# The Urnfield period Dragomelj I hoard: archaeological and chemical investigations

# Dragomelj I, depo kulture žarnih grobišč: arheološke in kemijske raziskave

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**Izvleček**

Naselbinski depo I iz Dragomlja sodi v Ha B1. Z več kot 86 kg kovinskih polizdelkov se dopolnjuje z livarskimi dejavnostmi v bližnjem naselju Podgorica. Naselji sta bili zbirni, proizvodni in izmenjalni središči na transportnih poteh iz bakrovih rudišč v vzhodnih Alpah proti jugu. Dvokonični ingoti z osrednjo perforacijo kažejo pomenljivo povezanost s kemično sestavo s kositrno zlitino in skromnimi slednimi elementi (Sb, Ni, As). Nasprotno vsebujejo ingoti brez osrednje perforacije veliko slednih elementov. Različne oblike ingotov so bronastodobni metalurgi izdelali za prepoznavanje njihove sestave. Raznovrstna sestava ingotov kaže na različna izvorna halkopiritna in polimetalna rudišča. Kositrna litina večine ingotov in nekaj pogač je posledica recikliranja ali namernega dodajanja kositra. Analiza svinčevih izotopov izkazuje raznovrsten izvor predmetov. Poleg verjetnih izvornih območij, Mitterberga in Trentinskega, je mogoča tudi oskrba iz bližnjih karavanških bakrovih rudišč.

**Ključne besede:** Dragomelj; pozna bronasta doba; depo; ingoti; metalurgija; analize ICP-AES; analize svinčevih izotopov

**Abstract**

The hoard with over 86 kg of metal products unearthed in the settlement at Dragomelj is dated to Ha B1 and complements the remains of foundry activities in the nearby settlement at Podgorica. The twin settlements were centres of collection, production, and exchange located on the transport routes that connected the eastern Alpine copper mines with areas to the south. The products in the hoard include biconical ingots with a shaft hole that show a significant correlation between form and chemical composition, which is characterised by tin alloy and modest trace elements (Sb, Ni, As). In contrast, the biconical ingots without a shaft hole contain higher amounts of trace elements. This suggests that the Bronze Age smiths produced different forms of ingots to distinguish between the different metal compositions. The diverse composition of the ingots also indicates the different origins of the chalcopyrite and polymetallic ores used in the production process. The tin alloy of most biconical and some plano-convex ingots is the result of recycling or intentional addition of tin. The analysis of lead isotopes confirms the diverse origin of the objects. In addition to the probable source areas of Mitterberg and Trentino, the supply of copper ores from the nearby Karavanke Mountains remains a possibility.

**Keywords:** Dragomelj; Late Bronze Age; hoard; ingots; metallurgy; ICP-AES analysis; lead-isotope analysis

Following several chance finds, archaeologists excavated a trial trench in 1995 and unearthed a hoard containing copper and bronze semi-products.[1] Later rescue excavations conducted in advance of motorway construction here brought to light the remains of a contemporary Late Bronze Age (LBA) settlement, with the hoard located just west of the excavation area and inside the settlement.[2]

[1] For excavation details regarding the LBA Dragomelj I hoard, see Turk, Svetličič, Pavlovič 2023, 94–100, Fig. 121–131 and Turk 2024, 52–55, Fig. 10–12, Table 1.

[2] See in this volume Turk, Svetličič, Fig. 2.

*Fig. 1:* Dragomelj, Hoard I. Select objects from the hoard.
*Sl. 1:* Dragomelj, depo I. Izbrani predmeti iz depoja.

Found in the topsoil near the hoard were numerous fragments of bronze objects that represent the remains of another hoard, named Dragomelj II and attributed to the Early Iron Age.[3]

The Dragomelj I hoard contains 52 items (*Fig. 1*) that consist of thirteen mostly fragmented biconical ingots (Cat. Nos. 1–13, *Pl. 1–3*; hereinafter BI) and 39 relatively well-preserved plano-convex ingots (Cat. Nos. 14–52, *Pl. 4–9*; hereinafter PCI). The BIs were only found in the topsoil and in the upper level of the hoard, where fragmented objects generally predominated (*Fig. 2*).[4]

In addition to fragmentation, several ingots from the Dragomelj I hoard display cuts caused by blows with a sharp object (e.g., on Cat. Nos. 41, 49, 50 and 52), most clearly on a PCI with a wedge-like cut (Cat. No. 15). Similar cuts are present on some of the PCIs known from the Carpathian area unearthed as hoard or stray finds.[5] They probably served to control the quality of the copper semi-products.[6]

Some ingots show deformations that indicate intentional breaking by bending (e.g., Cat. Nos. 8, 45 and 50). They were fragmented by design, as is clear from the precisely quartered piece of a PCI (Cat. No. 41), the shape of which has numerous parallels in the LBA hoards from the Pannonian

[3] Turk, Svetličič, Pavlovič 2023, 116–125, Fig. 150–154; see Turk, Svetličič in this volume.

[4] Turk 2024, 52–54, Fig. 10–12, Table 1: half of the ingots from the Dragomelj I hoard were found in secondary position within the topsoil (Cat. Nos. 1–2, 4–8, 10–13, 18, 24, 27, 31, 35, 38–40, 43–45, 48, 50–52); others were recorded in three levels *in situ* (*Fig. 2*).

[5] E.g., Mozsolics 1984, 38, Pl. 16: 4; 17: 2; ead. 2000, Pl. 82: 5,11; Žeravica 1993, Pl. 48: 723.

[6] Nessel 2017, 191–194, Fig. 23.

and Alpine areas.[7] Some of the contemporary parallels also show surface incisions to facilitate quartering.[8]

The worn, blunt, and even rounded fractures of the ingots show that the pieces were in use or circulation before their final deposition.[9] Of the twelve fragmented BIs, nine (75%) have worn fractures.[10] The most heavily worn ingot is Cat. No. 6, while two examples (Cat. Nos. 4 and 9) have the fracture near the tip beaten into a hammer-like shape.

Of the 16 PCI fragments, only six are worn (Cat. Nos. 43, 46 and 49–52), which represents just over 37%, a percentage that is considerably lower compared with that of the BIs. Most PCIs appear to have been buried in the hoard sooner after fracturing than the BIs. The vertical distribution of the worn BIs and PCIs in the hoard shows they were only present in the upper levels. This reveals that these upper levels mainly held fragmented pieces

[7] Čerče, Šinkovec 1995, Pl. 59: 74,76–77; 92: 74–75; 93: 83; Mozsolics 1984, Pl. 9: 1,5; 18: 2,3; ead. 2000, Pl. 65: 1,12; Tarbay 2022, Pl. 8: 52; 23: 80; 25: 81; Windholz-Konrad 2018, Pl. 2: 3; 5: 2–5; 9: 5; 17: 16; 18: 9; 19: 10; 34: 173; 39: 1–2.

[8] The Porpetto (Borgna, Turk 1998, 352, Fig. 1), Castions di Strada (Anelli 1954–57, 13–14, Pl. 4: 1–4) and Straßen hoards (Windholz-Konrad 2018, Pl. 5: 2); generally on the fragmentation of the plano-convex ingots: Nessel 2017, 175–187, Fig. 8–19.

[9] Pavlin, Turk 2014, 50–52, Pl. 1–2; Pavlin et al. 2024, 155.

[10] Only the ingots with Cat. Nos. 2 and 13 show sharp fractures.

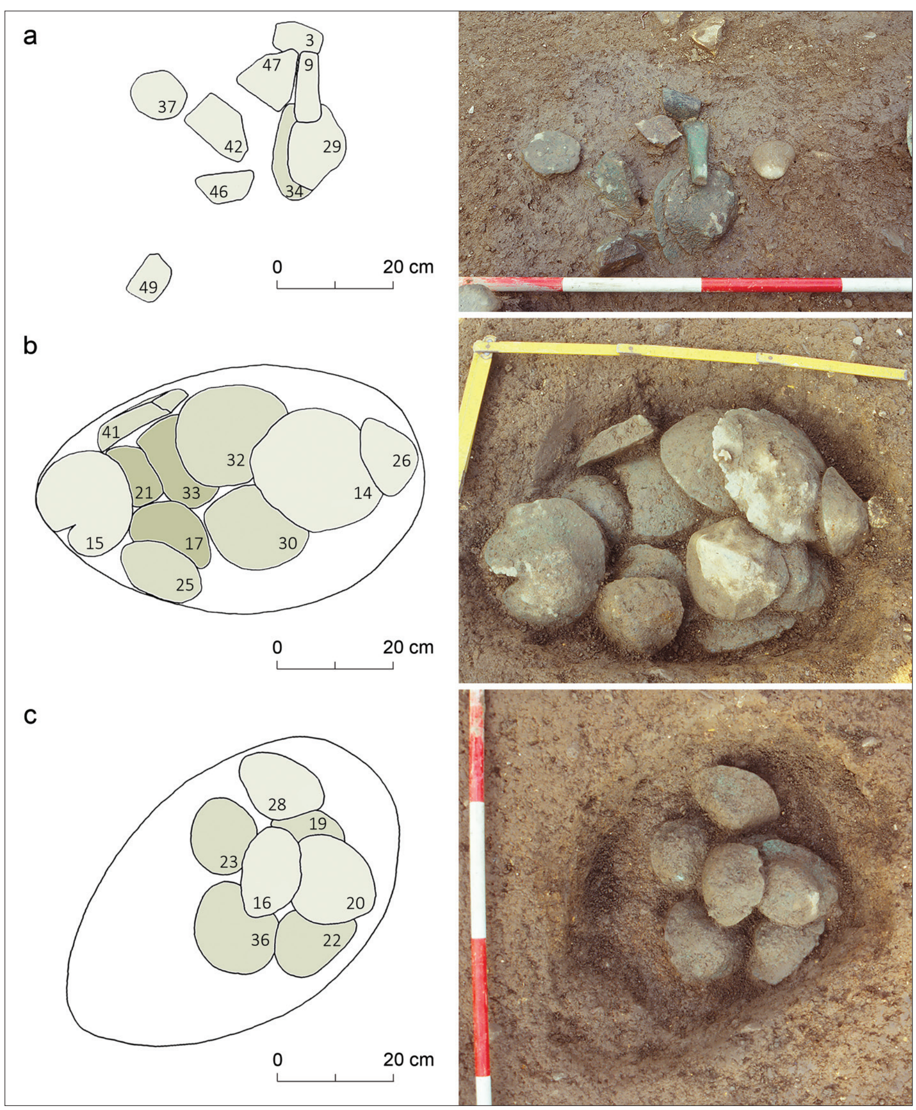


*Fig. 2:* Dragomelj, Hoard I. **a** – upper; **b** – middle; **c** – lower levels of the objects from the hoard *in situ*.
*Sl. 2:* Dragomelj, depo I. **a** – zgornja; **b** – srednja; **c** – spodnja lega predmetov v depoju *in situ*.

(all BIs and most PCIs) with worn fractures and that the inhabitants of the contemporary settlement frequently used the hoard to put ingots in or take them out (*Fig. 2*). In this sense, the Dragomelj hoard I appears to have functioned as a storage unit for copper or bronze semi-products.

## PLANO-CONVEX INGOTS

These ingots have rarely been the subject of a detailed analysis in the studies of Bronze Age metal goods.[11] As highly fragmented examples, the earliest PCIs sporadically appear in the hoards dating to the transition from the Early to the Middle Bronze Age,[12] and become numerous in the hoards buried during the LBA.[13]

A detailed formal analysis of PCIs is hindered by the fact that they mostly survive as heavily fragmented pieces that do not enable a reliable identification of their correct orientation (distinguishing between upper and lower sides) and original shape. The uneven lower side of most PCIs indicates that they were not cast in specially prepared moulds. According to the established view, the convex surface (and its variations) reflects the shape of a small pit made into the ground during each primary smelting of copper ore.[14] The hypothesis that most PCIs represent copper as raw material is confirmed by analyses of their chemical composition.[15] There are some examples, however, that point to a different origin. Some PCIs from the Early Urnfield period found in the Carpathian Basin incorporate part-melted pieces of finished bronze products identifiable on the upper side.[16] These PCIs often have a shaft hole in the centre. They were formed by remelting bronze products and are thus not a primary result of the metallurgical process, but rather evidence of Bronze Age recycling.

The lower side of five PCIs from the Dragomelj I hoard display hatched impressions (Cat. Nos. 30 and 37, possibly also on Cat. Nos. 14, 33 and 38). Cat. No. 30 bears such impressions at the opposite edges of the lower side. They may have been left by a specific tool that the metallurgists used to remove the PCIs from the casting pit immediately after pouring, possibly blacksmith tongs similar to those known from contemporary sites in Cyprus and Sardinia.[17] The relevance of such parallels is underscored by several similarities observed between some of the BIs from Dragomelj (see below) and the hoard finds from Cyprus and Sardinia.

The Dragomelj I hoard contains 39 PCIs or raw metal ingots, which places it in the category of 'raw metal' hoards.[18] It differs from most hoards of this category in the high share of complete PCIs. Considering their size, shape, and weight, the complete PCIs of this hoard are classified into six groups (*Fig. 3*):

1 – Small PCIs with a hemispherical section of a medium height, a diameter of up to 100 mm, and a weight between 700 and 900 g (Cat. Nos. 37–38).

2 – Medium-sized PCIs with a hemispherical section of a medium to large height, a diameter mainly between 120 and 135 mm, and a weight between 1600 and 2200 g; the average weight is 1910 g (Cat. Nos. 16–19, 23–27).

3 – Medium-sized PCIs with a high bell-shaped section, a diameter between 145 and 155 mm, and a weight between 2000 and 2900 g; the average weight is 2381 g (Cat. Nos. 20–22, 29, and 36).

4 – Medium-sized PCIs with a high conical section, a diameter between 130 and 155 mm, and a weight between 2800 and 3200 g (Cat. Nos. 28, 30 and 31).[19]

5 – Larger PCIs with a predominantly hemispherical section of a low to medium height, a diameter between 175 and 180 mm, and a weight between 2500 and 3500 g (Cat. Nos. 15, 33–35).[20]

[11] Mozsolics 1967, 96–98; ead. 1973, 79–89; ead. 1984; Dörfler et al. 1969; Trampuž Orel 1996, 177–181; Primas, Pernicka 1998, 35–38; Czajlik 1996; Czajlik, Molnár, Solymos 1999; Modl 2010, 128–129; Nessel 2017; Lutz, Krutter, Pernicka 2019, 364–366, Fig. 2–3.

[12] Mozsolics 1967, 98, Fig. 29; ead. 1984, Pl. 2: 7–19.

[13] Čerče, Turk 1996, 14–22, Fig. 3–5; for the wide distribution of such objects in the Mediterranean cf. the numerous PCIs from the Cape Gelidonya shipwreck off the coast of southern Anatolia (Bass 1967, 78–81, Fig. 93–94), dating to the 13th century BC, from the contemporary hoards of the western Mediterranean (Gomez Ramos 1993, Fig. 2, Pl. 2), and others.

[14] Bass 1967, 80–81, Fig. 95; Trampuž Orel 1996, 177.

[15] Trampuž Orel 1996, 182-183, Pl. 5; cf. the ICP-AES analysis below.

[16] Mozsolics 1981, 415–416, Fig. 7–8; Petrescu-Dîmbovița 1978, Pl. 76: 34; Modl 2019, 375–377, Fig. 2–3.

[17] Matthäus, Schumacher-Matthäus 1986, 173, Fig. 21: 3 (Foundry Hoard from Enkomi); Lo Schiavo, Macnamara, Vagnetti 1985, 23, Fig. 9 (Sardinia); Bass 1967, 109, Fig. 116–117 (Cape Gelidonya shipwreck).

[18] Čerče, Turk 1996, 26–27.

[19] The fragmented Cat. No. 31 weighs 1953 g, but its original weight is undeterminable.

[20] The fragmented Cat. No. 33 with its weight of 4244 g (without the missing part!) stands out from the weights

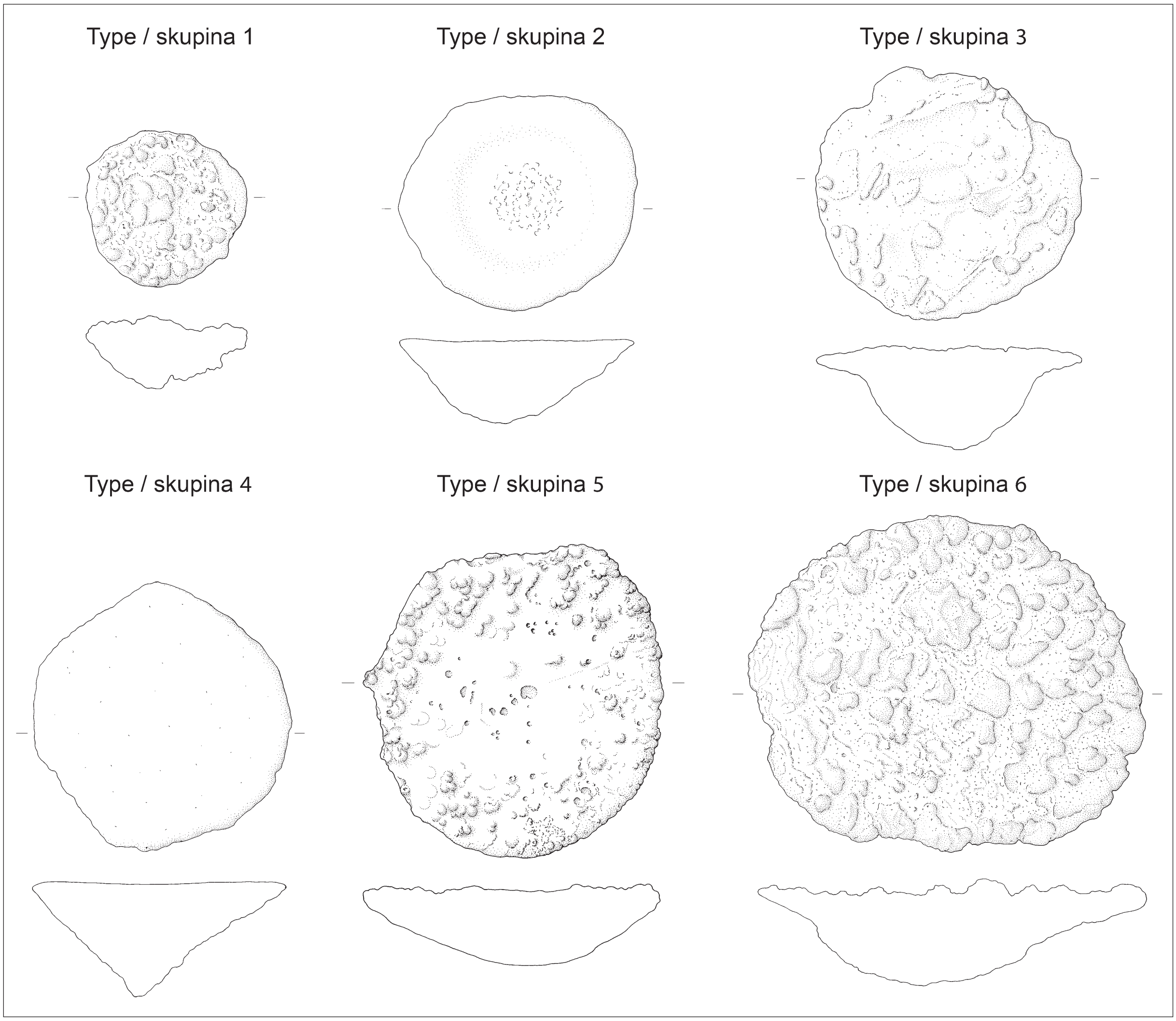


*Fig. 3:* Dragomelj, Hoard I. Typological table of plano-convex ingots. Scale = 1:4.
*Sl. 3:* Dragomelj, depo I. Tipološka preglednica pogač. M. = 1:4.

6 – Large PCIs with a cross-section of a low to medium height, a diameter between 200 and 220 mm, and a weight between 4100 and 4200 g (Cat. Nos. 14 and 32).

Two of the PCIs surviving as fragments (Cat. Nos. 40 and 42) may also belong to Group 5 due to their low hemispherical section and presumed size. Two PCIs (Cat. Nos. 41 and 46) must have been parts of very large and heavy ingots, such as are unknown among the complete examples; of particular interest is the quarter-section of Cat. No. 41 that weighs 2398 g, suggesting that the complete PCI weighed around 10 kg.[21]

The proposed classification considers not only the shape, but also the diameter and the weight of the PCIs, as some of their formal differences may have been the result of chance rather than intent. This is how we understand the PCIs of Groups 2 and 3 (with hemispherical and bell-shaped sections): the basic hemispherical shape of the pit for casting the PCIs of Group 2 could also produce bell-shaped PCI if a larger quantity of molten metal was poured, resulting in PCIs of a slightly greater weight, diameter, and height. Weight as an independent variable indicates the formation of several groups.[22] Most clearly distinguishable are the lightest Group 1 (between 700 and 900

of other PCIs of the group and is the heaviest object in the hoard.

[21] Cf. Borgna, Turk 1998, 352, Fig. 1, for the PCI from Porpetto in Friuli that weighs over 11 kg; Mozsolics 1984, 61, for the PCI of a similar weight recovered from the Danube at Nyergesújfalu.

[22] Turk, Svetličič, Pavlovič 2023, 102–103, Fig. 134–135.

g) and the heaviest Group 6 (over 4000 g). The weights of other PCIs do not show the expected frequency distribution in the shape of a Gaussian curve, but rather two additional concentrations, one between 1600 and 2300 g (Group 2) and the other between 2500 and 3400 g (Groups 4 and 5). The bell-shaped PCIs of Group 3 are divided between these two concentrations, with three examples in the first and two examples in the second concentration. As for the fragments of PCIs, their weights predominantly range from 200 to 700 g, with only a few between 1100 and 2400 g.

Parallels for the above-established groups of PCIs are numerous, but spatially and chronologically dispersed. For the PCIs of Group 1, the closest parallels from Slovenia and its vicinity come from Jurka vas, Miljana, Črmošnjice, and Debeli vrh.[23] In Pannonian hoards, similar PCIs have been found in the Kurd, Gyermely, and Română horizons (Ha A1–B1/2).[24] They are also known from the hoards in the eastern Alps,[25] Transylvania,[26] and Tuscany between Manciano and Samprugnano.[27] These PCIs are dated to both the Early and the Late Urnfield period, as such hindering a more precise dating of the Group 1 PCIs from Dragomelj.

