legnica represent metal from the same deposit as the ingots. Most of the ingots published by Modarressi-Tehrani (et al. 2016) are of uncertain date, but some of them are associated with Bronze Age settlements. The chemical compositions of these finds are varied, with 0.02–7% of antimony, 0.003–7% of lead and $<$ 0.05% of silver. Only three of these ingots contain added tin, but one of the bars (no. 934) that contains 13% of tin (together with about 1.7% of arsenic, 2% of antimony, and 6% of lead) has lead isotope composition very similar to the bronze razor with looped handle from Grave 11 (11/9) in the LBA cemetery in Legnica. This razor contains only about 0.4% of lead, 0.6% of antimony and 0.3% of silver, therefore the chemical composition of this razor is rather different to the bar 934. The bronze bar no. 934 was found at a settlement site in the Špania Dolina-Pieski, where prehistoric sherds were also found, but an accurate dating of this bar from Slovakia is not possible (Modarressi-Tehrani et al. 2016, 111-112). Further, there is a significant difference in the content of silver in all the ingots from Hron and the metals from Legnica. While the silver content of the four analysed samples from the metallurgists‘ graves is between 0.3 and 0.9%, the ingots contain in all cases an order of magnitude less of this metal (Modarressi-Tehrani et al. 2016, Table 1, p. 114).

In conclusion, the lead isotope and chemical analyses of these four metal samples from the LBA cemetery in Legnica indicate that multimetallic ores from the Erzgebirge in Saxony are the most likely source of these metals, with a possibility that they could be indeed made of metals originating either from the Erzgebirge or Slovak Ore Mountains, or a mixture of these ores. However, the presence of tin, that occurs only in the Erzgebirge Mountains, not in the Slovak ore Mountains, supports an origin from the Erzgebirge.

Finally, it needs to be mentioned that these metals used in Lower Silesia in the LBA have very different lead isotope characteristics from the lead–zinc-silver ores in an important deposit in south-western Poland near the town of Olkusz, where silver and lead mining have been active in the later periods (Fig. 10).

The identification of lead consistent with an origin in the Erzgebirge in the moulds for casting bronze artefacts in western Poland gives further support to the possibility of the use of tin from Erzegebirge in this region in the Bronze Age. These are the first results indicating the direct use of metals from these deposits in the casting process, but many more lead isotope and chemical analyses of tin bronzes from this region of Europe are needed to confirm this hypothesis.

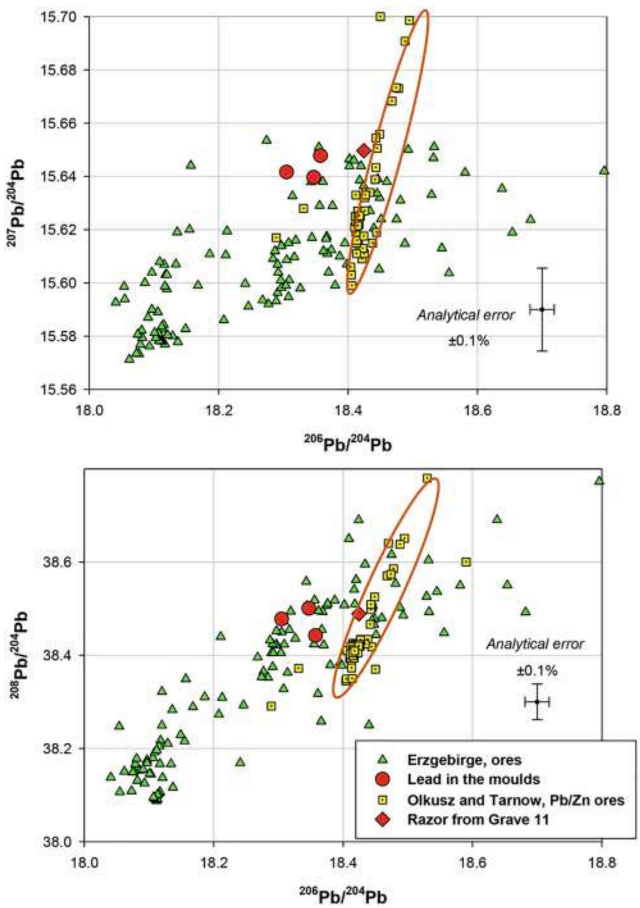

Fig. 10. Comparisons of lead isotope ratios of zinc-lead deposits from Tarnowskie Góry and Olkusz (OXALID) with lead in metals from the cemetery in Legnica.