Parallels for the PCIs with a hemispherical section of a medium to great height (Group 2) come from the Madriolo and Miljana hoards, attributed to the beginning of the Late Urnfield period,[28] and from several Pannonian hoards.[29] The bell-shaped PCIs of a high section (Group 3) are also limited to the transition from the Early to the Late Urnfield period or beginning of the latter, with parallels in the Madriolo, Miljana, and numerous contemporary Pannonian hoards, as well as in a settlement find from Rogoza in the Podravje region.[30] The PCIs of a high conical section of Group 4 also have parallels in the Madriolo and Miljana hoards.[31]

The larger PCIs from Dragomelj with a low hemispherical section of Group 5 are closest in form to the Velem type according to Czajlik.[32] The large PCIs with a low section of Group 6 are similar to Czajlik's Nyergesújfalu type and the eastern Alpine PCIs of Type 3;[33] both types occur across a broad time span between Ha A1 and Ha B2.

The presented parallels indicate a long span for Groups 1, 5, and 6 that lasted throughout the Urnfield period, while Groups 2, 3, and 4 were limited to Ha B1(2), or Horizon III of the southeastern Alpine hoards.[34] The diverse formal array of the PCIs from the Dragomelj I hoard is closest to those of similar shapes from the Madriolo and Miljana hoards, as well as those from the western Pannonian hoards from Velem and Sághegy.

## BICONICAL INGOTS

Elisabetta Borgna undertook a general analysis of the biconical and hammer-shaped ingots when tackling the examples unearthed in Friuli.[35] Later reports, analytical studies, and integral publications have revealed additional aspects of their distribution and chemical characteristics.[36]

The results of these publications may be summarised in the following conclusions:

1 – The rough, unfinished surface and the non-functional, transport-suitable shape of the biconical ingots reveal them to be semi-products

[23] Černe, Šinkovec 1995, 157, 169, 203, Pl. 59: 79; 68: 118; 93: 84; for a commentary of the unusual elemental composition of the PCI from Jurka vas, with high tin and lead content (Trampuž Orel 1996, 224, Anal. No. 454), cf. below; Dörfler et al. 1969, Pl. 4: 8; 9: 23.

[24] They belong to the Pölöske and Gór groups according to the typology of these PCIs (Czajlik 1996, 171, Fig. 17–19).

[25] Type 4 of the Bronze Age PCIs from the Salzburg area (Lutz, Krutter, Pernicka 2019, 364–366, Fig. 2–3).

[26] Șpălnaca II, Cetea and Dezmir (Petrescu-Dîmbovița 1978, Pl. 158: 642; 218: 34–35; 228a: 16).

[27] Peroni 1961, I 5 (10): 160–161.

[28] Borgna 1992, Pl. 7: 36; Dörfler et al. 1969, Pl. 3: 7; 5: 12; 7: 17–18; 8: 20.

[29] Lovasberény and Beremend from the Gyermely horizon (Mozsolics 1985, Pl. 245: 29–30; 252: 22), possibly also Öreglak and Balatonkiliti from the Kurd horizon (*ib.*, Pl. 85: 4; 99: 8).

[30] Borgna 1992, Pl. 7: 37; Dörfler et al. 1969, Pl. 2: 4; 4: 9–10; 5: 11; plano-convex ingots of the Uzsabánya I type: Czajlik 1996, 170, Fig. 11–13; Črešnar 2010, 52–53, Fig. 27.

[31] Borgna 1992, Pl. 6: 35; Dörfler et al. 1969, Pl. 6: 14.

[32] Czajlik 1996, 170, Fig. 8–10; for the Miljana hoard: Dörfler et al. 1969, Pl. 3: 6; for the Sipbachzell hoard in Oberösterreich: Höglinger 1996, Pl. 30: 528; for the Polizello hoard in Sicily: Giardino 1995, Fig. 14 A: 5.

[33] Czajlik 1996, 169, Fig. 2–6; Lutz, Krutter, Pernicka 2019, 364–366, Fig. 2–3.

[34] Turk 1996, 113–119.

[35] Borgna 1992, with references.

[36] Villamarzana: Arenoso Callipo, Bellintani 1994, 25–27; Kanalski Vrh I and II: Žbona-Trkman, Bavdek 1996; Dragomelj I: Turk 1997; Porpetto: Borgna, Turk 1998; formal typology and chemical analyses: Trampuž Orel 1996, 180–181, 193–194; Trampuž Orel, Heath, Hudnik 1998, 232–234, Fig. 10; Trampuž Orel, Heath 2001, 150–155, Fig. 9–12; Pellegrini 1995, 514–515.

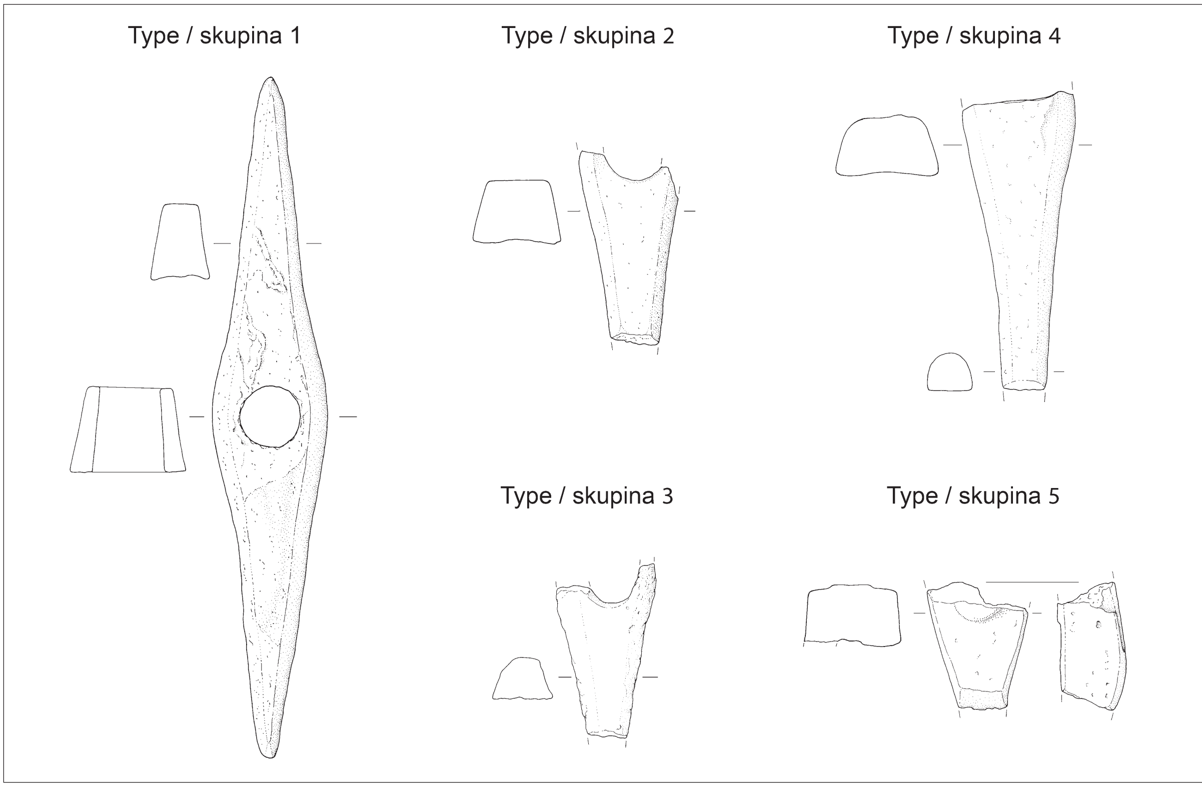


*Fig. 4:* Dragomelj, Hoard 1. Typological table of biconical ingots. Scale = 1:4.
*Sl. 4:* Dragomelj, depo 1. Tipološka preglednica dvokoničnih ingotov. M. = 1:4.

intended for distribution or further processing. Unlike PCIs, which are primary products of copper ore extraction, BIs are secondary semi-products cast in one-piece moulds. Their diverse chemical composition, featuring high levels of trace elements (antimony, arsenic, cobalt, and nickel), indicates they originate from complex ore deposits. The high lead and significant tin content in some BIs indicate a pre-prepared bronze alloy intended for final casting.

2 – The distribution of BIs shows concentrations in central Italy and the lower Po Plain, but particularly in Friuli and in western and central Slovenia (*Fig. 5*). Hoards with BIs are less common in the Pannonian plain and regions north and west of the Alps, in which ingots generally occur singly.

3 – Of relevance for dating BIs are the hoards of a mixed composition such as those from Montagnana and Frattesina in the lower Po Plain, Kanalski Vrh I in western Slovenia, Miljana, Ivanec Bistranski, and Kapelna in northern Croatia, as well as Albertville and Goncelin in the western Alps.[37] These hoards date to *Bronzo finale 2* according to the Italian chronology, *Ha A2–B1* according to the central European chronology, or Horizon 3 of the hoards from the south-eastern Alpine area. The raw metal hoards containing only these BIs share the same dating.

In Slovenian terminology, Neva Trampuž Orel distinguished between pick-shaped and hammer-shaped ingots.[38] However, the fragmentation of many ingots hinders the identification of their original form. Considering the limited period of their occurrence and their specific functionality, it seems more reasonable to view all their variations as a single phenomenon.[39]

The Dragomelj I hoard contains thirteen BIs (Cat. Nos. 1–13), of which one is complete and others fragmented to varying degrees. Despite the small number, they come in a variety of forms (*Fig. 4*):

1 – Ingots with a shaft hole, conical ends, and a high trapezoidal section (Cat. Nos. 1, 2 and 5). Similar examples are known from the Madriolo, Schiers, Albertville, 'tra Manciano e Samprugnano',

[37] Bellintani, Peretto 1984; De Min, Bietti Sestieri 1984, 403–404; Žbona-Trkman, Bavdek 1996; Vinski-Gasparini 1973, 168; Bocquet, Lebascle 1983, 48–52; Borgna 1992, 54–59; Turk 1996, 113–115.

[38] Trampuž Orel 1996, 180.

[39] Cf. the argumentation in Turk, Svetličič, Pavlovič 2023, 105–106.

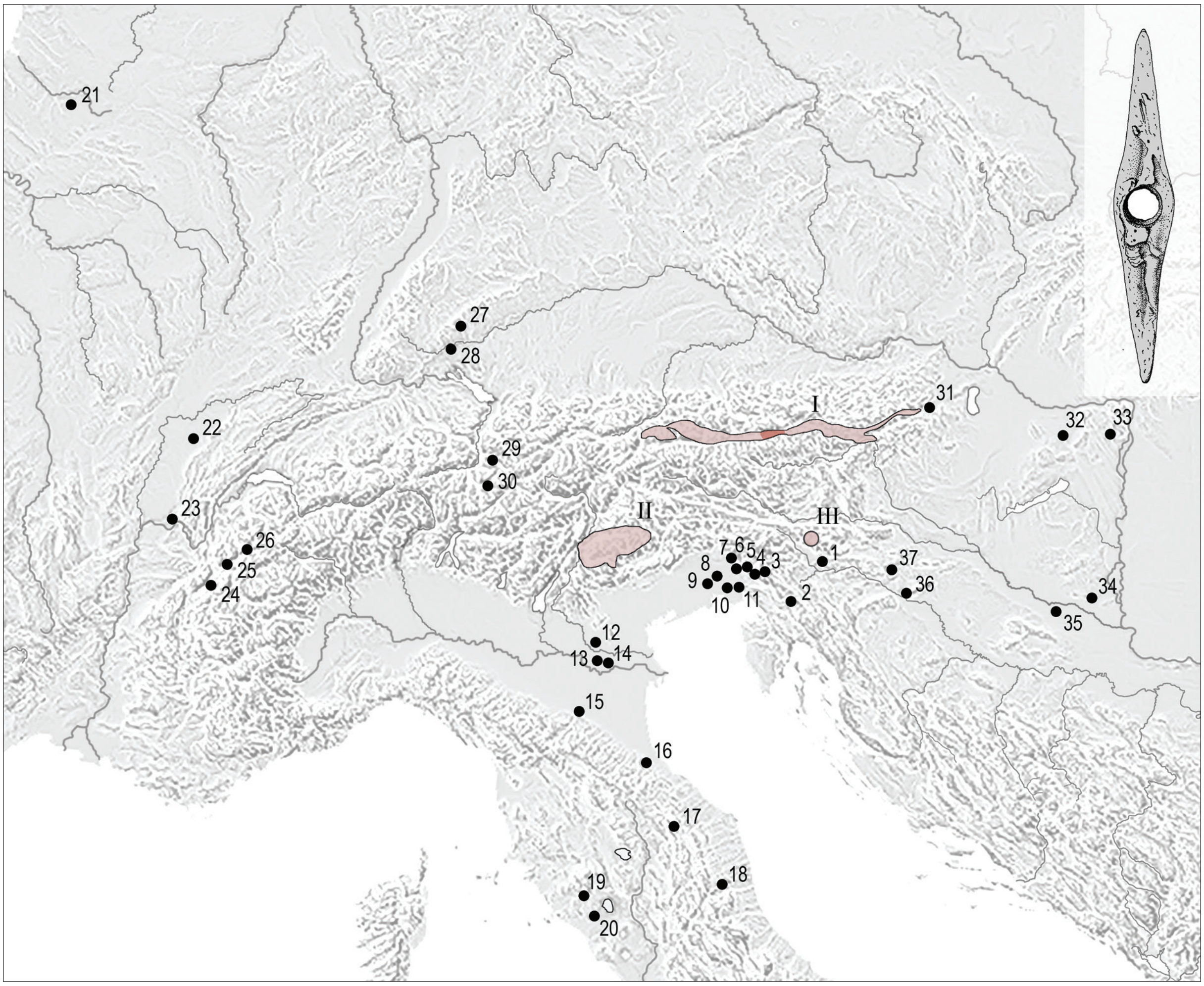


*Fig. 5:* Distribution of biconical ingots and select copper ore regions.
*Sl. 5:* Razprostranjenost dvokoničnih ingotov in izbranih bakrovih rudišč.
(supplemented after / dopolnjeno po Turk, Svetličič, Pavlovič 2023, 108, Fig. 142; Trampuž Orel, Heath 2001, Fig. 13; Urankar 2012, Add. 7a; Artioli et al. 2016, Fig. 1)

**1** – Dragomelj I; **2** – Veliki Otok I; **3** – Kanalski Vrh I in II; **4** – Sv. Jakob nad Debenjem; **5** – Purgessimo; **6** – Madriolo; **7** – Nimis; **8** – Galleriano; **9** – Rividischia; **10** – Porpetto; **11** – Redipuglia; **12** – Montagnana; **13** – Frattesina II in III; **14** – Villamarzana; **15** – Bologna – San Francesco; **16** – Poggio Berni; **17** – Chiuse del Frontone; **18** – Marsia, Ascoli Piceno; **19** – 'tra Manciano e Samprugnano'; **20** – Piano di Tallone; **21** – Caix; **22** – Larnaud; **23** – Lagnieu; **24** – Goncelin; **25** – Albertville, Saint–Pierre–d'Albigny; **26** – Thénésol; **27** – Pfeffingen; **28** – Beuron; **29** – Schiers; **30** – Filisur; **31** – Mahrersdorf; **32** – Bokod; **33** – Biatorbágy; **34** – Beremend; **35** – Kapelna; **36** – Ivanec Bistranski; **37** – Miljana.
Copper ore regions / Območja bakrovih rudišč: **I** – Grauwacken ore area with the Mitterberg region highlighted in darker colour / rudonosno območje Grauwacken s temneje označeno regijo Mitterberg; **II** – Trentino, Alto Adige, Veneto / Trentinsko, Zgornje Poadižje, Benečija; **III** – Karavanke (Počivalnik).

Villamarzana, and Kapelna hoards,[40] to which we should probably add the ingot with a high trapezoidal section from the hoard found at Sv. Jakob nad Debenjem.[41] The three ingots of this group suggest there are minimal differences between the continental biconical ingots and the Sardinian double axes. Although most of the latter are curved and produced in two-piece moulds,[42] some are made in single-piece moulds and formally close to Group 1 of the BIs from the Dragomelj I hoard.[43]

[40] Borgna 1992, Pl. 1: 2,5–6; 2: 3; 12: 2–3; Keller-Tarnuzzer 1935, 82, Fig. 1; Bocquet, Lebascle 1983, Fig. 6: 3; 18A: 2; Peroni 1961, I 5: 73,75,78,81,97; Arenoso Callipo, Bellintani 1994, Fig. 28: 4–5; Vinski-Gasparini 1973, Pl. 111: 16.

[41] Nanut 2018, 150, Pl. 2: 6.

[42] Lo Schiavo 1986, 240–241, Fig. 16.7; ead. 1998, 196, Fig. 1, 7.

[43] Ead. 1990, Fig. 217; Becker 1984, 170–171.

2 – BIs with a shaft hole and a square or low rectangular/trapezoidal section (Cat. Nos. 4, 7, and 12, probably also the smaller fragment with Cat. No. 13).[44] Parallels come from fourteen hoards across the distribution area, while one is a stray find from Udine.[45] Similar shapes, produced in two-piece moulds, include Mediterranean double axes of a square section from Sardinian sites, from Enkomi in Cyprus, and the shipwreck off Cape Gelidonya in southern Anatolia.[46] They date to the 13th and 12th centuries BC (Cyprus, Cape Gelidonya), or broadly to the LBA (Sardinia).

3 – BIs with a shaft hole and a hemispherical section (Cat. No. 6). Ingots of a similar section come from the hoards of Kanalski Vrh I and II, Madriolo, and 'tra Manciano e Samprugnano', indicating a concentration in the Caput Adriae area.[47]

4 – BIs without a shaft hole and with a low hemispherical or slightly trapezoidal ('loaf-shaped') section (Cat. Nos. 3, 9, 10 and 11). Similarly as the ingots of the previous type, these also primarily occur in the hoards with predominant semi-products from Kanalski Vrh I and II, Madriolo, and 'tra Manciano e Samprugnano', possibly also from the Pfeffingen and Beuron hoards from Schwaben as exceptional examples from further north.[48]

5 – BIs with a low rectangular section and a round flat boss replacing the central hole (Cat. No. 8). Trampuž Orel listed parallels for this specific form from the hoards of Kanalski Vrh II, Veliki Otok I, and Madriolo,[49] to which we can add a stray find from Udine.[50]

The BIs of the first two types are characteristic of the wide area extending from central Italy to central Europe and the western Alps, whereas those of the last three types are predominantly found in the hinterland of the northern Adriatic. The distribution of all five types reveals the said hinterland as their main area (*Fig. 5*). Only here do we find all five types of BIs established in the Dragomelj I hoard. With the exception of the extraordinary 'tra Manciano e Samprugnano' hoard from Tuscany, no other hoards reveal such a broad array of BIs. The types not present in the Dragomelj I hoard include short hammer-shaped ingots,[51] roughly made conical-elliptical ingots characteristic of Pannonia during the Gyermely horizon,[52] and ingots with a parting line on the lower side, while their upper side is unevenly cast as on other BIs; the last ones being rare.[53] In contrast, the parting line on both the upper and lower sides of the ingot from Mahrersdorf indicates a closed mould and a similarity with the Mediterranean axes.[54] Unusual in the curved shape of both ends is the BI from the Caix hoard in northern France, which is similar in its basic shape and a low trapezoidal section to those of Group 2 from Dragomelj.[55] A similarly curved shape is observable on the double axe from one of the hoards from Enkomi in Cyprus.[56]

Similarities with the Mediterranean axes made in two-piece moulds can also be observed in the weights of the BIs across Europe. In his study on the weights and weighing in Bronze Age central Europe, Pare identified that the weight of all complete BIs corresponds to a multiple of the Cypriot weight unit of 475 g.[57] The only complete ingot

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[44] In the integral publication, the fragmented ingot with Cat. No. 6 (G1229) is erroneously ascribed to this group of BIs, while Cat. Nos. 7 and 12 (G1230 and G1231) are missing: Turk, Svetličič, Pavlovič 2023, 107.

[45] Madriolo: Borgna 1992, Pl. 1: 1; 2: 4,7–8; 3: 9–10; 4: 16,24; Udine: ead. 1992, Pl. 11: 1; Porpetto: Borgna, Turk 1998, Fig. 1; Albertville and Goncelin: Bocquet, Lebascle 1983, Pl. 6: 2,8; Larnaud: Déchelette 1924, 407, Fig. 164; Schiers: Keller-Tarnuzzer 1935, Fig. 2–10; Filisur: Wyss 1971, Fig. 7: 6; Bologna – San Francesco: Zannoni 1888, Pl. 25a; 'tra Manciano e Samprugnano': Peroni 1961, I 5: 69,76–77,79,89; Villamarzana: Arenoso Callipo, Bellintani 1994, Fig. 28: 1; Frattesina II: Salzani 2000, 40, Fig. 4: 26–28; Frattesina IV: id. 2003, 44, Fig. 3: 15; Montagnana: Bianchin Citton 1986, Fig. 11: 68–69; 14: 131; Kapelna: Bulat 1967, Pl. 1: 7, 3: 7; Miljana: Vinski-Gasparini 1973, Pl. 112: 12,18–23.

[46] Lo Schiavo, Macnamara, Vagnetti 1985, 14–15, Fig. 5–7; Lo Schiavo 1998, Fig. 2: 4,3; Matthäus, Schumacher-Matthäus 1986, Fig. 21: 4,6.

[47] Žbona-Trkman, Bavdek 1996, Pl. 113: 272; 115: 10; Borgna 1992, Pl. 4: 17; Peroni 1961, I 5: 133.

[48] Žbona-Trkman, Bavdek 1996, Pl. 110: 200–205; 112: 241–245; 113: 265; 115: 16–17,20; 116: 22–28; Borgna 1992, Pl. 5: 27,29–31; Peroni 1961, I 5: 54,59,88,95; Stein 1979, Pl. 77: 24; 93: 12.

[49] Trampuž Orel, Heath, Hudnik 1998, 232, Pl. 2; Žbona-Trkman, Bavdek 1996, Pl. 114B: 4; 115: 11,15; Čerče, Šinkovec 1995, Pl. 139: 1; Borgna 1992, Pl. 5: 26.

[50] Borgna 1992, Pl. 11: 4.

[51] Udine, Redipuglia: Borgna 1992, Pl. 10: 1–4; 11: 3; Kapelna: Bulat 1967, Pl. 3: 8–9.

[52] The Bokod, Biatorbágy and Beremend hoards: Mozsolics 1985, Pl. 232B: 5; 237: 28–30; 252: 15, and the Madriolo hoard from Friuli: Borgna 1992, 38–39, Pl. 6: 34.

[53] Schiers: Keller-Tarnuzzer 1935, Fig. 2, 4–5; 'tra Manciano e Samprugnano': Peroni 1961, I 5: 106.

[54] Mayer 1977, 18–19, Pl. 125: 1.

[55] Gaucher 1981, Fig. 112: D12.

[56] Matthäus, Schumacher-Matthäus 1986, Fig. 26: 37.

[57] Pare 1999, 496–497, Table 12.

from the Dragomelj hoard (Cat. No. 1) weighs 2,844 g, which is almost precisely a sixfold multiple of this unit (475 g × 6 = 2850 g).[58] According to Pare, biconical ingots, together with several other objects or weights in northern Italy, *Caput Adriae*, and Pannonia mark the adoption of eastern Mediterranean or Cypriot weight standards from the 12th century BC onward.[59]

The average length of the fragmented BIs varies by region.[60] Their degree of fragmentation increases from the Alpine regions of France, Switzerland, Austria, Slovenia, and Friuli, where the average length is between 8 and 20 cm, to Romagna and Tuscany, where the more highly fragmented examples show an average length between 2 and 8 cm. This may reflect an increasing share of small fragments along the routes leading from the ore deposits to the final destinations in northern and central Italy. In this parameter, the BIs from Dragomelj with an average length of 10.3 cm are similar to those from Friuli.

## CHEMICAL INVESTIGATION

### ICP-AES analyses

Fifty complete and fragmented ingots from the Dragomelj I hoard, comprising twelve biconical ingots (BI) and 38 plano-convex ingots (PCI), were analysed as part of a long-term chemical study on Slovenian copper and bronze artefacts (1996 – present). The analysis was performed at the National Institute of Chemistry in Ljubljana, Slovenia, using inductively coupled plasma atomic emission spectrometry (ICP-AES). The full details on sampling, preparation, analysis, and quality control have already been published.[61] The results are presented in *Fig. 6* as weight fractions (wt%).

When discussing the results, it is essential to remember measurement uncertainty when comparing elemental compositions across different objects. One source of measurement uncertainty is sample homogeneity and hence the representativeness of a sample, especially when using small-diameter bits for large, often internally heterogeneous objects.[62] PCIs are an excellent example, often having complex internal structures that include large vesicles and slag, but also displaying internal stratification due to more than one pouring of molten material in the case of large ingots. [63] The solubility of elements in copper also varies; for example, lead is only sparingly soluble in copper, and as the content of lead increases, it forms around grain boundaries, eventually pooling to form globules and even a lead core, which can potentially result in it being over or under-represented.[64] Sub-sampling from the original turnings represents another source of uncertainty. In this case, a representative sample was created by combining turnings from holes drilled at the top and bottom of the centre of the ingot.

### Tin

The content of tin (Sn) in the analysed ingots is shown in *Fig. 7*. Chemical analysis reveals that seven of the BIs (Cat. Nos. 1, 2, 4, 5, 6, 8, and 10) contain added Sn (2.23–5.12 wt%) and are low Sn bronzes. Among the LBA hoards from Slovenia, such levels of Sn (approx. ≤5 wt%) are typically associated with sickles.[65] The non-Sn-bronze BIs (Cat. Nos. 3, 9, 11, and 12), with high amounts

[58] Also significant are the weights of the fragmented ingots with heavily worn fractures with Cat. Nos. 4, 6, and 12 (981 g, 976 g, and 927 g) exhibiting approximately one third of the weight of the complete ingot (2844 g) with Cat. No. 1 (Turk, Svetličič, Pavlovič 2023, 109, Fig. 143).

[59] Pare 1999, 507–508.

[60] Tasca, Vicenzutto 2020, 254–255, Fig. 1–2.

[61] Trampuž Orel, Heath, Hudnik 1998, 224; Trampuž Orel, Heath, Orel 2016, 303–304.

[62] Sampling (drilling) of smaller cast objects such as sickles shows good reproducibility when sampled at different locations within an object, see Trampuž Orel et al. 1991, 268.

[63] Modl 2019, 375.

[64] Trampuž Orel, Heath 1998, 244.

[65] Trampuž Orel 1996, 186–187, Fig. 2.

→

*Fig. 6:* Dragomelj, Hoard I. Results of the ICP-AES analysis.
*Sl. 6:* Dragomelj, depo I, rezultati analiz ICP-AES.

* – Catalogue numbers of objects in the first publication / kataloške številke predmetov v prvi objavi (Turk, Svetličič, Pavlovič 2023, G1226–G1277); < d.l. – below the detection limit / pod mejo zaznavnosti: Sn (0.006 wt%), Pb (0.015 wt%), As (0.03 wt%), Ni (0.0045 wt%), Sb (0.03 wt%), Co (00.0015 wt%), Bi (0.015 wt%), Ag (0.0045 wt%), Fe (0.0012 wt%), Zn (0.04 wt%). Half the d.l. was used for statistical analysis / za statistično analizo je bila uporabljena polovica meje zaznavnosti; n.d. – not determined / ni določeno.

| Cat. No. / Kat. št. | Cat. No. / Kat. št.* | | Element (wt% / utežni %) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Cu | Sn | Pb | As | Ni | Sb | Co | Bi | Ag | Fe | Zn |
| 1 | 1226 | BI | 88 | 4.576 | 1.77 | 0.10 | 0.038 | 0.34 | 0.056 | 0.039 | 0.054 | 1.047 | 0.447 |
| 2 | 1227 | BI | 85 | 3.026 | 10.6 | 0.07 | 0.018 | 0.08 | 0.027 | 0.010 | 0.108 | 0.697 | 0.081 |
| 3 | 1234 | BI | 85 | 0.030 | 0.17 | 1.58 | 1.887 | 4.76 | 0.646 | 0.027 | 0.391 | 0.249 | 0.136 |
| 4 | 1228 | BI | 88 | 4.560 | 6.93 | 0.33 | 0.322 | 0.10 | 0.094 | 0.022 | 0.248 | 0.110 | 0.370 |
| 5 | 1232 | BI | 88 | 2.230 | 6.25 | 0.19 | 0.017 | 0.24 | 0.102 | 0.026 | 0.152 | 0.765 | 0.131 |
| 6 | 1229 | BI | 88 | 5.123 | 6.83 | 0.19 | 0.032 | 0.03 | 0.045 | 0.041 | 0.057 | 1.135 | < d.l. |
| 7 | 1230 | BI | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. |
| 8 | 1238 | BI | 86 | 3.505 | 7.62 | 0.12 | 0.029 | 0.34 | 0.039 | < d.l. | 0.099 | 0.883 | 0.235 |
| 9 | 1233 | BI | 86 | 0.096 | 0.56 | 3.99 | 4.676 | 0.92 | 1.421 | 0.017 | 0.089 | 0.881 | 0.146 |
| 10 | 1235 | BI | 80 | 4.563 | 0.04 | 2.36 | 5.044 | 0.04 | 2.764 | 0.028 | 0.007 | 5.448 | 0.049 |
| 11 | 1237 | BI | 93 | 0.009 | 0.08 | 0.41 | 3.489 | 0.21 | 0.497 | < d.l. | 0.082 | 2.265 | < d.l. |
| 12 | 1231 | BI | 90 | 0.053 | 0.32 | 1.64 | 5.844 | 0.35 | 2.131 | < d.l. | 0.323 | 0.664 | < d.l. |
| 13 | 1236 | BI | 86 | 0.094 | 0.69 | 3.29 | 4.437 | 1.70 | 1.853 | 0.032 | 0.339 | 1.753 | 0.112 |
| BI min. | | | 80 | 0.009 | 0.04 | 0.07 | 0.017 | 0.03 | 0.027 | <d.l. | 0.007 | 0.110 | <d.l. |
| BI max. | | | 93 | 5.12 | 10.6 | 3.99 | 5.84 | 4.76 | 2.76 | 0.041 | 0.391 | 5.45 | 0.447 |
| BI Avg. / povpr. | | | 87 | 2.32 | 3.49 | 1.19 | 2.15 | 0.76 | 0.806 | 0.027 | 0.162 | 1.325 | 0.190 |
| 14 | 1239 | PCI | 94 | 0.008 | 0.04 | 0.18 | 0.049 | 0.47 | 0.009 | 0.017 | 0.355 | 0.204 | 0.038 |
| 15 | 1240 | PCI | 87 | < d.l. | 0.04 | 0.22 | 2.470 | 0.03 | 0.042 | 0.022 | 0.009 | 0.424 | < d.l. |
| 16 | 1241 | PCI | 91 | 0.024 | < d.l. | 1.74 | 4.038 | 0.33 | 0.117 | n.d. | < d.l. | 0.680 | < d.l. |
| 17 | 1242 | PCI | 78 | 0.008 | 0.20 | 3.46 | 0.047 | 11.6 | 0.004 | 0.073 | 0.179 | 0.038 | 0.027 |
| 18 | 1243 | PCI | 99 | 0.008 | < d.l. | 0.71 | 1.958 | 0.12 | 0.102 | < d.l. | < d.l. | 0.872 | < d.l. |
| 19 | 1244 | PCI | 90 | 0.028 | 0.04 | 1.09 | 3.192 | 0.19 | 0.057 | 0.021 | 0.013 | 0.385 | < d.l. |
| 20 | 1245 | PCI | 80 | 0.031 | 0.18 | 3.38 | 0.339 | 12.5 | 0.008 | 0.083 | 0.854 | 0.339 | < d.l. |
| 21 | 1246 | PCI | 97 | 0.003 | < d.l. | 0.89 | 3.867 | 0.28 | 0.076 | n.d. | < d.l. | 0.280 | < d.l. |
| 22 | 1247 | PCI | 79 | 0.017 | 0.63 | 3.57 | 5.532 | 10.8 | 1.761 | 0.098 | 0.122 | 1.056 | < d.l. |
| 23 | 1248 | PCI | 96 | 0.008 | 0.04 | 0.20 | 5.088 | 0.05 | 0.075 | 0.022 | 0.014 | 0.493 | 0.056 |
| 24 | 1249 | PCI | 86 | < d.l. | < d.l. | 0.06 | 0.034 | < d.l. | 2.316 | < d.l. | < d.l. | 13.14 | < d.l. |
| 25 | 1250 | PCI | 94 | 0.049 | 0.72 | 0.09 | 0.447 | 0.12 | 0.102 | < d.l. | 0.067 | 2.014 | 0.316 |
| 26 | 1251 | PCI | 95 | 0.029 | 1.13 | 0.05 | 0.039 | 0.04 | 0.047 | 0.027 | 0.071 | 1.399 | 0.648 |
| 27 | 1252 | PCI | 95 | 0.040 | 4.63 | 0.20 | 0.048 | 0.32 | 0.039 | 0.077 | 0.102 | 0.579 | 0.635 |
| 28 | 1253 | PCI | 96 | 0.062 | 0.47 | 1.59 | 0.200 | 0.32 | 0.233 | 0.129 | 0.094 | 0.825 | 0.001 |
| 29 | 1254 | PCI | 96 | 0.105 | 1.52 | 0.07 | 0.042 | 0.08 | 0.053 | 0.023 | 0.046 | 2.330 | 0.495 |
| 30 | 1255 | PCI | 95 | 0.042 | 0.39 | 0.03 | 0.022 | 0.09 | 0.036 | < d.l. | 0.041 | 1.028 | 0.310 |
| 31 | 1256 | PCI | 96 | 0.038 | 0.29 | 0.10 | 0.016 | 1.87 | 0.046 | 0.078 | 0.073 | 0.631 | 0.366 |
| 32 | 1257 | PCI | 89 | < d.l. | 0.04 | 1.55 | 5.171 | 0.31 | 0.057 | 0.021 | 0.012 | 0.539 | 0.039 |
| 33 | 1258 | PCI | 99 | < d.l. | < d.l. | 0.03 | 0.134 | 0.11 | 0.008 | < d.l. | 0.043 | 0.327 | < d.l. |
| 34 | 1259 | PCI | 98 | 0.013 | 0.14 | 0.54 | 0.156 | 3.96 | 0.017 | < d.l. | 0.024 | 0.250 | < d.l. |
| 35 | 1260 | PCI | 94 | 0.008 | 0.87 | 1.51 | 0.132 | 3.25 | 0.044 | < d.l. | 0.384 | 0.456 | < d.l. |
| 36 | 1261 | PCI | 83 | 0.155 | 0.06 | 0.04 | 0.002 | < d.l. | 0.086 | 0.064 | 0.135 | 1.610 | 0.053 |
| 37 | 1262 | PCI | 95 | 0.014 | 0.01 | 1.13 | 2.161 | 0.23 | 0.127 | < d.l. | < d.l. | 1.084 | < d.l. |
| 38 | 1263 | PCI | 100 | < d.l. | < d.l. | 0.90 | 0.508 | 0.23 | 0.046 | < d.l. | < d.l. | 0.800 | < d.l. |
| 39 | 1264 | PCI | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. |
| 40 | 1265 | PCI | 92 | 0.045 | 0.04 | 0.59 | 4.143 | 0.12 | 0.906 | < d.l. | 0.078 | 1.548 | < d.l. |
| 41 | 1266 | PCI | 99 | < d.l. | < d.l. | 0.07 | 0.047 | < d.l. | 0.016 | n.d. | < d.l. | 0.698 | < d.l. |
| 42 | 1267 | PCI | 96 | < d.l. | 0.03 | 0.37 | 0.100 | 3.50 | 0.017 | < d.l. | 0.032 | 0.568 | < d.l. |
| 43 | 1268 | PCI | 98 | < d.l. | 0.08 | 0.52 | 0.382 | 0.87 | 0.028 | n.d. | < d.l. | 0.393 | < d.l. |
| 44 | 1269 | PCI | 88 | 0.050 | 0.26 | 1.14 | 3.073 | 1.73 | 1.312 | < d.l. | 0.758 | 0.873 | 0.086 |
| 45 | 1270 | PCI | 95 | 0.011 | 0.07 | 1.03 | 0.275 | 2.32 | 0.046 | < d.l. | 0.198 | 0.872 | < d.l. |
| 46 | 1271 | PCI | 84 | 2.10 | 0.25 | 0.91 | 2.148 | 1.09 | 2.004 | 0.023 | 0.059 | 5.827 | 0.026 |
| 47 | 1272 | PCI | 93 | < d.l. | 0.08 | < d.l. | 0.106 | 0.02 | 0.092 | < d.l. | 0.047 | 7.645 | < d.l. |
| 48 | 1273 | PCI | 93 | < d.l. | 0.17 | 0.63 | 0.155 | 5.45 | 0.016 | < d.l. | 0.041 | 0.213 | < d.l. |
| 49 | 1274 | PCI | 93 | < d.l. | 0.06 | 1.11 | 0.074 | 4.04 | 0.073 | < d.l. | 0.012 | 1.300 | < d.l. |
| 50 | 1275 | PCI | 93 | < d.l. | 0.01 | 4.11 | 0.130 | 5.50 | < d.l. | 0.115 | 0.317 | 0.000 | < d.l. |
| 51 | 1276 | PCI | 94 | 0.011 | 0.08 | 0.42 | 3.169 | 0.21 | 0.460 | < d.l. | 0.053 | 2.018 | < d.l. |
| 52 | 1277 | PCI | 96 | 0.121 | 0.11 | 1.95 | 0.190 | 0.14 | 0.515 | 0.241 | 0.074 | 2.649 | < d.l. |
| PCI min. | | | 78 | < d.l. | < d.l. | 0.02 | 0.002 | < d.l. | < d.l. | < d.l. | < d.l. | < d.l. | < d.l. |
| PCI max. | | | 100 | 2.099 | 4.63 | 4.11 | 5.53 | 12.5 | 2.316 | 0.241 | 0.854 | 13.1 | 0.648 |
| PCI Avg. / povpr. | | | 93 | 0.081 | 0.33 | 0.95 | 1.307 | 1.91 | 0.289 | 0.037 | 0.113 | 1.48 | 0.094 |
| **Total / Skupaj** | | | **Cu** | **Sn** | **Pb** | **As** | **Ni** | **Sb** | **Co** | **Bi** | **Ag** | **Fe** | **Zn** |
| **min.** | | | 78 | < d.l. | < d.l. | < d.l. | 0.002 | < d.l. | < d.l. | < d.l. | < d.l. | < d.l. | < d.l. |
| **max.** | | | 100 | 5.123 | 10.59 | 4.11 | 5.844 | 12.54 | 2.764 | 0.241 | 0.854 | 13.135 | 0.648 |
| **Avg. / povpr.** | | | 91 | 0.619 | 1.09 | 1.01 | 1.510 | 1.63 | 0.413 | 0.033 | 0.125 | 1.446 | 0.107 |

of As, Ni, and Sb, predominantly belong to Type 4 without a shaft hole (*Fig. 8*). One BI of Type 4 (Cat. No. 10) is an exception, containing tin (4.56 wt%) and high amounts of As (2.36 wt%), Ni (5.04 wt%), and Co (2.76 wt%) (*Fig. 8*: 10). The composition of the ingot with Cat. No. 13, tentatively attributed to Type 2, suggests that it is similar to that of the copper ingots without a shaft hole (Type 4, Cat. Nos. 3, 9, and 11). We should note that the alloying of Sn is rare among the published compositions of contemporaneous BIs.[66]

Regarding plano-convex ingots, four of the 38 PCIs and their fragments (Cat. Nos. 29, 36, 46, and 52) contain Sn above what we expect for raw copper. The highest amount is found in Cat. No. 46 (2.1 wt%). Together with other PCIs (Cat. Nos. 29, 36, and 52) where Sn is >0.1 wt%, it suggests the possible presence of recycled Sn-bronze in the copper. Plano-convex ingots containing Sn >1 wt% are rare in the analysed hoards from Slovenia.

Only a few analyzed PCIs from Slovenia contain 0.1–1.4 wt% Sn, suggesting the presence of recycled Sn bronze.[67] These include the hoards of Udje and Kanalski Vrh II. The former belongs to Ha A or Horizon 2 of the south-eastern Alpine hoards.[68] The recycled Sn bronze in the PCIs from Udje can be viewed as similar to contemporaneous phenomena in the Pannonian hoards.[69] Typically, Sn would have been added to the copper just before casting to allow greater control over the alloy, and the lack of tin (and lead) may have been a conscious decision to keep the pure copper separate, i.e., that PCIs were (typically) kept as identifiable forms of pure (un-alloyed) copper while other material was in cast ingot form at least for the earlier hoards. Notably, the PCIs from the recently published Jelenov klanec hoard from Kranj also show that adding scrap tin-bronze (Sn: 1.77–1.86 wt%) was more common at the beginning of the Early Iron Age.[70] In terms of dating and composition, Dragomelj I is close to the Kanalski Vrh II and Pod Kotom–jug hoards.[71]

## Lead

The lead (Pb) mineral galena, its most common mineral in the form of lead (II) sulphide, is often associated with copper ores, and as a result, copper can sometimes naturally contain several per cent of Pb.[72] This and the fact that only small amounts of added Pb are needed (1–2 wt%) to improve castability make determining the demarcation between unalloyed and alloyed copper with Pb challenging. Moreover, recycling

[66] Trampuž Orel 1996, 188 (Anal. Nos. 607, 645 and 729).
[67] Trampuž Orel 1996, Anal. Nos. 438, 450 (Jurka vas); 770, 772, 774, 776, 777 (Kanalski Vrh II); 815 (Pekel); 831 (Silovec); 893, 894, 897, 899 (Udje).
[68] Turk 1996, 108–112.
[69] Mozsolics 1981.
[70] Pavlin et al. 2024, 186–187, Table 4, Fig. 10.
[71] Žbona-Trkman, Bavdek 1996, 64–67; Trampuž Orel, Urankar 2009, 155, Fig. 94: Anal. Nos. 15–16.
[72] Pernicka 2014, 256.

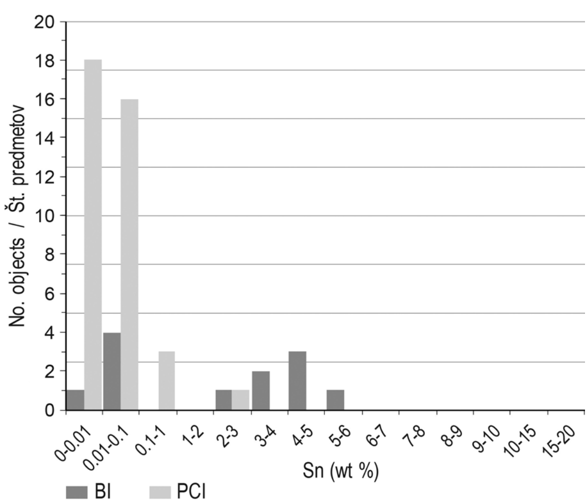


*Fig. 7:* Dragomelj, Hoard I. Tin content (Sn wt%).
*Sl. 7:* Dragomelj, depo I. Vsebnost kositra (Sn wt%).
BI – biconical ingots / dvokonični ingoti; PCI – plano--convex ingots / planokonveksne pogače.