6. The presence of casting tools in the sepulchral rite

Due to the lack of characteristic determinants, the only indicative anthropological analysis of the 'metallurgists' graves' from Legnica was conducted for grave 153. There, the burnt remains of an adult, aged 20–30, probably male, were placed in a large vase (Hałuszko and Łukowiak, 2016, p. 207). The deposition of metallurgy-related artefacts, mainly in the graves of males, was described by A. Jockenhövel (2019, p. 14). Unfortunately, for the Late Bronze Age, we still have too little data from anthropological analyses, and determining the gender solely on the basis of 'male' equipment is not accurate enough (see e.g. the female grave no. 11 with razor) to clearly state male domination in such graves.

The gender of a person buried with casting tools is indirectly related to the metallurgist's social role and status in the community. Various researchers describe metallurgists differently, from a wandering specialist to a stigmatized stranger, a person closely associated with the community or excluded from its life, a representative of the elite, a ruler with a high status or an intermediary in commercial exchange, a character worshiped equally with deities or even a shaman and proto-scientist bearing secret knowledge, a liaison between two worlds (recently: Molloy and Mödlinger, 2020, additional literature there). Attempts were made to correlate this varied image with grave finds. Most often, casting tools are considered the private property of the deceased person, which they used in their life. Individuals buried in graves are considered skilled professionals or artisans, using metallurgy as a source of benefits or the means necessary for survival. As specialists have a certain set of skills and knowledge, they should be regarded highly in the community. However, this situation is usually not reflected in the Late Bronze Age graves, which are characterized by a sparse number of metal artefacts and sometimes also ceramics. In the case of Legnica cemetery, this is exemplified by graves 5, 42, and 153.

The fact that so few of the so-called metallurgists' graves have been discovered so far and that they do not occur evenly on the territory of the urnfield culture is explained by some researchers by the overall lack of metallurgical activities in these communities, the low popularity of the profession, or passing valuable tools to the next generations of craftspeople. Whereas it is difficult to give an unambiguous answer to these questions, it is worth looking into the latter explanation.

Assuming the long-term use of stone and metal moulds (Drescher, 1957, p. 74), it is highly probable that the tools will be passed on for several generations, particularly taking into account the issues of obtaining the raw material of appropriate quality for the production of stone moulds and the time-consuming work associated with the initial preparation of its surface with metal chisels or axes to produce the exact matching negatives. The effort put into their production, as well as the required specialist knowledge and skills, meant that even if they were not that valuable commercially, they surely had to be priceless for those who used them (not to mention their symbolic value). Considering the limited access to metal and the fact that simple axe or sickle moulds were used to produce items for the whole community, having even one such tool enabled the production of several dozen items. With a set of several casting moulds of the same type, such as two stone axe moulds laid in grave 42, it was possible to make dozens, if not hundreds, of new artefacts. However, contrary to passed-on permanent (stone, metal) casting moulds, the semi-permanent ones were deposited in graves (e.g. moulds from grave 5 or clay moulds from other sepulchral contexts: Bojadła, Mojęcice, Masłów, Lower Silesia or Stradow, Brandenburg; Seger, 1909; Weineck, 1892). Scientific analyses presented here have proven the use of the casting moulds from Legnica prior to their deposition. The multiple use of clay axe and sickle moulds has been asserted by experimental studies (5–10 casts; Nowak, 2018) and indicates that they could certainly have been treated as casting tools. However, it is not very likely that they have been passed on through several generations of metalworkers. Unlike their permanent counterparts, these moulds were more susceptible to environmental conditions (e.g. moisture), which could adversely affect their durability and cause damage.

Depositing permanent and semi-permanent casting moulds and other metallurgy-related items in graves does not have to be associated with a simple transfer of the role that the deceased had in life. As indicated by various researchers (e.g. Mierzwiński, 2003, p. 178), it is difficult to agree with the view that this was the way of showing ownership of the artefacts. Winkelmann states emphatically that 'the deceased did not bury themselves'. Items deposited in the grave do not only constitute rights of possession and ownership, but also indicate the respect and importance of the deceased to the community where they lived and functioned (Winkelmann, 1977, p. 100, quoted in Jockenhövel, 2019, p. 10). The dead were not active participants in the mortuary activities, although they could certainly influence them by their status and decisions made during their lifetime. Therefore, indirectly and not necessarily, through deposited artefacts, they certify the complex attitude of the living towards the dead and, therefore, through their social role (Mierzwiński, 2003, p. 178).