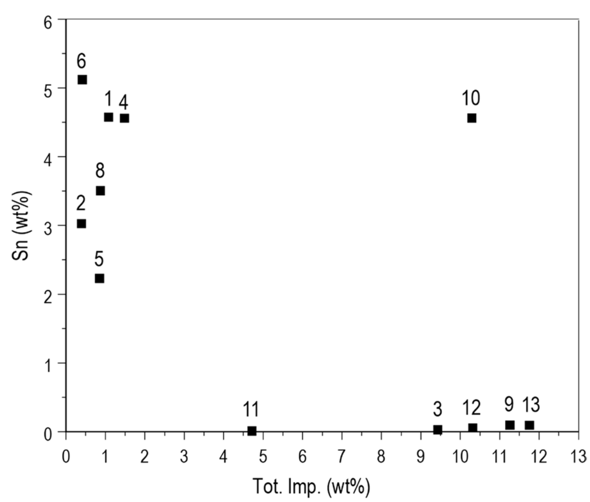


*Fig. 8:* Dragomelj, Hoard I. Tin (Sn wt%) to total sum of impurities (Tot. Imp. wt%) ratio.
*Sl. 8:* Dragomelj, depo I. Razmerje med kositrom (Sn wt%) in vsoto nečistoč (Tot. Imp. wt%).

copper that contains Pb can add to this problem.[73] From the literature, lead contents of >1wt%,[74] >3%,[75] or >5%[76] are suggested to indicate the deliberate addition of Pb. The examination of the analysed raw material (PCI) from the LBA hoards in Slovenia shows that except for a possible PCI from Udje,[77] Pb is typically <0.06 wt% and rarely exceeds 0.1 wt%, agreeing with the literature that a value >1 wt% is a good indicator of alloying with Pb.

The content of Pb (*Fig. 9*) in the Dragomelj finds ranges from <d.l. to 10.6 wt% (avg.: 1.09 wt%). Among the ingots are six leaded tin-bronze (Cu-Sn-Pb) BIs (Cat. Nos. 1, 2, 4, 5, 6, and 8) with Pb content ranging from 1.77 to 10.6 wt% and all having low impurities (≤1 wt%). Of these, five are of the biconical form with a shaft hole (Types 1–3: Cat. Nos. 1, 2, 4, 5, and 6), while two (Cat. Nos. 8 and 10) are without the shaft hole. In PCIs, lead ranges from <d.l. to 5.53 wt% (avg.: 0.33 wt%). Three PCIs also contain Pb <1 wt%: Cat. No. 27 (4.63 wt%), Cat. No. 26 (1.13 wt%) and Cat. No. 29 (1.5 wt%), indicating the recycling/mixing of Sn-Pb-Cu bronze and Pb-Cu, similar to that suggested by the Sn contents of specific artefacts.

| Pb wt% | Objects / Predmeti | | PCI | | Ingots | |
|---|---|---|---|---|---|---|
| | Ha A | Ha B | Ha A | Ha B | Ha A | Ha B |
| Number / Število | 434 | 131 | 102 | 9 | 7 | 199 |
| Average / Povprečje | 0.87 | 4.28 | 0.10 | 0.13 | 7.51 | 24.84 |
| Min | <l.d. | 0.02 | <l.d. | 0.02 | <l.d. | 0.01 |
| Max | 38.8 | 57.1 | 1.01 | 0.24 | 49.5 | 89.1 |

*Fig. 10:* The amount of lead in the copper PCIs and cast ingots in the Ha A and Ha B hoards from Slovenia (see Note 80).
*Sl. 10:* Vsebnost svinca v bakrenih pogačah in ulitih ingotih v depojih iz Ha A in Ha B v Sloveniji (gl. op. 80).
PCI – plano-convex ingots / planokonveksne pogače.

Although Sn-Pb-Cu bronzes and Pb-Cu objects are known in western and southern Europe during the Bronze Age, adding Pb to copper and bronze objects increased decisively in the Late Urnfield period (Ha B) and Early Iron Age (*Fig. 10*).[78] In contrast to PCIs, cast ingots (BIs) also contain significant additions of Pb.

Lead was likely added to copper and bronze to reduce copper's overall melting temperature and increase fluidity and castability, allowing an effective filling of intricate moulds.[79] However, the reason for adding high amounts of Pb to copper used for objects such as the shaft-hole axes from the hoards of Šempeter[80] and Jelenov klanec in Kranj[81] remains unclear. These objects may have had a value beyond their mechanical properties, i.e., a ritual or pre-monetary purpose.[82]

## Iron

The amount of iron (Fe) in the ingots from Dragomelj ranges from <d.l. to 13 wt% (*Fig. 6*). The Fe content in the artefacts from Slovenian hoards is typically low (<0.1), with levels >1% more frequent in PCIs (0.01 to 45.6 wt%; avg. = 2.45 wt%) then

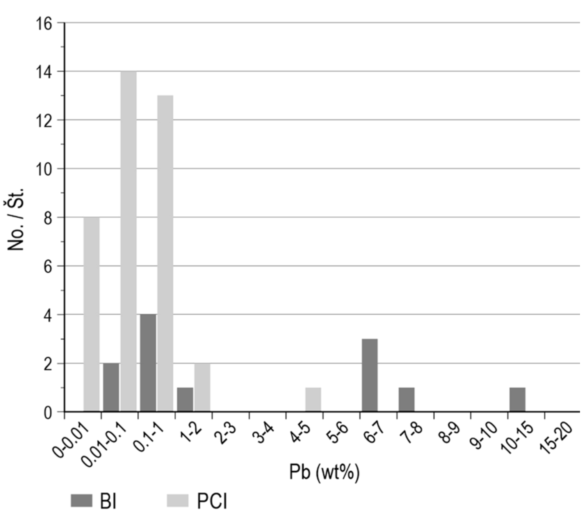


*Fig. 9:* Dragomelj, Hoard I. Lead content (Pb wt%).
*Sl. 9:* Dragomelj, depo I. Vsebnost svinca (Pb wt%).
BI – biconical ingots / dvokonični ingoti; PCI – plano--convex ingots / planokonveksne pogače.

[73] Muhly 1985, 80.
[74] Liversage 2000, 65.
[75] Northover et al. 2008, 4.
[76] Pernicka et al. 1990, 268–270.
[77] Trampuž Orel 1996, 234, Anal. No. 894: Pb = 1 wt%; see an additional outlier from the Jurka vas hoard (Čerče, Šinkovec 1995, 203, Pl. 93: 84; Trampuž Orel 1996, Anal. No. 454), which is also an outlier in its extremely high amount of tin (8.83 wt%).

[78] Trampuž Orel 1996, 189–201, Fig. 4–6; Trampuž Orel, Heath 1998.
[79] Craddock 1978; Klein, Hauptmann 1999, 1080.
[80] Trampuž Orel 1996, 233 (Anal. Nos. 854–867), Trampuž Orel, Heath 1998, 240–245, Table 1.
[81] Pavlin et al. 2024, Table 4, Fig. 13.
[82] Staniaszek, Northover 1983; Trampuž Orel, Heath 1998, 246.

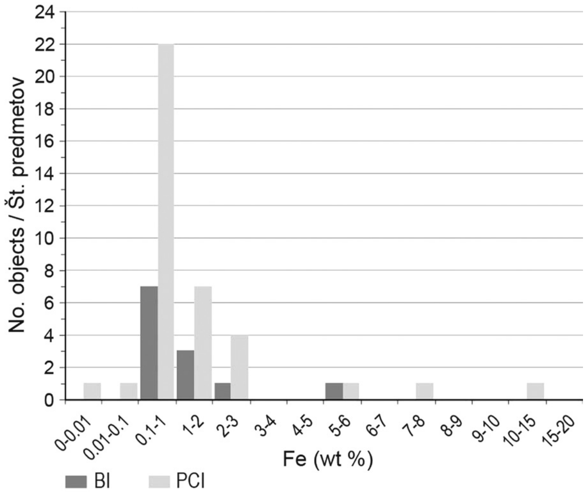


*Fig. 11:* Dragomelj, Hoard I. Iron content (Fe wt%).
*Sl. 11:* Dragomelj, depo I. Vsebnost železa (Fe wt%).
BI – biconical ingots / dvokonični ingoti; PCI – plano--convex ingots / planokonveksne pogače.

in cast ingots (<l.d. to 14.9 wt%; avg.: 0.9 wt%). The PCI fragment with ≈ 45 wt% comes from the Kanalski Vrh I hoard.[83] As expected, the average Fe content in cast objects is lower, given that casting represents a potential further purification step in removing Fe and other oxidisable impurities.[84] In the case of the Dragomelj hoard, the distribution of Fe (*Fig. 11*) in the PCIs (< l.d. to 13.1 wt%; avg. = 1.5 wt%) and the BIs (0.1 to 5.4 wt%; avg. = 1.3 wt%) is similar; it is also similar to that of the raw material (PCIs) in the Ha A and B hoards, which is indicative of smelting sulphidic (chalcopyrite) ores.[85]

Chemical analysis alone cannot distinguish between different forms of Fe, such as Fe oxides versus metallic Fe dissolved in copper. This distinction requires further metallographic analysis.[86] It is well-reported that the Fe content depends on the smelting process[87], which indicates the smelting of sulphidic ores and the sophistication of the smelting practices. A Fe content >3 wt% is typically associated with strongly reducing conditions during primary smelting, where Fe is reduced and dissolves into the copper.[88]

[83] Trampuž Orel 1996, 229, Anal. No. 716.
[84] Pernicka 1999, 254.
[85] Trampuž Orel 1996, 201–202, Fig. 9.
[86] Chemical analysis typically provides elemental compositions without directly revealing the specific chemical forms (phases).
[87] Craddock, Meeks 1987.
[88] Craddock, Meeks 1987; Trampuž Orel et al. 2002, 66, 71.

## Other impurities

The diagnostic impurities in the copper of the Dragomelj hoard (As, Ni, Sb, Ag, Bi, and Co) reveal different, but distinct impurity patterns appearing in both BIs and PCIs. When impurities are summed together, there are ingots with similar low and significantly high levels of impurities (*Fig. 12–13*), ranging from 0.33 to 21.87 wt%, with most (72%) having >1 wt%. In the BIs, total impurities range from 0.31 to 11.6 wt% with an average of 5.09 wt%, while total impurities in the PCIs range from 0.15 to 21.9 wt%, averaging 4.60 wt%. Compared to the earlier finds from Slovenian hoards, copper with high impurities is characteristic of Ha B objects. Although the analyses of raw material from Ha B are skewed by the many cast ingots and other objects in the Kanalski Vrh I and II hoards, the analysis of the Dragomelj I and other hoards affirms this finding.[89]

The presence of high levels of impurities can significantly affect the observable properties and have a positive or detrimental impact (in the case of really high levels where the metal can be considered an alloy rather than copper with trace impurities) on the copper properties, e.g., hardness, castability, and workability. It can also alter the appearance of copper, giving it a more silvery metallic lustre. Such changes would have

[89] Trampuž Orel 1996, 202–209, Fig. 12–14; Trampuž Orel, Heath, Orel 2016, 305–310, Fig. 93–96.

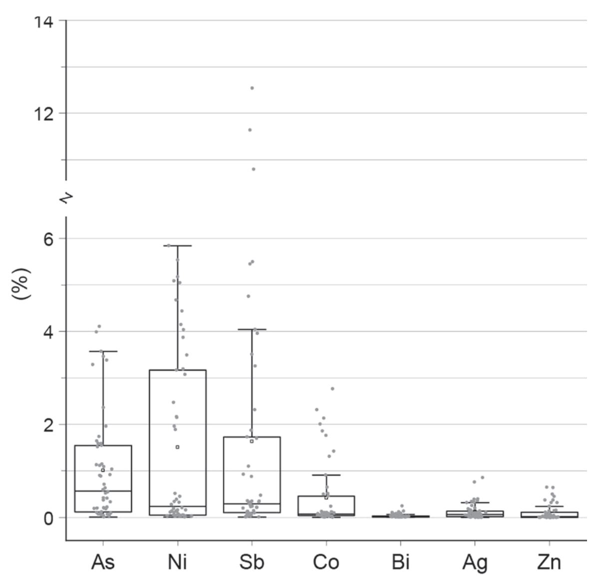


*Fig. 12:* Dragomelj, Hoard I. Box and whisker plots with levels of impurities in the ingots.
*Sl. 12:* Dragomelj, depo I. Škatlasti diagrami s prikazom pogostosti vsebnosti nečistoč v predmetih iz depoja.

been readily noticeable to the early smiths and may explain the possible test cuts on some PCIs (e.g., Cat. No. 15).[90]

As mentioned above, all but one of the BIs alloyed with tin and lead contain low amounts of these impurities (<1 wt%) compared to the other BIs (1–11 wt%). Together with other analysed objects in the hoards from Slovenia and elsewhere, it supports the hypothesis that this high-impurity copper, often derived from polymetallic ores such as fahlores and accessory minerals, was sometimes used when tin was perhaps unavailable, contributing to alloy properties similar to those of bronze. It also shows that high-impurity copper was often diluted with purer copper to enhance its workability to obtain the desired metallurgical properties.[91] The evidence for the former can be seen in the compositions of many hoard finds from Slovenia and elsewhere.[92]

Individually, elemental contents show the following ranges: (As from <d.l. to 4.11 wt% (avg. 1.01 wt%), nickel (Ni) from 0.002. to 5.84 wt% (avg. 1.51 wt%), antimony (Sb) from <d.l. to 12.54 wt% (avg. 1.63 wt%), cobalt (Co) from <d.l. to 2.76 wt% (avg. 0.41 wt%), bismuth (Bi) from <d.l. to 0.24 wt% (avg. 0.033 wt%), silver (Ag) from <d.l. to 0.85 wt% (avg. 0.125 wt%) and zinc (Zn) from <d.l. to 0.648 wt% (avg. 0.209 wt%) (*Fig. 6, 13*).

[90] Modl 2019; Haubner, Strobl 2022, 736.

[91] Trampuž Orel, Heath 2001, 170.

[92] Trampuž Orel, Heath 2001, 170; Lutz, Pernicka 2013, 122.

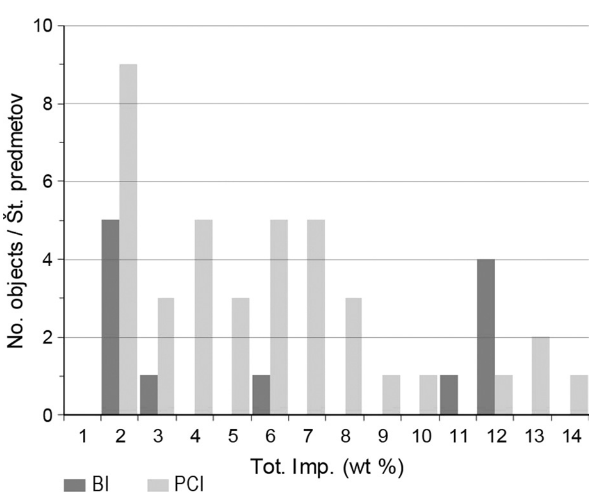


*Fig. 13:* Dragomelj, Hoard I. The amount of total impurities (As, Ni, Sb, Co, Bi, and Ag wt%) in the analysed ingots.
*Sl. 13:* Dragomelj, depo I. Vsebnost vseh nečistoč wt% (As, Ni, Sb, Co, Bi in Ag).
Tot. Imp. (wt%) – total sum of impurities / skupni seštevek nečistoč; BI – biconical ingots / dvokonični ingoti; PCI – plano-convex ingots / planokonveksne pogače.

In the case of the types of copper from Dragomelj, their composition with regards to the As, Ni, and Sb groups appear similarly distributed for both BIs and PCIs (*Fig. 14A*). Notably, the distribution of the copper types is similarly divided between copper with dominating Ni (Groups 3 (Ni>As>Sb) and 4 (Ni>Sb>As; Ni=Sb>As; Ni>Sb=As)) and copper with dominating Sb (Group 6 (Sb>As>Ni)) according to Trampuž Orel, who based her division on the original classification by Rychner and Kläntschi.[93] Compositions with dominant As (Groups 1 and 2) are few in Dragomelj. This pattern differs from the PCIs and cast ingots of a Ha A dating (*Fig. 14B*),[94] in which the As dominant Groups 1 and 2 prevail, although Group 3 is also represented, whereas a single PCI represents Group 4.

Compositionally, copper with Ni as the dominant impurity (Group 3) is known in the analysed ingots from Slovenia, but Ni contents >2 wt% are rare in PCIs, especially >5 wt%, while the same PCIs are low in As (<1 wt%) and Sb (<1 wt%). This copper (e.g., Cat. Nos. 11, 15, 21, 23, 40, and 51) appears closely related, possibly from the same source. Several ingots also have high amounts of Co (>1 wt%).

When considering the whole corpus of analysed Slovenian finds, a clear shift occurs not only from lower to higher impurity copper, but also from As as the dominant impurity in Ha A to Sb becoming more dominant in Ha B and increasing in concentration[95] or, more specifically, from Groups 1 (As>Sb>Ni, AS>Sb=Ni, AS=Sb>Ni) and 2 (As>Ni>Sb, AS=Ni>Sb) accounting for 77% of the copper type to Groups 5 (Sb>Ni>As) and 6 (Sb>As>Ni, Sb>As=Ni) (*Fig. 14C*). This change in the chemical signature is well-documented in the literature.[96] It is believed to represent a shift from using eastern Alpine chalcopyrite back to exploiting fahlore ores (tetrahedrite: $(Cu, Fe)_{12}Sb_4S_{13}$, and tennantite $(Cu, Fe)_{12}As_4S_{13}$). The reason for this

[93] Trampuž Orel 1996, 202–208, Fig. 11–14; Rychner, Kläntschi 1995, 27–28.

[94] Trampuž Orel 1996, App. A (data on the PCIs and cast ingots from the hoards of Čermožiše (Anal. Nos. 53–55), Črmošnjice (Anal. Nos. 126–138), Debeli vrh (Anal. Nos. 209–233), Hercegovščak (Anal. No. 261), Hočko Pohorje (Anal. Nos. 380–395), Jurka vas (Anal. Nos. 432–452), Pekel (Anal. Nos. 813–818), and Silovec (Anal. Nos. 823–834).

[95] Trampuž Orel 1996, 202–206, Fig. 11–13, App. A (data on the PCIs and cast ingots from the hoards of Kanalski Vrh I (Anal. Nos. 581–716), Kanalski Vrh II (Anal. Nos. 717–777), and Veliki Otok I (Anal. Nos. 905–917).

[96] Lutz 2013, 125.

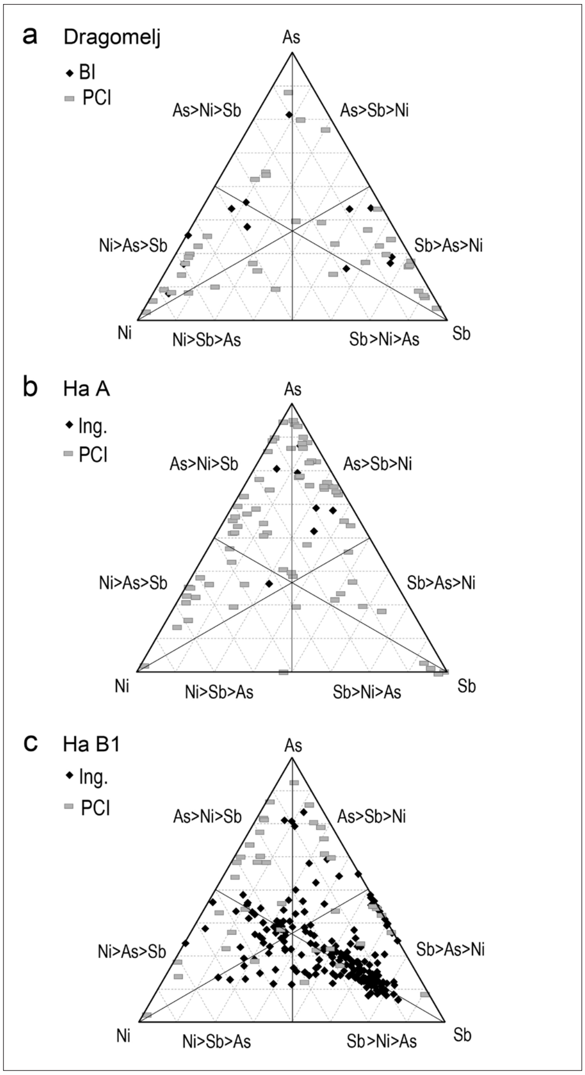


*Fig. 14:* Ternary plots of the relative ratios of As, Ni, and Sb from **a** – the Dragomelj I hoard in relation to ingots from other **b** – Ha A and **c** – Ha B hoards from Slovenia (see Notes 96–97).
*Sl. 14:* Trikotni diagrami relativnih razmerij As, Ni in Sb iz **a** – depoja Dragomelj I v primerjavi s pogačami in ingoti iz drugih slovenskih **b** – depojev Ha A ter **c** – depojev Ha B (gl. op. 96–97).
BI – biconical ingots / dvokonični ingoti; PCI – plano-convex ingots / planokonveksne pogače; Ing. – cast ingots / uliti ingoti.

| | **Element %** | | | | | |
|---|---|---|---|---|---|---|
| | As | Ni | Sb | Co | Bi | Ag |
| Min | 0.012 | 0.05 | <0.005 | <0.01 | <0.01 | >0.01 |
| Max | 3.1 | 9.5 | 0.41 | 0.46 | <0.01 | 0.46 |
| Median / Mediana | 0.32 | 0.40 | 0.028 | 0.04 | <0.01 | 0.04 |

*Fig. 15:* Table of typical amounts (%) of impurities of chalcopyrite copper from the Mitterberg area (see Note 100).
*Sl. 15:* Tabela značilnih vsebnosti (%) nečistoč pri halkopiritnem bakru z območja Mitterberg (gl. op. 100).

recurrence of the fahlore signature is thought to be either a decline in the importance of the major chalcopyrite deposits in the region (e.g., the Mitterburg deposits) or, more likely, an increase in the demand for copper, which could not be covered by the chalcopyrite mines alone, leading to the exploitation of other ores.[97] Overall, the Dragomelj I hoard compositionally fits well within the Ha A2/B1 period.

Regarding provenance, copper is either low in impurities or contains a few per cent Ni and As, but is low in Ag and Sb, which is typical of smelting chalcopyrite ores and accessory minerals, accounting for the high As and Ni. Copper from the eastern Alps, particularly the Mitterberg region (*Fig. 5*), would be a leading contender for this period, as it is a well-known primary source of chalcopyrite and associated Ni and As minerals. This region is known to have a complex geological history and a variety of mineral deposits, and has been exploited during the Early, Middle, and LBA, and even to the present day.

In particular, copper ores in this region have been associated with a variety of accessory minerals that contain arsenic, such as arsenopyrite (FeAsS) and enargite ($Cu_3AsS_4$), and nickel such as millerite (NiS), gersdorffite (NiAsS), and nickeline (NiAs), which are also present in the region. Mitterberg copper is defined as having an elemental composition that falls within specific elemental boundaries (*Fig. 15*).[98] Many of the Dragomelj ingots have compositional signatures within these boundaries (≈ 70%), i.e., characteristics of chalcopyrite that possibly originates from the region.

The remainder of the copper (≈ 30%) has a characteristic fahlore signature, high in Sb. The ratio of the two types is similar to that of chalcopyrite to fahlore copper proposed for Ha B3.[99] In the case of fahlore copper, there appear to be two groups: fahlore and fahlore rich in Ni and Co. The eastern Alps (Northern Grauwacken Zone) also have known prehistoric mining sites where fahlore (tetrahedrite-tennantite series) ores were exploited in the Bronze Age, such as the Schwaz-Brixlegg mining district in the lower Inn Valley.[100]

The fahlore copper from Schwaz and Brixlegg is characterised by high As, Sb, Ag, and Bi, but

[97] Pernicka, Lutz, Stöllner 2016.
[98] Lutz, Krutter, Pernicka 2019, 369.
[99] Grutsch et al. 2019, 343.
[100] Krismer et al. 2011.

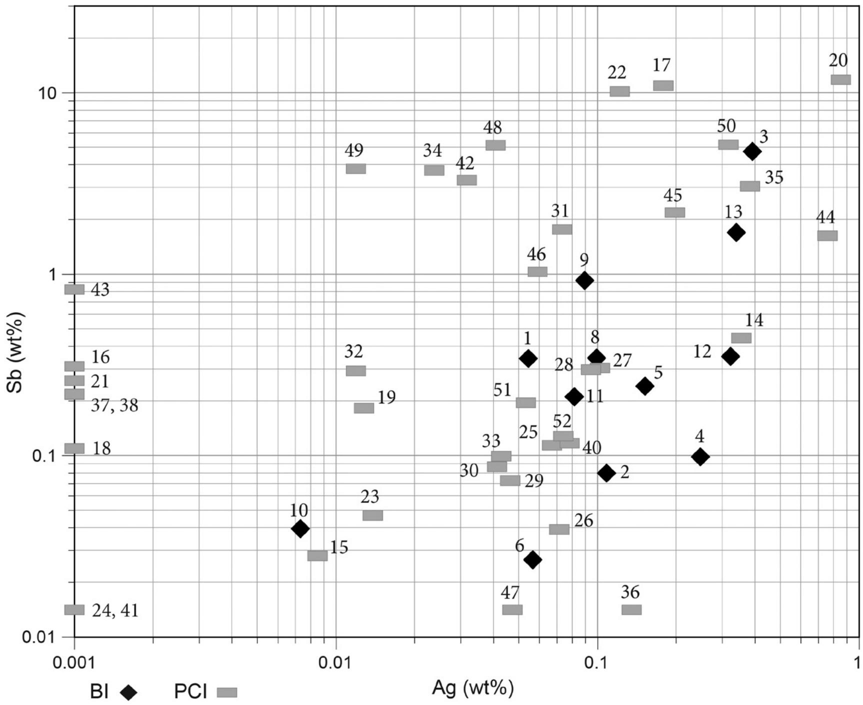


*Fig. 16:* Dragomelj, Hoard I. Sb to Ag ratio.
*Sl. 16:* Dragomelj, depo I. Razmerje med Sb in Ag.
BI – biconical ingots / dvokonični ingoti; PCI – plano-convex ingots / planokonveksne pogače.

low levels of cobalt and nickel.[101] However, only a few of the ingots (e.g., Cat. Nos. 20 and 44*)* have the characteristic fahlore copper, i.e., Group 6 with high Sb (≈ 1 wt%), high Ag (>0.5 wt%) and low Ni (<1 wt).[102] In the Dragomelj ingots and the analysed Slovenian LBA ingots, Ag is <1 wt% (*Fig. 16*).[103]

There are also ingots with exceptionally high antimony content, i.e., in the several per cent range, with three PCIs having >10 wt% (Cat. No. 17: 11.6 wt%, Cat. No. 20: 12.5 wt%, and Cat. No. 22: 10.8 wt%). All three have As ≈ 3 wt%, two have low Ni <1 wt%, Bi (<0.1 wt%), and Co (<0.01 wt%). Silver is above 0.1 wt%. The PCI with Cat. No. 22 differs in that it has >5 wt% Ni, while those with Cat. Nos. 17 and 20 have compositions similar to the PCIs (4.5 wt% As, 0.02 wt% Ni, 9.9 wt% Sb, 1.2 wt% Ag) from Velem-Szent Vid, in western Hungary,[104] Rannersdorf in Lower Austria (61 wt% As, 0.02 wt% Ni, 9.9 wt% Sb, 1.2 wt% Ag)[105] and pre-Alpine Bavaria (e.g., (No. 26) 4.3 wt% As, 0.01 wt% Ni, 10.5 wt% Sb, 1.17 wt% Ag) that date to Ha A2/B1, which the authors trace back to the fahlore deposits of the Schwaz-Brixlegg deposits.[106] Based on their metallographic examination of the Velem ingot, Haubner and Strobl propose that this results from the deliberate reaction of molten copper with antimonite ($Sb_2S_3$) rather than smelting copper ores rich in antimony.[107]

As for the BIs, they are widely spread in the Friuli region of north-eastern Italy. Here, the hoard that shares compositional similarities with Dragomelj was found at Porpetto and its analysis shows copper with variable amounts of impurities: 1–4 wt% As, 1.5–8.3 wt% Ni, 1–9.5 wt% Sb, 0.51 wt% Ag, characteristically with Ni-fahlore (+ Co) compositions.[108] Isotopically, the signals of the Porpetto ingots and other objects are, according to Canovaro, characterised by the overlap of the Trentino-Alto Adige, central European and Austrian fields.[109] She suggests the exploitation of

[101] Lutz, Pernicka 2013, 23.
[102] Möslein, Pernicka 2019, 403; Lutz 2016, Fig.17; Tropper et al. 2019, 158.
[103] Trampuž Orel 1996, App. A.
[104] Haubner, Strobl 2022, 736. The Velem PCI is not from any of the five Velem-Szent Vid hoards (Mozsolics 2000, 89–90), but a stray find kept at the Landesmuseum Burgenland in Austria.
[105] Reiter, Linke 2016, 167.
[106] Möslein, Pernicka 2019, 403.
[107] Haubner, Strobl 2022, 745.
[108] Canovaro 2016, 64.
[109] Canovaro 2016, 118.

the Cruvino mine in the western Alps, as well as of the copper sources in the southern Alps.

Making sense of the chemical compositions in copper in the LBA is complicated by the apparent traces of recycling, evident from the Sn content and, to a lesser degree, the Pb content in specific ingots. Other factors include the polymetallic nature of many of the ore deposits from the southern and eastern Alpine copper mining areas and the mixing (co-smelting) of chalcopyrite and fahlore copper ores, which can account for the presence of intermediate compositions, so-called 'Diluted Fahlore Copper'.[110] The idea centres on mixing high-impurity metal with copper smelted from chalcopyrite as a substitute for Sn[111] or to reduce the adverse effects of high As and Sb contents.[112] In the case of Dragomelj, the likely primary source of copper is the eastern Alps, particularly around the Mitterberg area in Salzburg, Austria. However, the southern Alps, specifically the Trentino-Alto Adige region in Italy, and local copper ore sources in the Karavanke mountains as sources of copper remain possibilities.[113]

### Lead isotope ratios

Archaeometric analyses, such as elemental composition, are standard practice in Slovenian archaeology, while the lead isotope analysis (LIA) was so far only used in one study, by Rafko Urankar.[114] In the present study, LIA was applied to a selection of twelve copper and bronze objects from the Dragomelj I hoard. Lead isotope ratios ($^{208}$Pb/$^{206}$Pb, $^{207}$Pb/$^{206}$Pb, $^{208}$Pb/$^{204}$Pb, $^{207}$Pb/$^{204}$Pb, $^{206}$Pb/$^{204}$Pb) were determined using a multi-collector inductively coupled plasma mass spectrometer (MC-ICP-MS) at the Department of Environmental Sciences at the Jožef Stefan Institute, Ljubljana, Slovenia. The samples were prepared the same way as for the elemental analysis in the previous section, followed by additional anion-exchange chromatography to separate lead from the matrix.[115]

The BIs with Cat. Nos. 1, 4, 5, and 8 show Pb concentrations of >1.5%, indicating an intentional addition of Pb. The BI with Cat. No. 3 is enriched with Sb and low in Pb. The PCIs with Cat. Nos. 14, 20, 30, 34, 43, 47, and 50 show traces of Pb (<1%), most probably coming from the Cu ore. Since PCIs are typically made from raw copper, the chemical composition and Pb isotopic composition can be used to trace the source of the ore. In *Fig. 17*, the Pb isotopic composition of the objects from the Dragomelj I hoard is presented with the LIA results for different Cu ores originating from Austria, Italy, Serbia, and Slovenia.[116] The Pb isotope ratios show substantial variability in the Dragomelj objects. The PCIs are distributed in four groups with distinct Pb isotopic compositions pointing to four sources. One group (Cat. Nos. 34 and 43) has the Pb isotopic ratios in the range of those Cu ores coming from Mitterberg ores; one (Cat. No. 14) overlaps with the Pb isotopic pattern from Mitterberg and Austroalpine (AA) ores; the third (Cat. Nos. 3, 20, 47, and 50) overlaps with the ores from Carnia and the southern Alpine regions in northern Italy; the fourth (Cat. No. 30) has a Pb isotope composition similar to the Cu ores from the Valsugana region in northern Italy. The Pb isotopic composition of the Cu ores coming from Valsugana overlaps with the ores coming from Carinthia, Salzburg, and Styria, although there is no indication that the mines in Carinthia were active in prehistoric times.[117] Geographically, these Cu ore areas are closer to Dragomelj than the Cu ore from Valsugana. As expected, the ores from the Lower Austria region have a very distinct Pb isotopic signature,[118] and it is quite sure that those ores were not used in Dragomelj objects. Moreover, Urankar in his PhD thesis also presented the LIA results for the Cu ores from Slovenia (Počivalnik, Kladje, Železniki, Okoška gora, and Kopje) together with selected artefacts from different hoards (Dragomelj and Kanalski Vrh).[119] In his study, some ingots overlap nicely with the ore from Počivalnik. The Pb isotopic data from Slovenian Cu ore areas are spread around the Pb isotopic compositions of the artefacts analysed in the present study. In both studies, the artefact with Cat. No. 3[120] was analysed, and the results are in agreement, confirming the comparability of the results.

110 Grutsch et al. 2019, 340–347.
111 See above No. 91.
112 Lutz, Pernicka 2013.
113 Artioli et al. 2016; Schreiner 2007; Urankar 2012.
114 Urankar 2012.
115 Goltnik et al. 2022.

116 Mitterberg: Tomczyk, Żabiński 2024; northern Italy: Artioli et al. 2016; Serbia: Radivojević, Rehren, Pernicka 2021; Slovenia: Urankar 2012.
117 Artioli et al. 2016.
118 Mödlinger, Trebsche, Sabatini 2021.
119 Urankar 2012, 71–73,78–85, Add. 22–26.
120 Marked as DPN_18 in Urankar 2012 (Add. 24).

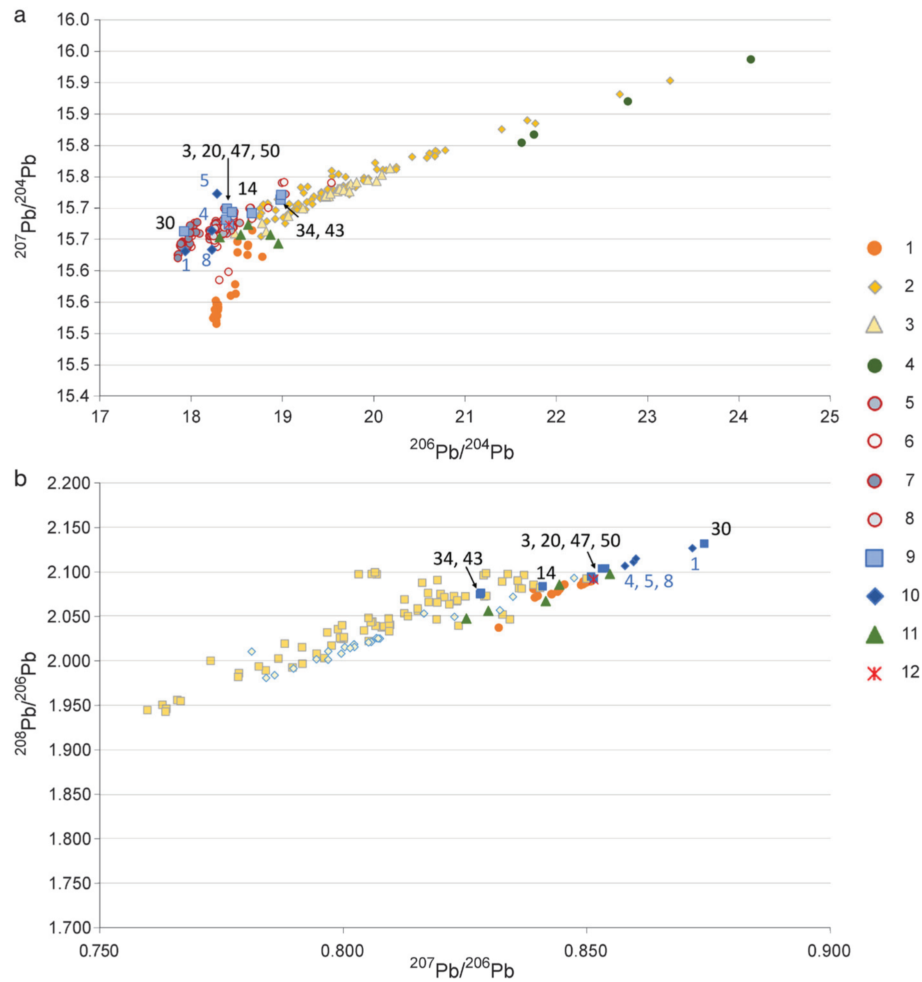


*Fig. 17:* Plot of LIA data for the objects from the Dragomelj I hoard and for the ores from Mitterberg (Tomczyk, Żabiński 2024), northern Italy (Artioli et al. 2016), Serbia (Radivojević, Rehren, Pernicka 2021), and Slovenia (Urankar 2012). **a** – $^{207}Pb/^{204}Pb$ to $^{206}Pb/^{204}Pb$ ratio; **b** – $^{208}Pb/^{206}Pb$ to $^{207}Pb/^{206}Pb$ ratio.

*Sl. 17:* Diagram s podatki iz analize svinčevih izotopov v izbranih predmetih iz depoja Dragomelj I ter bakrovih rud iz Mitterberga (Tomczyk, Żabiński 2024), severne Italije (Artioli et al. 2016), Srbije (Radivojević, Rehren, Pernicka 2021) in Slovenije (Urankar 2012). **a** – razmerje med $^{207}Pb/^{204}Pb$ in $^{206}Pb/^{204}Pb$; **b** – razmerje med $^{208}Pb/^{206}Pb$ in $^{207}Pb/^{206}Pb$.

**1** – Serbia / Srbija; **2** – Mitterberg ore / ruda iz Mitterberga; **3** – Mitterberg slag / žlindra iz Mitterberga; **4** – Prigglitz-Gasteil ore / ruda iz Prigglitz-Gasteila; **5** – southern Alpine AATV regions / južnoalpsko Zgornje Poadižje, Trentinsko in Benečija; **6** – Austroalpine AAT / Avstrijskoalpska geološka območja v Zgornjem Poadižju in na Trentinskem; **7** – Valsugana; **8** – Carnia / Karnija; **9** – Dragomelj; **10** – Dragomelj (BIs + Pb / dvokonični ingoti s svinčevo leguro); **11** – Slovenia / Slovenija; **12** – Dragomelj PN 18 (BI Cat. No. 3 / dvokonični ingot kat. 3) – see Note / gl. op. 120.

The Pb isotopic pattern of the BIs with Cat. Nos. 1, 4, 5, and 8 deviate from the Cu ores as Pb (ore) was added during production. Unfortunately, the number of artefacts analysed is too limited for the LIA to provide a link to their source at present.

As discussed previously, the chemical composition shows the base material likely originated from the eastern Alps, either the Mitterberg or the Schwaz/Brixlegg area in the Inn valley, or from the southern Alpine area.[121] The current LIA data show that the ore trading routes were quite diverse. They also allow us to suspect some of the Cu ore may have come from the northern Italian mines, especially from the Carnia and southern Alpine AATV (Alto Adige, Trentino, and Veneto regions) areas. This assumption aligns with the study of Pb isotopes in Scandinavian, German, and Italian Bronze Age artefacts (swords), where the data showed the Cu ore probably originated from Italy (southern Alpine AATV areas).[122] Based on

[121] Trampuž Orel, Orel 2010.

[122] Ling et al. 2019.

their LIA, the authors stated that from the Middle Bronze Age onwards, the Italian Alps were already a leading supplier of Cu to central and northern Europe. As evident from *Fig. 17,* the source cannot be determined given that the LIA values for the artefacts analysed in this study overlap with ores from different locations. Moreover, the presence of recycled copper, bronze and added leaded bronze evident in some PCIs further complicates their interpretation. Therefore, additional chemical tracers should be used to achieve further discrimination.

## CONCLUSION

The location of the Dragomelj I hoard indicates that it was buried at a distance of about 20 meters from the nearest excavated contemporaneous houses.[123] However, it was only excavated with a small trench outside the main excavation area and there may have been additional houses in the unexplored area to the west of the excavation area, closer to the hoard.

As a settlement hoard, it is comparable to the contemporaneous hoards from Frattesina in the Po valley, two of which have a partially comparable composition, with a significant proportion of BIs and PCIs.[124] Luigi Salzani assumes they were founder's hoards, buried with a metallurgical purpose. A contemporary hoard from Rannersdorf in Lower Austria, also discovered on the outskirts of the contemporary settlement, is similar to Dragomelj in its composition with predominant copper PCIs.[125]

Apart from the hoard, there are only rare indications of metallurgical activities among the settlement finds from Dragomelj. These include two grooved stone hammers with no clear context.[126] Their raw materials are quartz sandstone (*Fig. 18b*) and tonalite, originating in the eastern Karavanke mountains (*Fig. 18a*). The origin of the second hammer perhaps indicates

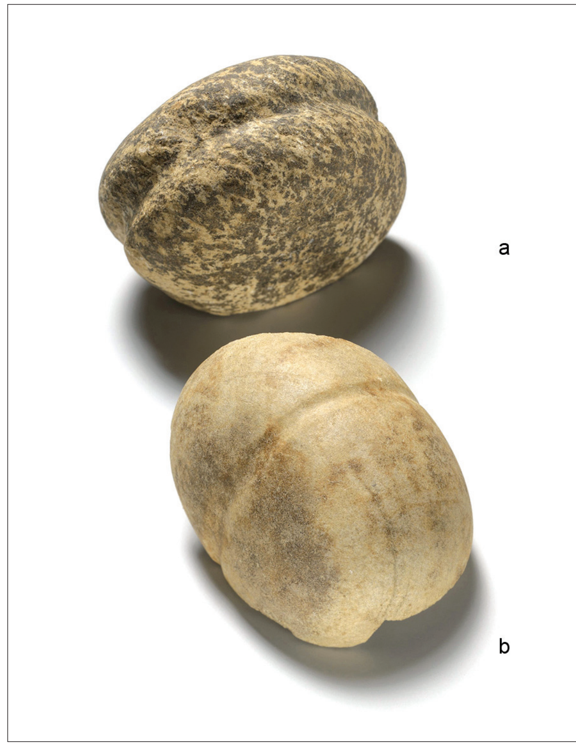


*Fig. 18:* Dragomelj, Late Bronze Age settlement, two grooved stone hammers.
*Sl. 18:* Dragomelj, kamnita tolkača z izjedo iz poznobronastodobnega naselja.

an as yet unidentified copper ore extraction area in the eastern Karavanke or Pohorje mountains exploited during the LBA.[127] Analogies for the stone hammer in *Fig. 18b*, with a groove across the narrower diameter, are frequent in the copper mines over wide areas of western and central Europe.[128] Grooved hammers are the most common type of mining hammers in prehistory. Similar hammers, alongside those with a groove at maximum diameter (an example in *Fig. 18a*), appear in the metallurgical-foundry areas of Bronze Age settlements. In nearby Podgorica, an example was excavated in a large pit together with a mould.[129] One was also unearthed in the foundry area in the settlement of Kalnik–Igrišće, in northern Croatia.[130] These finds show that such tools were also associated with foundry and the

[123] See in this volume Turk, Svetličič, Fig. 2.

[124] Frattesina II: Salzani 2000, 40–45, Fig. 3: 26–36, 4: 37–43; Frattesina IV: Salzani 2003, 40–44, Fig. 3: 13–16.

[125] Reiter, Linke 2016, 145–149, Fig. 3–7. In close proximity to the hoard from Rannersdorf, there was a pit with a hearth and a grooved stone hammer (*ib*., 159–161, Fig. 35–37), which suggests an area of metallurgical activities comparable to the one at Podgorica (see in this volume Vojaković).

[126] Turk, Svetličič, Pavlovič 2023, 109–110, 378, G899–G900.

[127] Cf. Teržan 1983.

[128] Groer 2008, 20–25.

[129] Vojaković, Novšak 2022, 63, G169; see in this volume Vojaković.