As pointed out by B. Nessel (2013, p. 141), placing a metallurgical tool in the grave does not only mean that the deceased was a metallurgist; these items may also represent the most important role that the person played in the community. In the reconstruction of social stratification based on cemetery studies, it is indicated that care given to the deceased is closely related to their position in life. Moreover, the distinction between the social person and social identity, as well as emphasizing certain features of the deceased by the community, were very important (Ciesielska, 2001, p. 9). In the context of these remarks, burying an individual with metallurgical tools does not necessarily indicate that their only occupation, profession, or craft was related to such activity. Grave deposits cannot be understood only as an element related to the person's identity in life, but also as the end result of a series of mortuary activities performed by funeral participants, aimed at highlighting and emphasizing the nature of their relationship with the deceased, as well as signaling the person's identity (Parker Pearson, 1999, p. 84). The sacrifice-gift relationship is linked to ritual, or the sacred and magical context (Mierzwiński, 2003, p. 179). Funerary deposits should not be viewed merely as personal items, marked or not by the relationship with the deceased, but as elements involved in the exchange of gifts with the person (Parker Pearson, 1999, p. 85).

Funerary deposits can be viewed as a component of resurrection magic, serving as a link to strengthen the deceased's ties to the community. Placing gifts in graves forms a bridge between the worlds of the dead, ancestor-deities, and the living. According to the functional model, Z. Woźny (2005, p. 122) indicates that dying only changes the person's status of community participation, which allows for interpreting funerary deposits as a continuation of the principle of reciprocity, also present in other types of rituals. By freeing themselves from mortality in a controlled manner (ritualized death), the deceased gain the posthumous possibility of contacting the living members of the community (Mierzwiński, 2012, p. 76). Z. Woźny also refers to the structural method according to which the deceased undergoes a specific process through the rite of passage: from the normality of life, through the abnormality of crossing the border, to transformation into an immortal ancestor. Funeral deposits, by becoming a bridge between the world of the living and the realm of ancestors, transform in the same way (Woźny, 2005, pp. 121–122).

The above observations discussing the presence of bronze metallurgy-related artefacts in graves do not close the possibilities of interpreting this complicated phenomenon, and do not directly answer the questions about the social role and status of people buried in the so-called metallurgists‘ graves. Depositing items in the graves was not only related to marking the role of the deceased in society but was also primarily symbolic. The buried person had no influence on the rituals and practices accompanying the funeral, nor did they decide on the nature of the grave offerings. Their role was related to who they were in life, but also to what they were to become (an immortal ancestor). Reducing the deposition of items related to specific activities (casting tools in this case) only to the property of representation of the performed profession or craft seems to be a far-reaching trivialization.

7. Conclusion

An unprecedented number of bronze metallurgy-related items were discovered in three funerary complexes (graves 5, 42, and 153) from the cemetery in Spokojna Stree, Legnica. These graves did not differ in terms of structure or inventory from other sepulchral objects discovered at the site. The casting moulds found in the graves, used for the manufacture of various items, prove that the local community was able to satisfy independently the demand for everyday tools (i.e., sickles and axes), as well as toiletries and weapons.

Using several analytical methods, it was possible to identify the items deposited after use and unused (ED XRF), to determine the chemical composition of the layers inside the casting moulds as well as the droplet of metal from one of the moulds and the finished cast (SEM EDS). The origin of the metal used by local metallurgists has been assessed by lead isotope analysis using MC ICP MS. The potential use of metals from the Erzgebirge is particularly intriguing, because few metals found on Bronze Age sites have been linked to this ore deposit, which could have been one of the more important sources of tin in the later Bronze Age.

The proposed analytical methodology allows a holistic approach to the issues of the Late Bronze Age process of manufacture of bronze artefacts based on the combined archaeological and analytical examination of the objects deposited in the so-called metallurgists‘ graves.

CRediT authorship contribution statement

Kamil Nowak: Conceptualization, Project administration, Funding acquisition, Investigation, Writing – original draft, Writing – review & editing, Visualization. **Zofia A. Stos-Gale:** Data curation, Writing – original draft, Writing – review & editing, Visualization. **Tomasz Stolarczyk:** Resources, Visualization. **Beata Miazga:** Formal analysis, Investigation, Data curation, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A

"Metallurgist's graves"–archaeological and anthropological evidence.