[130] Vrdoljak 1992, 78–79, Pl. 2: 3. A grooved stone hammer is also known from the Oloris settlement in Prekmurje (Dular, Šavel, Tecco Hvala 2002, 60, Pl. 32: 3).

processing of bronze metal into finished bronze products.[131]

The contemporary nearby settlement at Podgorica to the south of the Pšata stream also revealed two moulds, which corroborate local metallurgical activities.[132]

The foundry area in Podgorica, together with the Dragomelj settlement to the north of the Pšata stream, are seen as forming a wider functional metallurgical complex, an integral part of which is more than 86 kg of copper and bronze semi-products from the Dragomelj I hoard. The hoard thus functioned as the raw material base for foundry activities, perhaps in the LBA settlement in Dragomelj, but certainly in the contemporary settlement in Podgorica. The twin settlements were collection centres of metal semi-products and their metallurgical processing into finished products. They were important accumulation, production, and exchange centres on the transport routes between the ore-mining areas in the southern and eastern Alps and the centres to the southwest in the Po plain (Frattesina) and the southeast in the Balkan direction.[133]

Regarding the dating of the Dragomelj hoard, the parallels for the BIs from larger hoards of mixed composition indicate the transition from the Early to the Late Urnfield period or Ha A2/B1. Indirectly, the Dragomelj hoard can also be dated with the help of the contemporary settlement. The pottery and radiocarbon analyses date the Dragomelj settlement to the Early and transition to the Late Urnfield period, between the 13$^{th}$ and 10$^{th}$ centuries BC.[134] Assuming the hoard was buried – or, to put it in functional terms, was in use – at the end of the settlement life span, we can date it to the late 11$^{th}$ or early 10$^{th}$ century BC.

The formal characteristics of the PCIs attest to their distribution areas between the Pannonian plain and the Apennine peninsula and the broader trans-regional areas of the Mediterranean basin and central Europe. The formal characteristics of the BIs show a significant concentration in central/western Slovenia and Friuli in north-eastern Italy (*Fig. 5*), where three of their five formal types (*Fig. 4*: Types 3–5) are present almost exclusively.

Combining the formal and chemical typologies reveals a meaningful correlation between the high-impurities BIs (Cat. Nos. 3, 9, 10, 11, and 13) and the formal Type 4 (*Fig. 4*: Type 4 – without the central shaft hole), with a single outlier (Cat. No. 12). The BIs of Types 1, 2, and 3 with the central shaft hole (Cat. Nos. 1, 2, 4, 5, and 6), as well as the only BI with the round flat boss where the shaft hole is usually situated (Type 5; Cat. No. 8) are low impurities / alloyed tin ingots.[135] The appearance of the BIs thus carried the information on their composition. We can also surmise that the round flat boss of the Type 5 ingot carried similar compositional information for the LBA users as the shaft-hole BIs.

The diverse composition of the Dragomelj ingots demonstrates the different provenances of the copper used in their production. The different compositional patterns find convincing analogies in the Ha A2/B1 phase of the eastern Alpine LBA hoard contexts. A shift can be seen from As to Ni as the predominant impurity, likely due to the exploitation of chalcopyrite copper ore and its accessory minerals, resulting in compositions featuring high Ni and even Co. Also observed is the distinct reappearance of the fahlore signature, marked by Sb dominant compositions. Furthermore, the Dragomelj ingots provide evidence of diluted fahlore ores leading to intermediate compositions. Within the predominant Ni impurity ingots, the abundant and low Ni variants are attested. Such compositions are found across the entire Alpine mountain range in Ha A2/B1 phase. Furthermore, there is strong evidence of recycling and mixing coppers/bronzes in the Dragomelj material, as the majority of the BIs and some PCIs contain tin above what would be expected naturally.

The lead isotope analysis reveals similarly diverse origins of the Dragomelj copper. According to LIA, copper is divided into four distinctive groups that are potentially associated with the Mitterberg and Alto Adige–Trentino mining areas, but perhaps also other areas of copper supply, such as the Karavanke mountains in closer proximity.

*Translation: Andreja Maver*

[131] Horst 1986.

[132] Vojaković, Novšak 2022, G101, G168; see in this volume Vojaković.

[133] Marzatico 2021; Gavranović et al. 2022.

[134] Turk, Svetličič, Pavlovič 2023, 111, No. 51; see in this volume Turk, Svetličič, Fig. 6.

[135] Similar as in the case of the BI with the central shaft hole from Mahrersdorf in Lower Austria (Mödlinger, Trebsche 2020, 12, Fig. 3: 1, Table 2).

## CATALOGUE

All objects are kept in the Narodni muzej Slovenije, except Cat. Nos. 2, 6, 13, 35, and 51, which are in private possession (ZN). The numbers with the prefix G refer to the catalogue numbers of objects in the first publication (Turk, Svetličič, Pavlovič 2023, G1226–G1277).

Abbreviations / Okrajšave:

BI – biconical ingot / dvokonični ingot
d. – diameter / premer
h. – height / višina
Inv. No. – inventory number / inventarna številka
l. – length / dolžina
PCI – plano-convex ingot / plano konveksna pogača
wt. – weight / teža
w. – width / širina

*Plate 1*

1. BI with a shaft hole, complete; section: high, trapezoidal; l. 36.1 cm, w. 6.2 cm, h. 4.6 cm, wt. 2844 g; Inv. No. P 19202; G1226.
2. BI with a shaft hole, missing one tip; section: high, trapezoidal; l. 22.8 cm, w. 6 cm, h. 4.2 cm, wt. 1978 g; ZN 1; G1227.

*Plate 2*

3. Fragment of a BI; section: moderately low, trapezoidal with rounded upper edges; fractures partly worn; l. 15.6 cm, w. 5.9 cm, h. 3.4 cm, wt. 1045 g; Inv. No. P 19181; G 1234.
4. Fragment of a BI with a shaft hole; section: high, rectangular; fractures moderately worn towards the extremity and highly worn towards the centre; l. 11.8 cm, w. 6.1 cm, h. 2.4 cm, wt. 981 g; Inv. No. P 19166; G1228.
5. Fragment of a BI with a shaft hole; section: of a medium height, trapezoidal; fractures worn; l. 10.2 cm, w. 4.9 cm, h. 3.4 cm, wt. 708 g; Inv. No. P 19174; G1232.
6. Fragment of a BI with a shaft hole; section: of a medium height, trapezoidal; fractures worn; l. 9.2 cm, w. 5.4 cm, h. 2.8 cm, wt. 976 g; ZN 2; G1229.

*Plate 3*

7. Fragment of a BI with a shaft hole; section: high, trapezoidal; fractures worn; l. 6.6 cm, w. 5.4 cm, h. 3.2 cm, wt. 497.5 g; Inv. No. P 22865; G1230.
8. Fragment of a BI; remains of a round flat boss replacing the central hole; section: rectangular; fracture highly worn towards the extremity and moderately worn towards the centre; l. 6.8 cm, w. 5.4 cm, h. 2.8 cm, wt. 450 g; Inv. No. P 19169; G1236.
9. Fragment of a BI; section: moderately high, trapezoidal; fractures worn; l. 7 cm, w. 5.8 cm, h. 3.4 cm, wt. 644 g; Inv. No. P 19183; G1233.
10. Fragment of a BI; section: low, trapezoidal with rounded upper edges; fractures worn; l. 7.3 cm, w. 5.9 cm, h. 3.2 cm, wt. 740 g; Inv. No. P 19203; G1235.
11. Fragment of a BI; section: of a medium height, semicircular; fractures worn; l. 8.8 cm, w. 6.2 cm, h. 3 cm, wt. 602 g; Inv. No. P 26437; G1237.
12. Fragment of a BI with a shaft hole; section: high, trapezoidal; fractures worn; l. 7 cm, w. 7.1 cm, h. 4 cm, wt. 927 g; Inv. No. P 26438; G1231.
13. Fragment of a BI; section: rectangular; l. 3.4 cm, w. 3.6 cm, h. 2.8 cm, wt. 167 g; ZN 5; G1238.

*Plate 4*

14. PCI; section: moderately high, asymmetric, bell-shaped; d. 21.7 cm, h. 6 cm, wt. 4098 g; Inv. No. P 19187; G1239.
15. PCI; section: moderately high, highly asymmetric, bell-shaped; with a clean triangular cut with an embedded small piece of ingot; d. 17.6 cm, h. 5.4 cm, wt. 3390 g; Inv. No. P 19184; G1240.
16. PCI; section: high, asymmetric, bell-shaped; d. 13.1 cm, h. 5.4 cm, wt. 1905 g; Inv. No. P 19194; G1241.
17. PCI; section: high, asymmetric, bell-shaped; d. 13.5 cm, h. 4.6 cm, wt. 1928 g; Inv. No. P 19192; G1242.
18. PCI; section: high, partly asymmetric, hemispherical; a small edge section is broken off; fracture worn; d. 12 cm, h. 4.5 cm, wt. 1644 g; Inv. No. P 26441; G1243.
19. PCI; section: moderately high, asymmetric, hemispherical; d. 14.2 cm, h. 5 cm, wt. 2190 g; Inv. No. P 19200; G1244.

*Plate 5*

20. PCI; section: high, asymmetric, bell-shaped; d. 15.1 cm, h. 5.6 cm, wt. 2012 g; Inv. No. P 19195; G1245.
21. PCI; section: high, partly asymmetric, bell-shaped; d. 14.5 cm, h. 6 cm, wt. 2292 g; Inv. No. P 19191; G1246.
22. PCI; section: high, asymmetric, bell-shaped; d. 15.2 cm, h. 4.6 cm, wt. 2050 g; Inv. No. P 19196; G1247.
23. PCI; section: high, asymmetric, hemispherical; d. 12.9 cm, h. 5.6 cm, wt. 2668 g; Inv. No. P 19198; G1248.
24. PCI; section: of a medium height, asymmetric, hemispherical; d. 13.1 cm, h. 4 cm, wt. 1814 g; Inv. No. P 19164; G1249.
25. PCI; section: of a medium height, hemispherical; d. 12.3 cm, h. 4.4 cm, wt. 1667 g; Inv. No. P 19185; G1250.
26. PCI; section: of a medium height, asymmetric, hemispherical; d. 13 cm, h. 4.6 cm, wt. 2070 g; Inv. No. P 19186; G1251.
27. PCI; section: high, asymmetric, conical, hemispherical; d. 11.3 cm, h. 4.8 cm, wt. 1306 g; Inv. No. P 19172; G1252.

*Plate 6*

28. PCI; section: high, conical, asymmetric; d. 15.3 cm, h. 5.4 cm, wt. 2918 g; Inv. No. P 19199; G1253.
29. PCI; section: moderately high, asymmetric, bell-shaped; d. 15.5 cm, h. 4.8 cm, wt. 2635 g; Inv. No. P 19180; G1254.
30. PCI; section: high, asymmetric, conical; hatched impressions at opposite edges on the underside; d. 14.7 cm, h. 6.2 cm, wt. 3193 g; Inv. No. P 19188; G1255.
31. PCI, missing apex and part of the underside; section: high, conical; d. 12.8 cm, surviving h. 3.6 cm, wt. 1953 g; Inv. No. P 19168; G1256.

*Plate 7*

32. PCI; section: moderately low, asymmetric, hemispherical; d. 20.4 cm, h. 5.4 cm, wt. 4170 g; Inv. No. P 19189; G1257.

33. PCI; section: moderately low, hemispherical; an edge section is broken off; d. 17.5 cm, h. 4.8 cm, wt. 4244 g; Inv. No. P 19190; G1258.
34. PCI, missing part of the edge; section: low, asymmetric; d. 18 cm, h. 4 cm, wt. 2526 g; Inv. No. P 19182; G1259.
35. PCI; section: low, asymmetric, hemispherical; d. 17.2 cm, h. 4.2 cm, wt. 2606 g; ZN 10; G1260.

*Plate 8*

36. PCI; section: moderately high, asymmetric, bell-shaped; d. 15.2 cm, h. 4.8 cm, wt. 2918 g; Inv. No. P 19197; G1261.
37. PCI; section: low, hemispherical; hatched impression on the underside; d. 9.9 cm, h. 2.6 cm, wt. 876 g; Inv. No. P 19176; G1262.
38. PCI; section: low, asymmetric, hemispherical; d. 8.8 cm, h. 3.4 cm, wt. 700 g; Inv. No. P 19201; G1263.
39. PCI, missing apex and part of the edge; section: presumably of a medium height and conical; d. 15.2 cm, h. 3.2 cm, wt. 1358 g; Inv. No. 21408; G1264.
40. Fragment of a PCI; traces of intentional breaking on the upper and lower sides; section: low; l. 16.3 cm, h. 3,4 cm, wt. 1788 g; Inv. No. P 26440; G1265.
41. Fragment of a PCI; traces of intentional breaking on the upper side; section: low; l. 15 cm, h. 3.6 cm, wt. 2398 g; Inv. No. P 19193; G1266.

*Plate 9*

42. Fragment of a PCI; section: low; l. 11.8 cm, h. 3.2 cm, wt. 1180 g; Inv. No. P 19178; G1267.
43. Fragment of a PCI; section: low; l. 9.9 cm, h. 2.2 cm, wt. 542 g; Inv. No. P 19167; G1268.
44. Fragment of a PCI; section: low; l. 8.2 cm, h. 2.6 cm, wt. 543 g; Inv. No. P 26439; G1269.
45. Fragment of a PCI; section: low; l. 8.8 cm, h. 2 cm, wt. 564 g; Inv. No. P 19170; G1270.
46. Fragment of a PCI; section: high, presumably conical; fractures moderately worn; l. 9 cm, h. 6.2 cm, wt. 1645 g; Inv. No. P 19179; G1271.
47. Fragment of a PCI; section: low; l. 7 cm, h. 2.6 cm, wt. 409 g; Inv. No. P 19177; G1272.
48. Fragment of a PCI; section: low; fractures worn; l. 10 cm, h. 2.4 cm, wt. 634 g; Inv. No. P 19165; G1273.
49. Fragment of a PCI; section: low; fractures worn; l. 8.2 cm, h. 2 cm, wt. 381 g; Inv. No. P 19171; G1274.
50. Fragment of a PCI; section: low; fractures worn; l. 5.9 cm, h. 2.6 cm, wt. 398 g; Inv. No. P 19173; G1275.
51. Fragment of a PCI; section: presumably high; fractures highly worn; l. 6 cm, h. 2.8 cm, wt. 204 g; ZN 6; G1276.
52. Fragment of a PCI; section: low; l. 5.3 cm, h. 3.2 cm, wt. 410 g; Inv. No. P 19175; G1277.


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# Dragomelj I, depo kulture žarnih grobišč: arheološke in kemijske raziskave

*Povzetek*

Dragomeljski depo I iz obdobja kulture žarnih grobišč (KŽG), odkrit leta 1995, sestavlja 52 predmetov (*sl. 1*), 13 večinoma razlomljenih dvokoničnih ingotov (DI; kat. 1–13, *t. 1–3*) in 39 pretežno dobro ohranjenih planokonveksnih pogač (PKP; kat. 14–52, *t. 4–9*), s čimer se uvršča med surovinske depoje. Obrabljene površine lomov fragmentiranih predmetov kažejo, da so bili pred deponiranjem v obtoku. Obrabljene lome je imelo 9 od 12 fragmentiranih DI (oz. 75 %) in le 6 od 16 fragmentiranih PKP (oz. 37 %). Večina PKP je po lomljenju očitno hitreje končala v depoju kot DI. Pregled zastopanosti DI in PKP z obrabljenimi lomi po posamičnih legah depoja kaže, da so ti ležali le v zgornjih legah. Očitno so bili tod večinoma razlomljeni predmeti (vsi DI in večina razlomljenih PKP) z obrabljenimi lomi, ki so jih prebivalci sočasnega dragomeljskega naselja pogosto jemali iz depoja in znova polagali vanj (*sl. 2*). Kaže, da je bil dragomeljski depo shrambno mesto bakrenih oz. bronastih polizdelkov.

## PLANOKONVEKSNE POGAČE

Konveksna oblika spodnje površine PKP po uveljavljenem stališču odraža obliko jamice, vkopane v tla ob primarnem topljenju bakrove rude. Na PKP iz dragomeljskega depoja I se na spodnji površini v nekaj primerih pojavlja grabljičast vtis (kat. 30 in 37, manj izrazito pri kat. 14, 33 in 38). To nakazuje, da so livarji takoj po vlivanju odstranili PKP iz livne jamice s kovaškimi kleščami, kakršne poznamo s sočasnih ciprskih in sardskih najdišč.

Po velikosti, obliki in teži PKP razvrščamo v šest skupin (*sl. 3*):

1 – Majhne PKP s srednje visokim polkrožnim presekom, premera do 100 mm ter težo med 700 in 900 g (kat. 37–38).

2 – Srednje velike PKP s srednje visokim do visokim polkrožnim presekom, s premerom praviloma med 120 in 135 mm ter težo med 1600 in 2200 g (kat. 16–19, 23–27).

3 – Srednje velike PKP z visokim zvončastim presekom, s premerom med 145 in 155 mm ter težo med 2000 in 2900 g (kat. 20–22, 29 in 36).

4 – Srednje velike PKP visokega koničnega preseka, s premerom med 130 in 155 mm ter težo med 2800 in 3200 g (kat. 28, 30 in 31).

5 – Večje PKP z nizkim do srednje visokim in pretežno polkrožnim presekom, s premerom med 175 in 180 mm ter težo med 2500 in 3500 g (kat. 15, 33–35).

6 – Velike PKP z nizkim do srednje visokim presekom, premera med 200 in 220 mm ter težo med 4100 in 4200 g (kat. 14 in 32).

Med depoji iz Slovenije z okolico so najboljše primerjave za PKP prve skupine iz Jurke vasi, Miljane, Črmošnjic in z Debelega vrha. Med depoji širšega območja Karpatske kotline so podobne PKP odkrite v horizontih Kurd, Gyermely in Románd (Ha A1–B1/2). Datirane so tako v starejšo kot v mlajšo KŽG. Natančna kronološka zamejitev PKP prve dragomeljske skupine ni mogoča.

Primerjave za PKP druge skupine so v depojih Madriolo in Miljana iz faze Ha B1 ter v nekaterih panonskih depojih. Tudi PKP tretje skupine so omejene na čas Ha A2/B1. Podobne PKP so prav tako zastopane v Madriolu in Miljani ter v številnih sočasnih panonskih depojih. Tudi PKP četrte skupine imajo primerjave v depojih Madriolo in Miljana.

Večje PKP pete skupine so oblikovno blizu tipu Velem po Czajliku. Velike PKP šeste dragomeljske skupine primerjamo s Czajlikovim tipom Nyergesújfalu in vzhodnoalpskimi PKP tipa 3. Oba tipa se pojavljata v širšem časovnem razponu med Ha A1 in Ha B2.

Glede na analogije se nakazuje dolg časovni razpon PKP 1., 5. in 6. skupine skozi celotno KŽG ter ožji časovni razpon PKP 2., 3. in 4. skupine v Ha B1.

## DVOKONIČNI INGOTI

DI so polizdelki, namenjeni distribuciji oz. nadaljnji predelavi. V nasprotju s PKP kot primarnim proizvodom izločanja bakra iz bakrove rude so DI sekundarni polizdelki, uliti v enojne kalupe. Razširjeni so v srednji Italiji in ob spodnjem toku Pada, predvsem pa v Furlaniji in zahodni Sloveniji (*sl. 5*). Manj številni so v Panonski nižini ter severno in zahodno od Alp. Za časovno opredelitev DI so pomembni depoji mešane sestave, v katerih se pojavljajo. Datirani so v čas Bronzo finale 2 italijanske kronologije, Ha A2–B1 srednjeevropske kronologije oz. v tretji depojski horizont jugovzhodnoalpskega prostora. Tudi surovinske depoje z le DI (in PKP) datiramo v isti čas.

Med 13 DI v dragomeljskem depoju I je eden ohranjen v celoti, preostali pa so bolj ali manj fragmentirani. Kljub maloštevilnosti so dragomeljski DI raznovrstnih oblik (*sl. 4*):

1 – DI s sredinsko luknjo, koničnima zaključkoma in visoko trapezastim presekom: kat. 1, 2 in 5. Podobne oblike so DI iz depojev Madriolo, Schiers, Albertville, med Mancianom in Samprugnanom, Villamarzana, Kapelna in Sv. Jakob nad Debenjem.

2 – DI s sredinsko luknjo in nizkim pravokotnim oz. trapezastim presekom: kat. 4, 7, 12 in 13. Primerjave za take DI so v depojih s celotnega območja razprostranjenosti.

3 – DI s sredinsko luknjo in polkrožnim presekom: kat. 6.

4 – DI brez sredinske luknje in z nizkim polkrožnim oz. blago trapezastim presekom: kat. 3, 9, 10 in 11. DI oblikovnih tipov 3 in 4 imajo primerjave v depojih s prevladujočimi polizdelki s Kanalskega Vrha I in II, iz Madriola in toskanskega depoja med Mancianom in Samprugnanom. Kažejo torej na koncentracijo obeh tipov na prostoru Caput Adriae.

5 – DI z nizkim pravokotnim presekom in okroglo pečatno izboklino na mestu sredinske luknje: kat. 8. Analogije za to specifično obliko so v depojih Kanalski Vrh II, Veliki Otok I in Madriolo ter v posamični najdbi iz Vidma.

Medtem ko so DI prvih dveh tipov značilni za širok prostor med srednjo Italijo, srednjo Evropo in zahodnimi Alpami, so tisti zadnjih treh tipov značilni predvsem za zaledje severnega Jadrana. Razprostranjenost vseh tipov DI kaže na osrednje mesto njihovega pojavljanja na tem območju (*sl. 5*).

## KEMIJSKE RAZISKAVE

### Analize ICP-AES

Dvanajst DI in 38 PKP iz depoja Dragomelj I smo analizirali z atomsko emisijsko spektroskopijo z induktivno sklopljeno plazmo (ICP-AES). Rezultati so prikazani na *sl. 6* kot utežni deleži (wt%).

### Kositer (Sn)

Sedem DI (kat. 1, 2, 4, 5, 6, 8 in 10) vsebuje dodan Sn (2,23–5,12 wt%). Gre torej za bronaste izdelke z nizko vsebnostjo Sn (*sl. 7*). DI brez dodanega Sn (kat. 3, 9, 11 in 12) z visokimi vsebnostmi As, Ni in Sb pretežno sodijo v tip 4 brez sredinske luknje (*sl. 8*). Izjema je DI tipa 4 (kat. 10) s Sn (4,56 wt%) in visokimi deleži As (2,36 wt%), Ni (5,04 wt%) in Co (2,76 wt%) (*sl. 8: 10*). Legura s Sn je med objavljenimi sestavami pri DI redka.