Grave 5

An urn grave with the cremated human remains was damaged before its discovery. Anthropological determination was not possible. It contained three ceramic vessels, a large number of pottery fragments, a small clay bead, a bronze bracelet fragment, and nine items related to metallurgical activity (Table 1). The artefact arrangement within the grave is impossible to reconstruct, as no plan (drawing or photographic) from the first excavation season is available. According to the information from the initial reports, the casting equipment was located in the urn (Sokołowska et al., 1973). It does not seem possible that all the artefacts were inside the urn, which could either be a cup (Fig. 4.11) or a pot (Fig. 4.14) due to their size. Most likely, some artefacts were placed inside and some next to it. The casting equipment discovered in grave 5 includes: casting moulds, a casting core, and a tuyere fragment. The discovered items were made of clay, and they were preserved whole and in fragments. All casting moulds belong to the bivalve type of mould and are used for gravity casting, placed vertically. The metallurgical equipment consists of:

No. 5/1 (ML/A – 1081/1a). A casting mould for the production of razors with a single-edged, crescent-shaped blade and a prominent long handle ending with a ring is referred to as the Herrnbaumgarten type, Legnica variant (Fig. 3.1; Gedl, 1981, p. 32; Jockenhövel, 1971, p. 208). The mould is damaged; the upper part with the razor tip negative and the pouring channel is missing. The mould has a modelled negative of the future casting with a trimmed circle for placing a core modelling the loop. Above the circle negative, there is a small hole with macroscopically visible greenish metal remnants. The hole served as a venting channel for the gases, through which some of the excess metal also poured out.

No. 5/2 (ML/A – 1081/1b). The second half of a mould for the production of razors with a single-edged, crescent-shaped blade (creating a set with no. 5/1). It contains only the negative of a handle with a ring at the end, the blade part is flat (Fig. 3.2).

A modelled groove located at the bottom of both halves (Nos. 5/1 and 5/2) enabled them to be bound together during casting.

Additionally, there are notches on both sides of the groove indicating the correct mould assembly. The 'contact' surfaces of both halves are flat with visible longitudinal scratches indicating their alignment by grinding. They adhere to each other exactly. Their outer sides have fingerprints resulting from sliding fingers pressed into the ceramic mass.

No. 5/3 (ML/A – 1081/2). Half of a casting mould is used to produce a socketed chisel with an annular protrusion at the socket edge (Fig. 3.3). In the upper part of the negative, there is a funnel-shaped pouring channel. Thanks to that, the liquified bronze could fill the mould, bypassing the socket core. On the edge of the negative and the pouring channel, the discolouration due to the effect of high temperature is clearly visible. Additionally, there is a thin, compact dark green layer on the negative surface.

No. 5/4 (ML/A – 1081/3a). Half of a mould used to produce spearheads with a rhomboid blade and an annular protrusion at the socket edge (Fig. 3.4). There are holes for the centering pin right next to the negatives of the sockets.

No. 5/5 (ML/A – 1081/3b). The second half of the above-described mould, preserved in two fragments, is for spearheads with a rhomboid blade and an annular protrusion at the socket edge (Fig. 3.5). The holes for the centering pin are drilled right through. In both halves (Nos. 5/4 and 5/5), there are funnel-shaped pouring channels in the upper part of the socket negative. Traces of heat exposure are locally visible on the negatives.

No. 5/6 (ML/A – 1081/4). Half of a casting mould, preserved in two fragments, was used to produce spearheads with an almond-shaped blade (Fig. 3.6). The mould has two small holes for centering pins in the upper and lower parts. There is a funnel-shaped pouring channel in the upper part of the negative. A large clay chip on the outside could be the result of firing or drying up of the still wet mould, possibly near the casting pit.

No. 5/7 (ML/A – 1081/5a). A casting mould which was used to produce two knobbed sickles (Fig. 3.7). Two Lusatian-type sickle negatives are modelled on both sides of the mould – on one side they show two ribs, on the other one rib on the edge of the ridge. Both negatives have separate pouring channels that run from the sickle knob to the edge of the mould. Bright and dark areas are visible on the negatives and channels, and there is a dark green compact layer on the negative surface.

No. 5/8 (ML/A – 1081/5b). The second part of the above described mould. The clay plate has an even surface without negatives and served as a "lid" to obtain a smooth underside of the cast sickles. To prove that the mould was used, there are on both surfaces the "burned" shapes of sickles and pouring channels (Fig. 3.8).