Štiri izmed 38 PKP vsebujejo Sn nad količino, ki bi jo pričakovali pri surovem bakru. Največ ga je v kat. 46 (2,1 wt%). Skupaj z drugimi PKP (kat. 29, 36 in 52), pri katerih je Sn > 0,1 wt%, kažejo na možno prisotnost recikliranega kositrnega brona v bakru. PKP, ki vsebujejo Sn > 1 wt%, so v analiziranih depojih iz Slovenije redke (Udje, Kanalski Vrh II in Kranj – Jelenov klanec).

### Svinec (Pb)

Vsebnost Pb (*sl. 9*) se giblje od izpod meje zaznavnosti (odslej: < d.l.) do 10,6 wt% (povprečje: 1,09 wt%). Med DI je šest osvinčenih kositrno-bronastih (Cu-Sn-Pb: kat. 1, 2, 4, 5, 6 in 8) z vsebnostjo Pb v razponu od 1,77 do 10,6 wt%. Vsi imajo nizko vsebnost nečistoč (≤ 1 wt%). Od tega jih je pet s sredinsko luknjo (tipi 1–3: kat. 1, 2, 4, 5 in 6), dva (kat. 8 in 10) pa sta brez nje. Pri PKP se svinec giblje od < d.l. do 5,53 wt% (povprečje: 0,33 wt%). Tri PKP vsebujejo Pb < 1 wt% (kat. 26, 27 in 29), kar kaže na recikliranje oz. mešanje Sn, Pb in Cu ter Pb in Cu z bronom. Dodajanje Pb bakrenim in bronastim predmetom se je izrazito povečalo v mlajši kulturi žarnih grobišč in starejši železni dobi (*sl. 10*). Svinec je bil verjetno dodan bakru oz. bronu za zmanjšanje temperature taljenja in povečanje fluidnosti, kar je omogočilo učinkovito ulivanje v kompleksne kalupe.

### Železo (Fe)

Količina Fe se giblje od < d.l. do 13 wt% (*sl. 6*). Po pričakovanjih je povprečna vsebnost Fe pri DI nižja. Ulivanje namreč pomeni potencialno nadaljnjo stopnjo odstranjevanja Fe in drugih oksidirajočih nečistoč. V dragomeljskem depoju I (*sl. 11*) je vsebnost Fe pri PKP (< l.d. do 13,1 wt%; povprečje: 1,5 wt%) in DI (0,1 do 5,4 wt%; povprečje: 1,3 wt%) podobna; podobna je tudi vsebnosti Fe pri surovcih (PKP) v slovenskih depojih iz Ha A in B, kar kaže na taljenje podobnih sulfidnih (halkopiritnih) rud.

### Druge nečistoče

Diagnostične nečistoče v bakru dragomeljskega depoja I (As, Ni, Sb, Ag, Bi in Co) tako pri DI kot pri PKP razkrivajo različne, a pomenljive vzorce. Seštevki nečistoč kažejo po eni strani na predmete s podobno nizkimi in po drugi na tiste z visokimi stopnjami nečistoč (*sl. 12–13*), ki segajo od 0,15 do 21,87 wt%, a večina (72 %) jih je z > 1 wt%. Pri DI se skupne nečistoče gibljejo od 0,31 do 11,6 wt% s povprečjem 5,09 wt%, medtem ko se skupne nečistoče pri PKP gibljejo od 0,15 do 21,9 wt% s povprečjem 4,60 wt%. V primerjavi z najdbami iz drugih slovenskih depojev je baker z visoko vsebnostjo nečistoč značilen za predmete iz Ha B.

Zelo verjetno je, da je bil ta baker pridobljen iz polimetalnih rud, kot so bakrove rude tipa *Fahlerz*, tetraedrit in tenantit, ter uporabljen, ko kositra ni bilo na voljo. Lastnosti teh zlitin so podobne lastnostim brona. Prav tako kaže, da je bil baker z visoko vsebnostjo nečistoč za dosego želenih metalurških lastnosti, denimo za izboljšanje njegove obdelovalne uporabnosti, pogosto razredčen s čistejšim bakrom.

Različne vrste bakra iz Dragomlja so glede vsebnosti As, Ni in Sb pri DI in PKP porazdeljene podobno (*sl. 14A*). Vzorec porazdelitve nečistoč se razlikuje od PKP iz Ha A (*sl. 14B*), pri katerih prevladujejo arzenovi bakri. Ob upoštevanju celotnega korpusa analiziranih slovenskih najdb opazimo jasen premik ne le od nižjih k višjim deležem primesi nečistoč v bakru, temveč tudi od As kot prevladujoče primesi v Ha A k vse bolj prevladujočemu Sb v Ha B (*sl. 14C*). Ta sprememba je verjetno odraz premika od uporabe vzhodnoalpskega halkopirita k ponovnemu izkoriščanju tetraedrita – $(Cu, Fe)_{12}Sb_4S_{13}$ in tenantita – $(Cu, Fe)_{12}As_4S_{13}$). Razlog za vnovičen pojav sledi teh mineralov naj bi bil upad pomena glavnih nahajališč halkopirita v regiji (npr. rudišča Mitterberg) ali – verjetneje – povečanje povpraševanja po bakru, ki ga rudniki halkopirita niso mogli izpolniti, to pa je vodilo v izkoriščanje drugih rud.

Večina (≈ 70 %) dragomeljskih DI in PKP ima v sestavi pokazatelje za izvorni halkopirit, verjetno regionalnega izvora. Preostanek (≈ 30 %) ima značilni "podpis *Fahlerza*" z visoko vsebnostjo Sb. Razumevanje kemične sestave in izvora bakra je v času KŽG zapleteno zaradi sledov recikliranja, razvidnih iz vsebnosti Sn, v manjšem obsegu pa tudi iz vsebnosti Pb. Poleg tega je treba med dejavniki bakrove sestave upoštevati polimetalno naravo številnih rudišč z južnih in vzhodnih alpskih območij pridobivanja bakra ter mešanje (sočasno taljenje) halkopirita in bakrove rude *Fahlerz*. To lahko pojasni prisotnost vmesnih sestav, tako imenovanega "razredčenega bakra *Fahlerz*". Gre za mešanje kovine z visoko stopnjo nečistoč z bakrom, pridobljenim iz halkopirita, in sicer kot nadomestek za Sn ali za zmanjšanje škodljivih učinkov visoke vsebnosti As in Sb. V primeru Dragomlja so verjeten primarni vir bakra vzhodne Alpe, zlasti v okolici območja avstrijskega Mitterberga. Kot možen vir velja upoštevati tudi južne Alpe, zlasti italijansko deželo Trentinsko – Zgornje Poadižje, in lokalna bakrova rudišča v Karavankah.

**Razmerja med svinčevimi izotopi**

Analiza svinčevih izotopov (ASI) je bila izvedena na manjšem vzorcu dvanajstih predmetov iz depoja Dragomelj I. Razmerja med svinčevimi izotopi ($^{208}Pb/^{206}Pb$, $^{207}Pb/^{206}Pb$, $^{208}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$, $^{206}Pb/^{204}Pb$) so bila določena z masnim spektrometrom z induktivno sklopljeno plazmo z več zbiralniki (MC-ICP-MS).

Štirje DI (kat. 1, 4, 5 in 8) izkazujejo vsebnost Pb >1,5 %, kar kaže na namerno dodajanje Pb. DI kat. 3 je legura s Sb in malo Pb. PKP kat. 14, 20, 30, 34, 43, 47 in 50 kažejo sledove Pb (< 1 %), ki najverjetneje izvirajo iz bakrove rude. Ker so PKP običajno izdelane iz surovega bakra, je mogoče kemično sestavo in izotopsko sestavo Pb uporabiti za sledenje vira rude. Na *sl. 17* je predstavljena izotopska sestava svinčenih predmetov iz depoja Dragomelj I, skupaj z rezultati ASI za različne bakrove rude iz Avstrije, Italije, Srbije in Slovenije. Razmerja med izotopi svinca kažejo precejšnjo variabilnost v dragomeljskih predmetih.

PKP so razdeljene v štiri skupine z različnimi izotopskimi sestavami Pb, ki kažejo na štiri izvorna območja. Prva skupina (kat. 34 in 43) ima izotopska razmerja Pb v predelu bakrovih rud z območja Mitterberga. Druga skupina (kat. 14) se prekriva z izotopskim vzorcem Pb iz mitterberških in t. i. avstroalpskih rudišč. Tretja (kat. 3, 20, 47 in 50) se prekriva z rudišči iz Karnije in z južnoalpskih območij v severni Italiji. Četrta skupina (kat. 30) ima izotopsko sestavo Pb podobno bakrenim rudam z območja Valsugana v severni Italiji. Rezultati ASI za bakrove rude s hriba Počivalnik v Karavankah, ki jih je predstavil R. Urankar v svoji doktorski disertaciji, se odlično ujemajo z dragomeljskim DI kat. 3.

Ti podatki ASI kažejo, da so bile bakrove trgovalne poti raznolike. Omogočajo nam tudi domnevo, da je baker vsaj delno izhajal iz severnoitalijanskih rudnikov, zlasti z območij Karnije in južnih Alp (deželi Trentinsko – Zgornje Poadižje in Benečija). Iz *sl. 17* je razvidno, da vira ni mogoče jasno določiti, saj se vrednosti ASI za analizirane predmete prekrivajo z rudami z različnih območij.

## ZAKLJUČEK

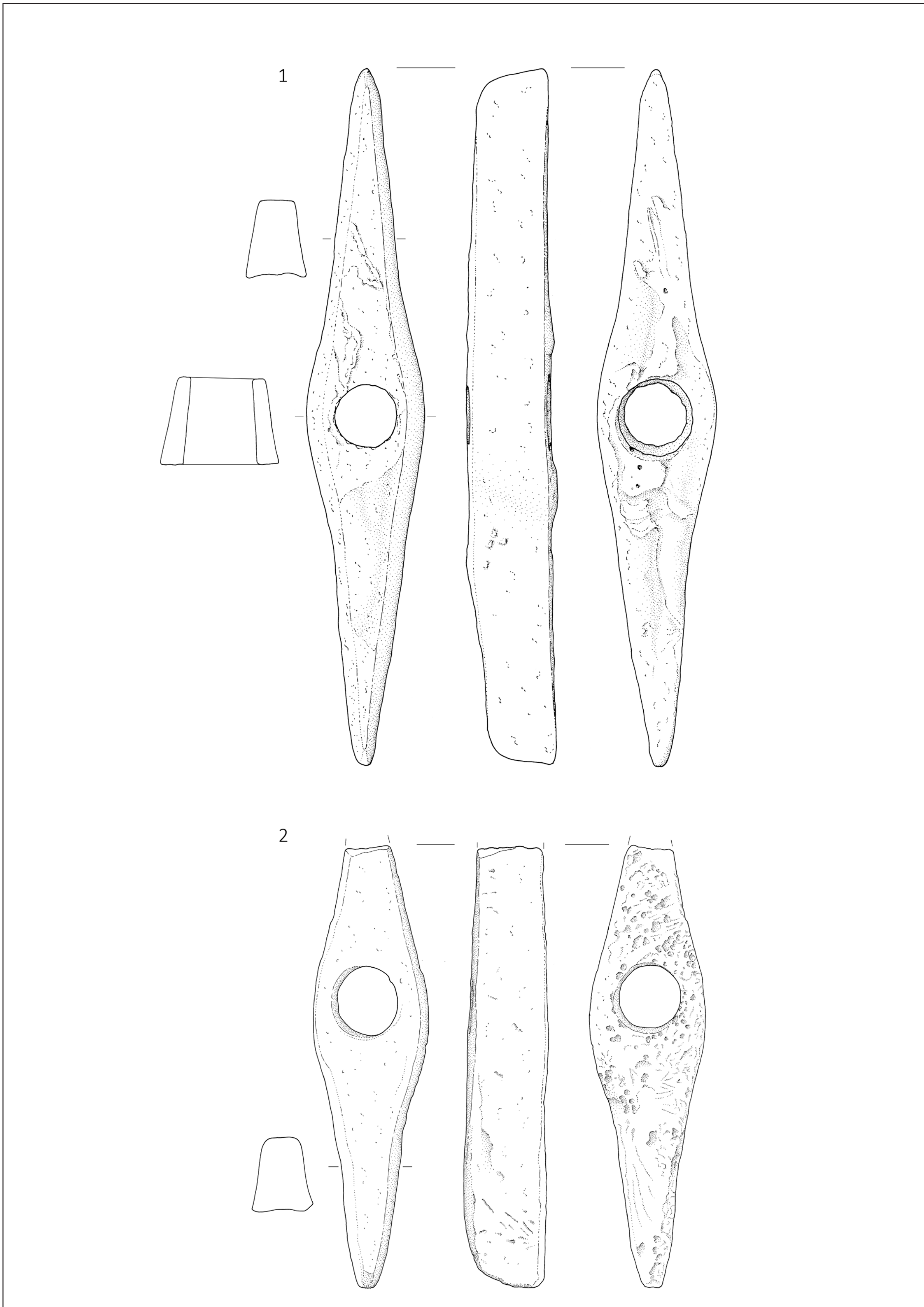
Depo Dragomelj I na podlagi primerljivih DI iz večjih depojev mešane sestave datiramo v Ha A2/B1. Kot naselbinski depo in po sestavi je primerljiv s sočasnima depojema iz Frattesine v Padski nižini in depojem iz Rannersdorfa v Spodnji Avstriji. L. Salzani domneva, da gre za metalurške, livarske depoje. K redkim preostalim pokazateljem metalurške dejavnosti med naselbinskimi najdbami iz Dragomlja prištevamo kamnita tolkača z žlebom iz kremenovega peščenjaka (*sl. 18b*) in vzhodnokaravanškega tonalita (*sl. 18a*). Izvor drugega tolkača morda kaže na še neugotovljeno območje pridobivanja bakrove rude v vzhodnih Karavankah ali na Pohorju, ki so ga izkoriščali v času KŽG. Podobni tolkači se pojavljajo na metalurško-livarskih območjih sočasnih naselij v bližnji Podgorici in na najdišču Kalnik – Igrišče na severu Hrvaške. Kamniti tolkači so bili poleg rudarjenja povezani tudi z livarstvom in predelavo bronaste kovine v končne bronaste izdelke. Dva kalupa, odkrita v sočasnem bližnjem naselju Podgorica, potrjujeta lokalne metalurške dejavnosti.

Livarsko območje v Podgorici skupaj z naseljem Dragomelj sestavlja funkcionalni metalurški kompleks, katerega sestavni del je več kot 86 kg bakrenih in bronastih polizdelkov iz depoja Dragomelj I. Depo je bil surovinska baza za livarske dejavnosti v sočasnem naselju v Podgorici. "Somestje" Podgorice in Dragomlja je bilo pomembno zbirališče kovinskih polizdelkov in njihove metalurške predelave v končne izdelke. Naselji sta bili pomembni akumulacijski, proizvodni in menjalni središči na prometnih poteh med bakrovimi rudišči v južnih in vzhodnih Alpah ter središči na jugozahodu v Padski nižini (Frattesina) in jugovzhodu v balkanski smeri.

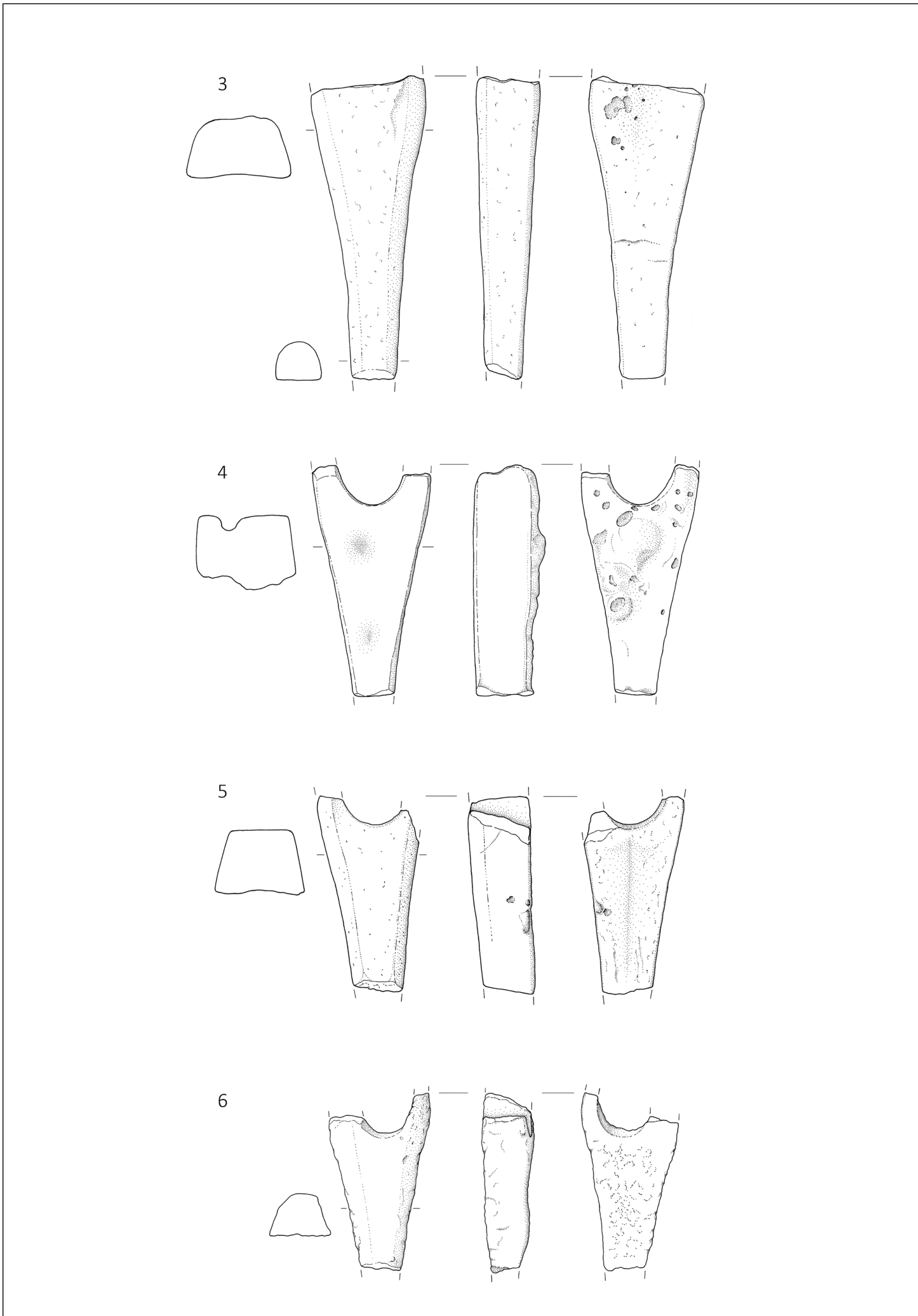
Kombinirana oblikovna in kemijska tipologija dragomeljskih DI razkriva povezavo med DI z visoko vsebnostjo nečistoč (kat. 3, 9, 10, 11 in 13) in oblikovnim tipom 4 brez sredinske luknje (*sl. 4*), z eno izjemo (kat. 12). DI tipov 1, 2 in 3 s sredinsko luknjo (kat. 1, 2, 4, 5 in 6) ter tudi edini DI z okroglo pečatno izboklino na mestu sredinske luknje (tip 5: kat. 8) so ingoti z nizko vsebnostjo nečistoč in s kositrno leguro. Oblika DI je torej nosila informacijo o njihovi sestavi.

Raznovrstna sestava dragomeljskih DI in PKP kaže na različne izvore bakra, uporabljenega pri njihovi izdelavi. Različni vzorci njihove sestave imajo prepričljive primerjave med predmeti iz vzhodnoalpskih depojev v času Ha A2/B1. Opazen je premik z As na Ni kot prevladujočo nečistočo, verjetno zaradi izkoriščanja halkopiritne bakrove rude in sorodnih mineralov, zaradi česar je v sestavi visoka vsebnost Ni in celo Co. Izrazit je tudi pojav sledov bakrovih rud vrste *Fahlerz*, ki ga označujejo sestave s prevladujočim Sb.

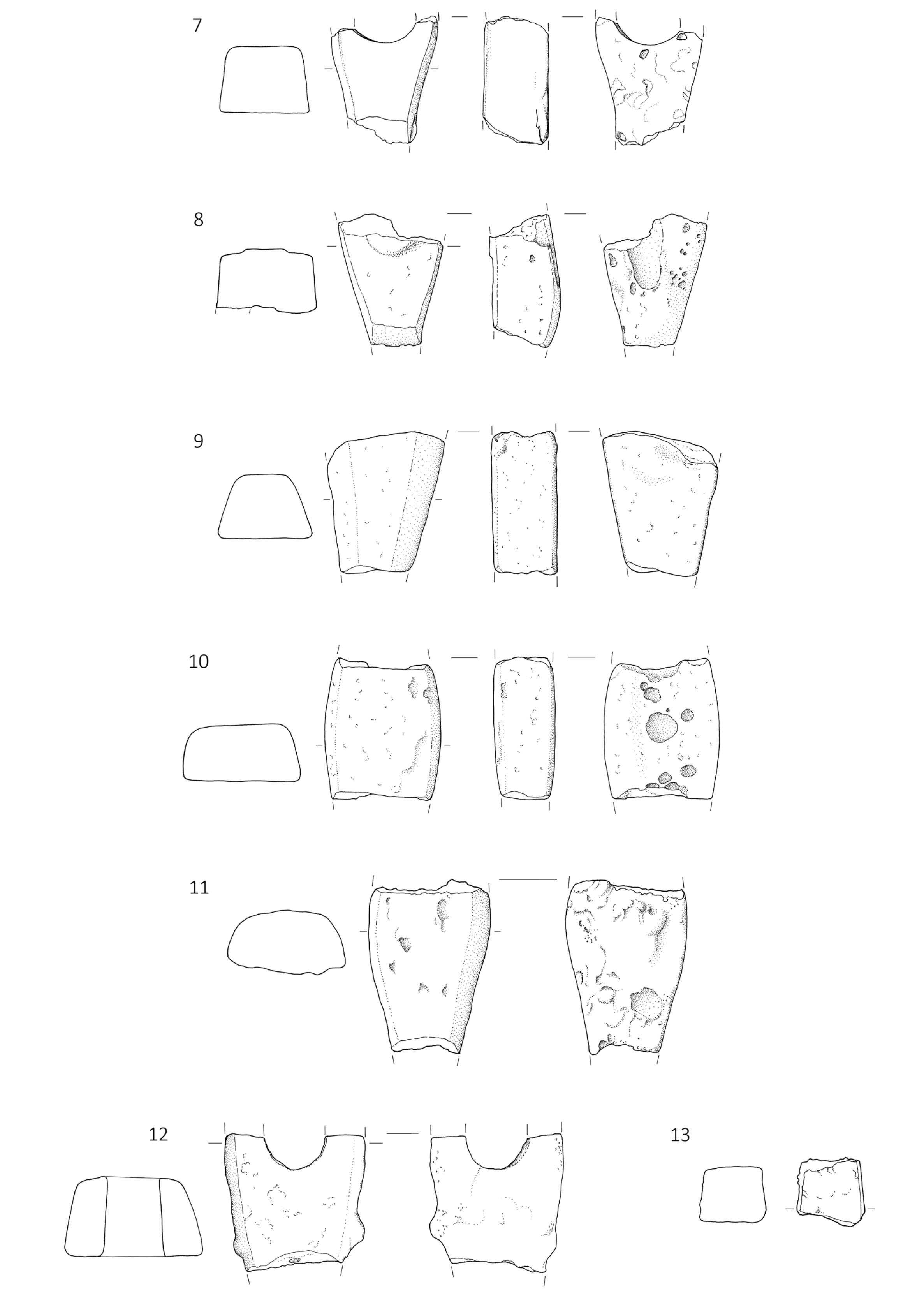
Analiza svinčevih izotopov razkriva podobno raznolik izvor dragomeljskega bakra. Na podlagi ASI je baker razdeljen na štiri skupine, morebiti povezane z rudišči v Mitterbergu in na območju dežele Trentinsko – Zgornje Poadižje, morda pa tudi z drugimi območji dobave bakra, kot so bližnje Karavanke.