No. 5/9 (ML/A – 1081/6). A fragment of a ceramic tuyere (Fig. 3.9). The artefact was lost. The only remaining information is its simplified drawing and dimensions. The difference in the diameter of the outlets indicates that the tuyere tapered towards one end and connected to the casting pit. Compared with the tuyere found in the cemetery in Bojadła, county Zielona Góra (30.7 cm external and 23 cm internal length, 6.7 cm and 3 cm outlet diameter, 1.5 and 0.7 cm wall thickness; Seger, 1909, p. 22), the fragment may come from the part attached to the bellows.

No. 5/10 (ML/A – 1081/7). A ceramic casting core (Fig. 3.10). It has the shape of an irregular cylinder, thickened in the middle and slightly tapering towards both ends that have been broken off. The item is damaged, and its surface is cracked. It is made of the same ceramic material as the casting moulds found in this grave. According to the information from the Copper Museum in Legnica archives, the casting core was related to one of the spearhead moulds (no. 5/6). Casting cores are rare finds in Poland. Similar artefacts were found in grave 73 in Piekary, Lower Silesia (Seger, 1909, p. 16) and in grave 89 in Karzec, in Wielkopolska Province (Malinowski, 1982, p. 250; Śmigielski, 1961, fig. 37.1–5). Interestingly, on the Polish territory, these artefacts were found in graves always together with casting moulds for socketed items, like in the case of the casting core from grave 5 in Legnica cemetery, found with a casting mould for a spearhead.

Grave 42

An urn grave with the cremated human remains is located 0.20-0.45 cm below the arable layer. Anthropological determination of the remains was not possible. The outline of grave vessels was discovered in humus mixed with coarse gravel; the grave was located on the N-S axis. Human bones appeared in the urn, in the scoop vessel 7, and next to the vessels (Fig. 4). Apart from the urn (not preserved), the grave included seven vessels (Fig. 4.1-7), 32 pottery fragments, two sets of bivalve stone moulds, a stone axe (Fig. 4.12), and a stone pebble (Fig. 4.13; Table 1). The moulds were deposited together in two sets. At the time of discovery, one of the halves was shifted, which is associated with slight damage to the grave. Casting moulds were placed next to the urn from the NE. Both moulds are complete, very well preserved, and differ slightly in length, width, and thickness.

No. 42/1 (ML/A – 1118/1). Half of a casting mould used to produce socketed axes (Fig. 4.8). There are three holes for centering pins drilled right through.

No. 42/2 (ML/A – 1118/2). The second half of the above-mentioned casting mould for socketed axes (Fig. 4.9) has three holes for centering pins.

The halves (no. 42/1 and 42/2) match each other perfectly.

No. 42/3 (ML/A – 1118/3). Half of a casting mould used to produce socketed axes (Fig. 4.10).

No. 42/4 (ML/A–1118/4). The second half of the above-mentioned casting mould for socketed axes (Fig. 4.11).

The halves (42/3 and 42/4) have 5 holes each for centering pins, and they match each other perfectly.

Grave 153

The grave was discovered at a depth of 0.37 m and, at its lowest point, reached 0.56 m. The outline of grave vessels was discovered below the arable layer, against the background of humus mixed with coarse gravel. Based on anthropological observations, the person buried in the grave was approximately 20–30 years old, most likely a male (Hałuszko and Łukowiak, 2016, p. 207). The finds in this grave included an urn and seven vessels (Fig. 5.1-8), a bivalve stone mould, and a fragment of a heavily corroded, undefined bronze artefact (Table 1). The mould was set up next to the bowl (no. 8 on the drawing plan in Figure 5), positioned a dozen centimetres NE of the urn covered with a clay plate (no. 1 on the drawing plan in Figure 5). Along with burnt human bones, the urn also contained charcoal and a bronze fragment. The findings include:

No. 153/1 (ML/A – 2377/9). A casting mould half used to produce socketed axes (Fig. 5.9). The mould is not completely preserved. There is a fragment broken off in the upper part.

No. 153/2 (ML/A – 2377/10). The second half of the above-mentioned casting mould for socketed axes (Fig. 5.10). This part was heavily damaged, cracked and preserved only as fragments. Casting moulds in graves 42 and 153 were used to produce socketed, Lusatian-type axes (referred to as the Czarków type, variant A), decorated with three vertical ribs and an annular protrusion at the socket edge. The Czarków type is one of the most common forms of socketed axes in Poland (Kuśnierz, 1998, p. 33). The dimensions of the sets differ slightly from each other. Modelled axe negatives are carefully smoothed.

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