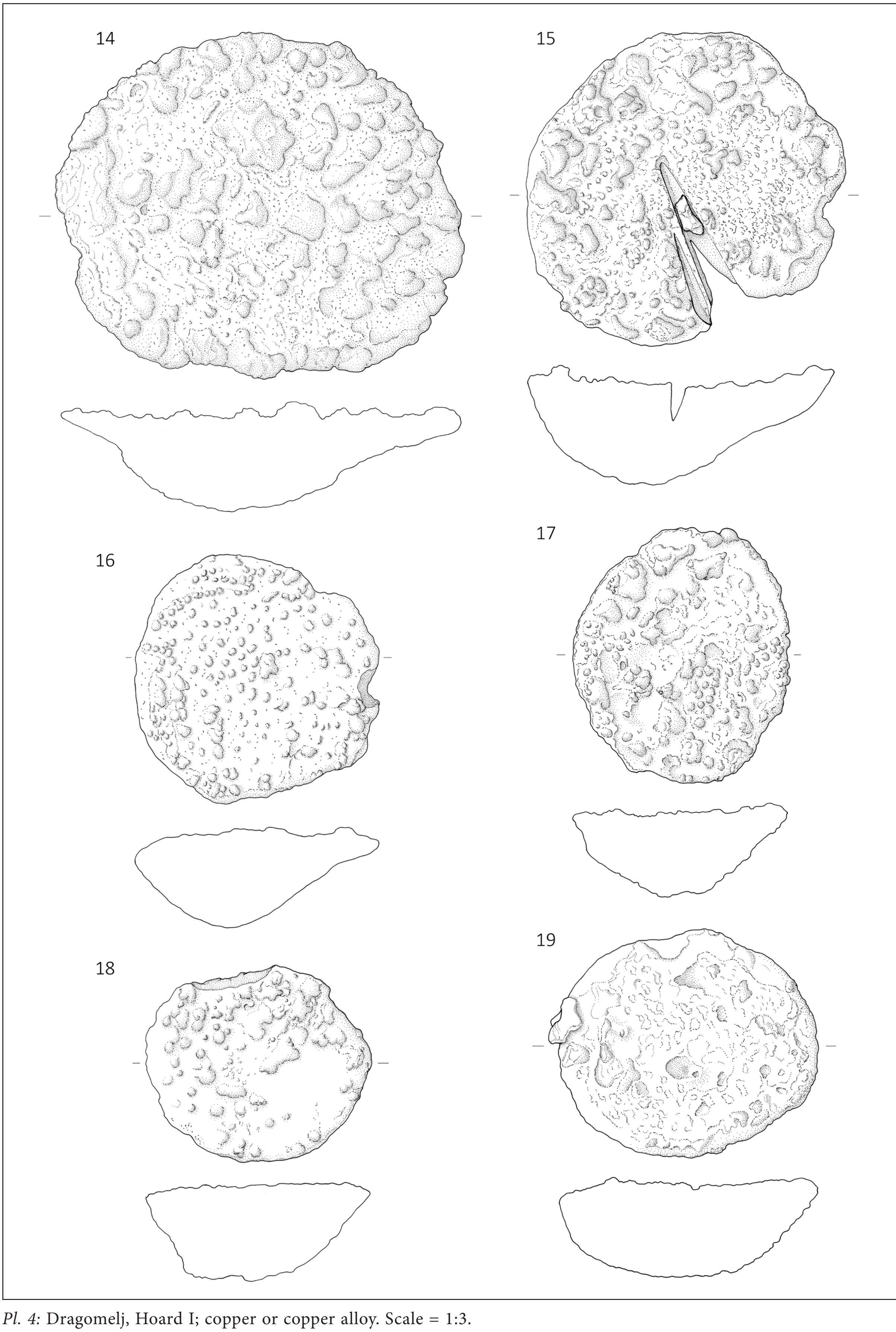

*Pl. 1:* Dragomelj, Hoard I; bronze. Scale = 1:3.
*T. 1:* Dragomelj, depo I; bron. M = 1:3.



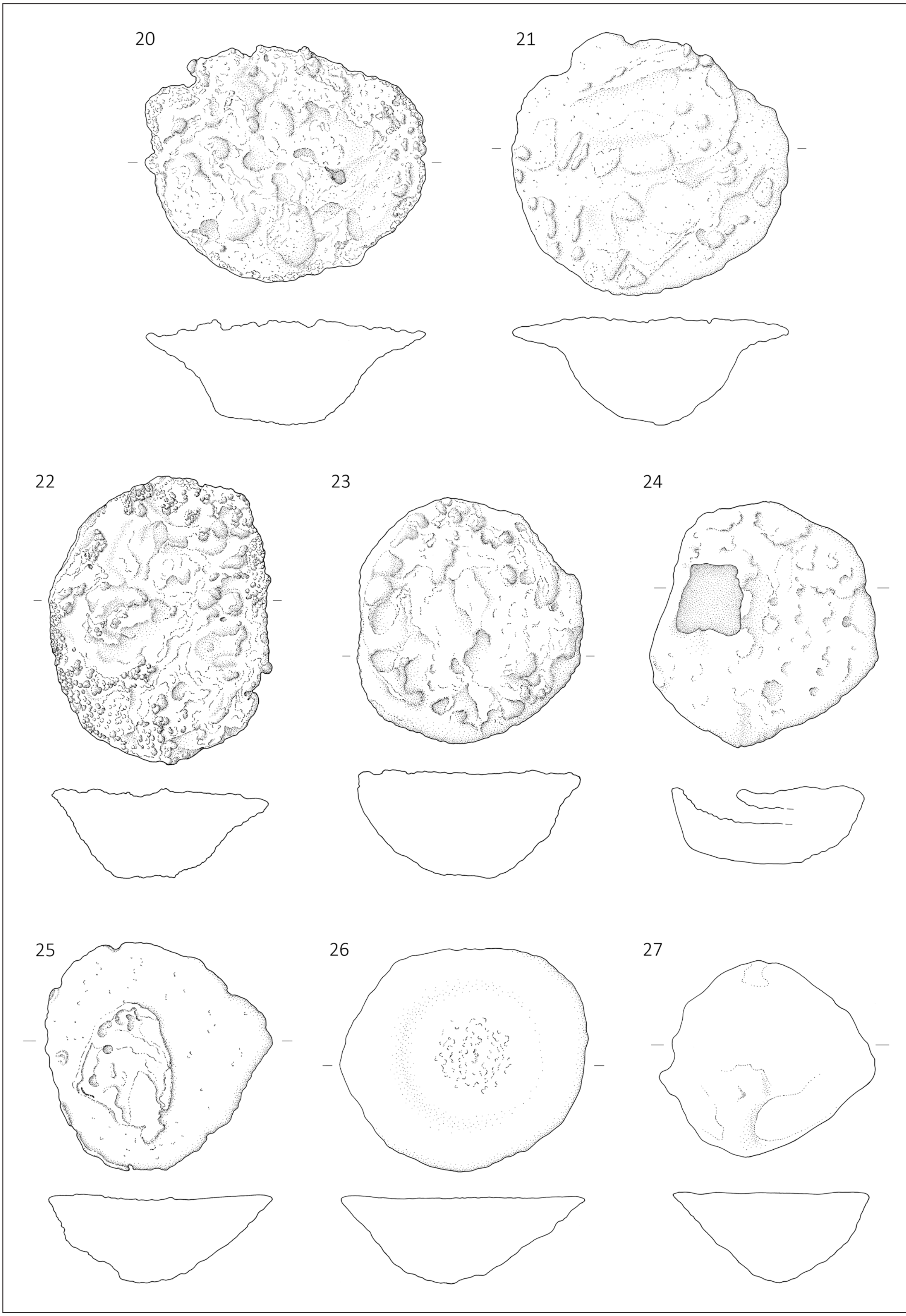

*Pl. 2:* Dragomelj, Hoard I; 3 copper alloy, 4–6 bronze. Scale = 1:3.
*T. 2:* Dragomelj, depo I; 3 bakrova litina, 4–6 bron. M = 1:3.



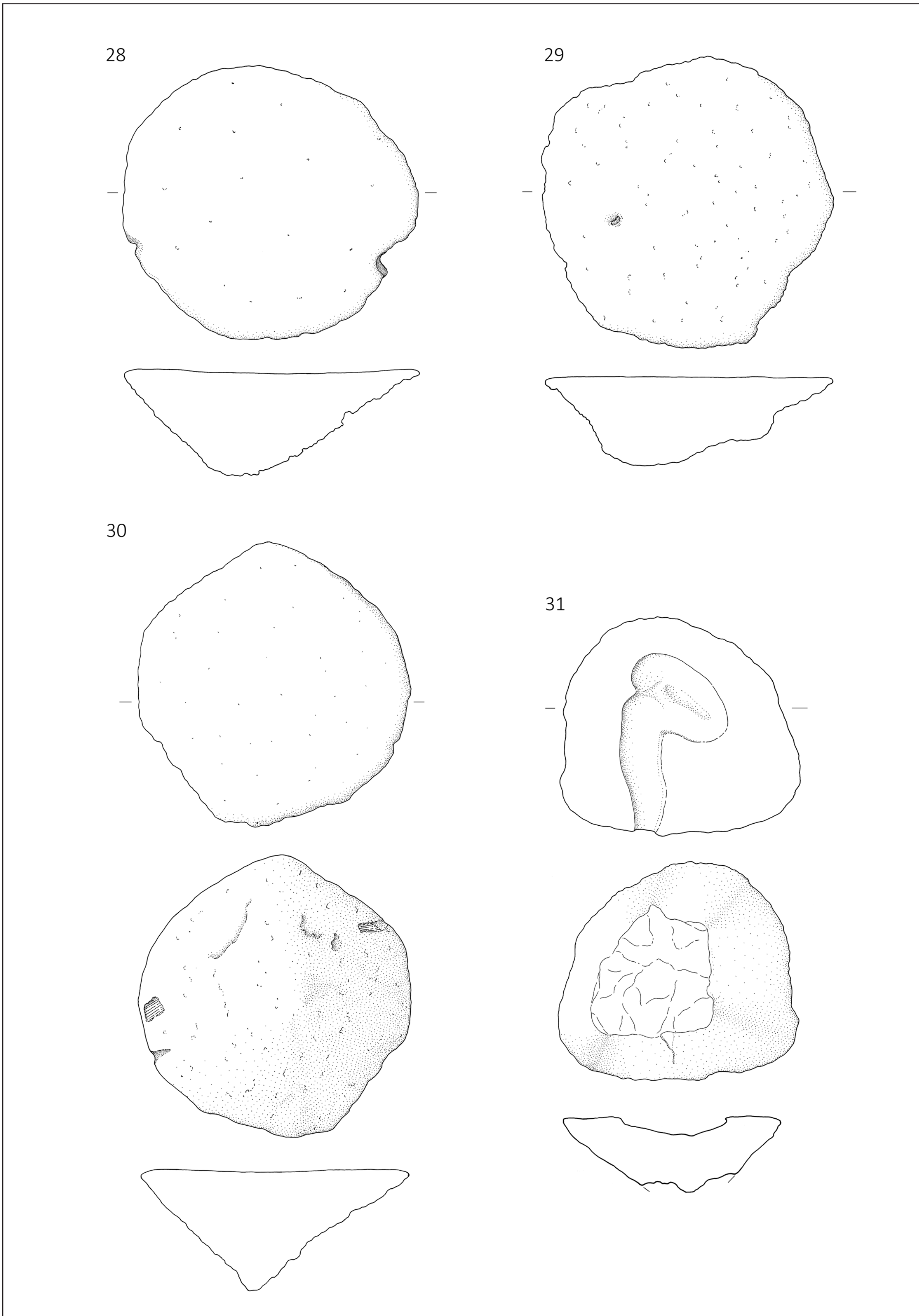

*Pl. 3:* Dragomelj, Hoard I; 7,9,11–13 copper alloy, 8,10 bronze. Scale = 1:3.
*T. 3:* Dragomelj, depo I; 7,9,11–13 bakrova litina, 8,10 bron. M = 1:3.




*Pl. 4:* Dragomelj, Hoard I; copper or copper alloy. Scale = 1:3.
*T. 4:* Dragomelj, depo I; baker oz. bakrova litina. M = 1:3.




*Pl. 5:* Dragomelj, Hoard I; copper or copper alloy. Scale = 1:3.
*T. 5:* Dragomelj, depo I; baker oz. bakrova litina. M = 1:3.




*Pl. 6:* Dragomelj, Hoard I; copper or copper alloy. Scale = 1:3.
*T. 6:* Dragomelj, depo I; baker oz. bakrova litina. M = 1:3.

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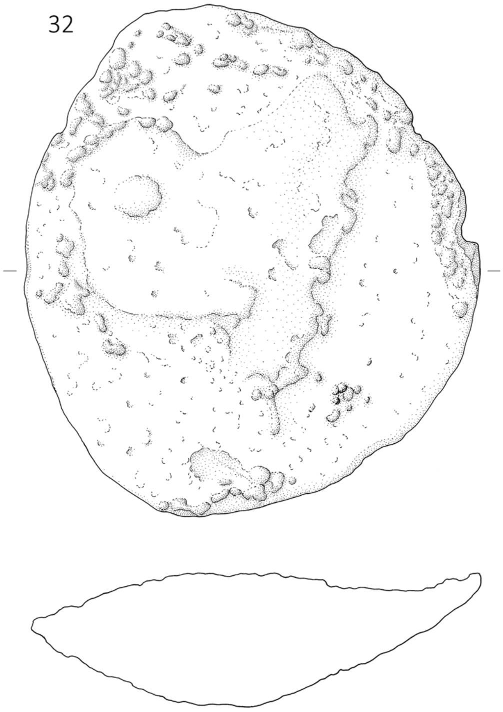

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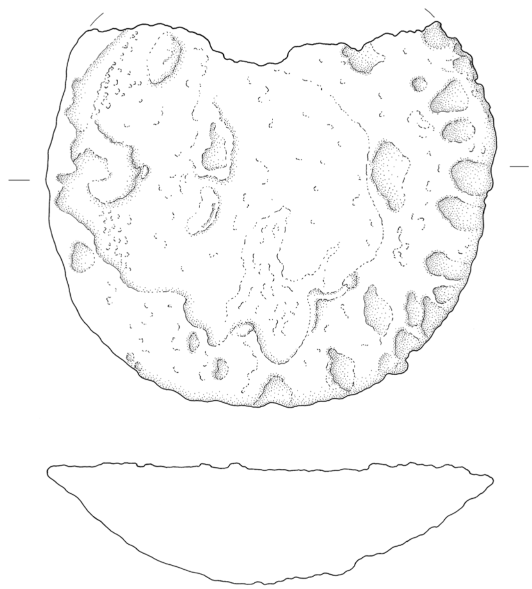

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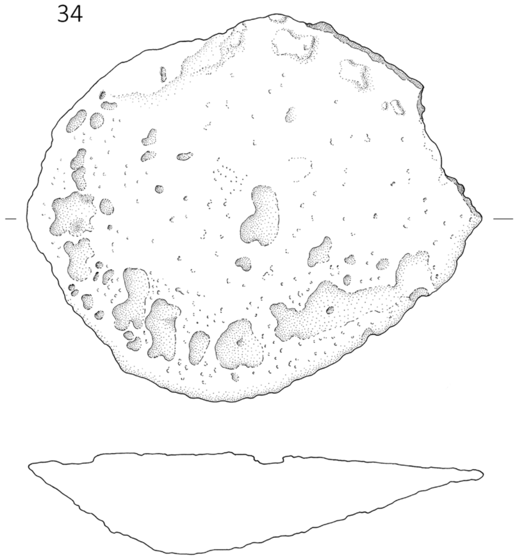

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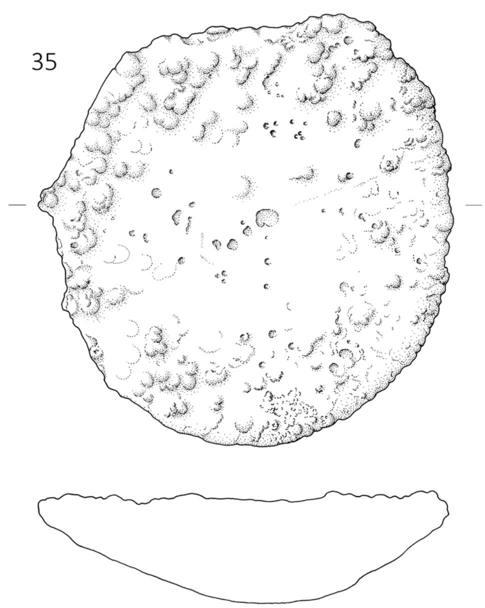
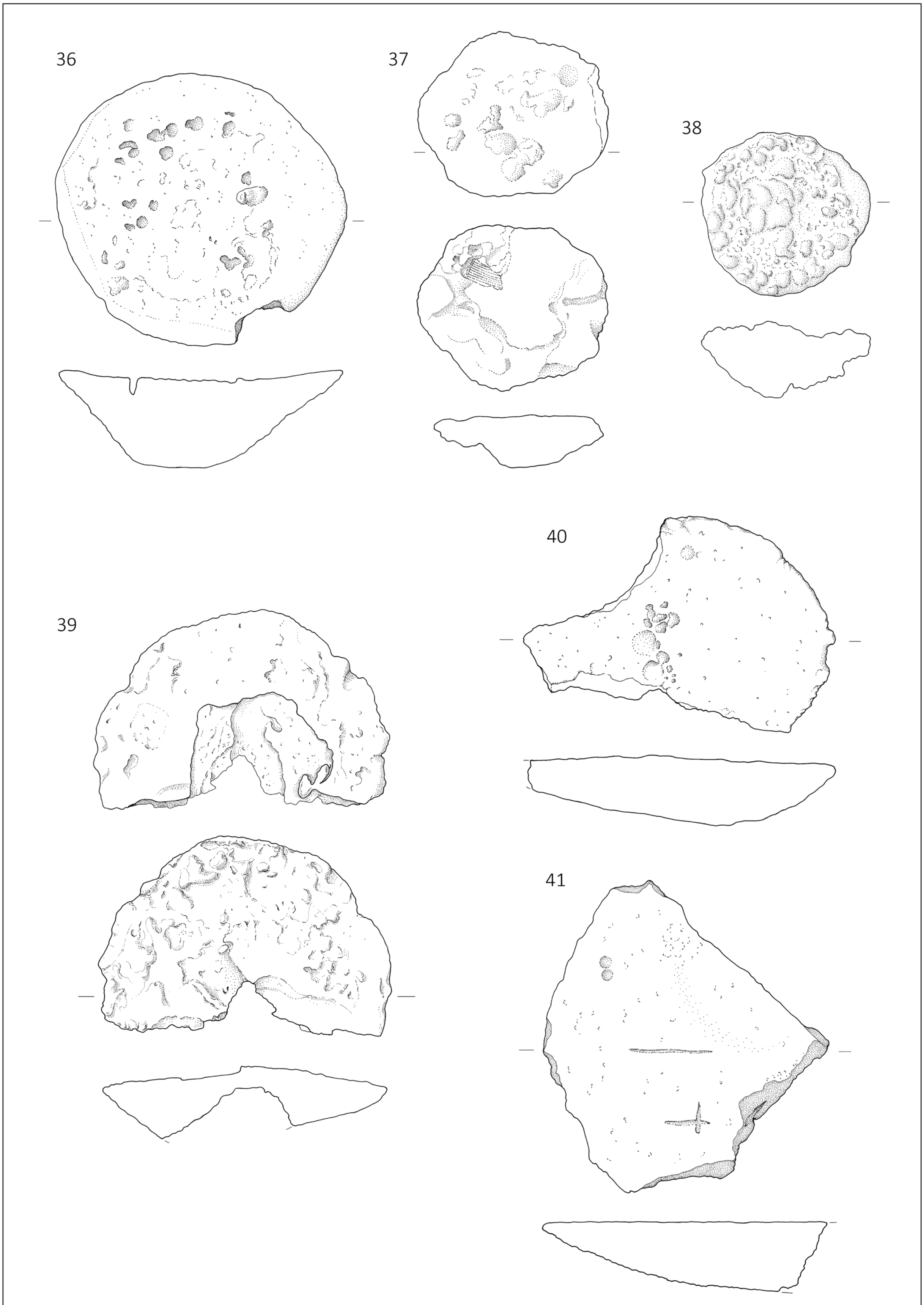
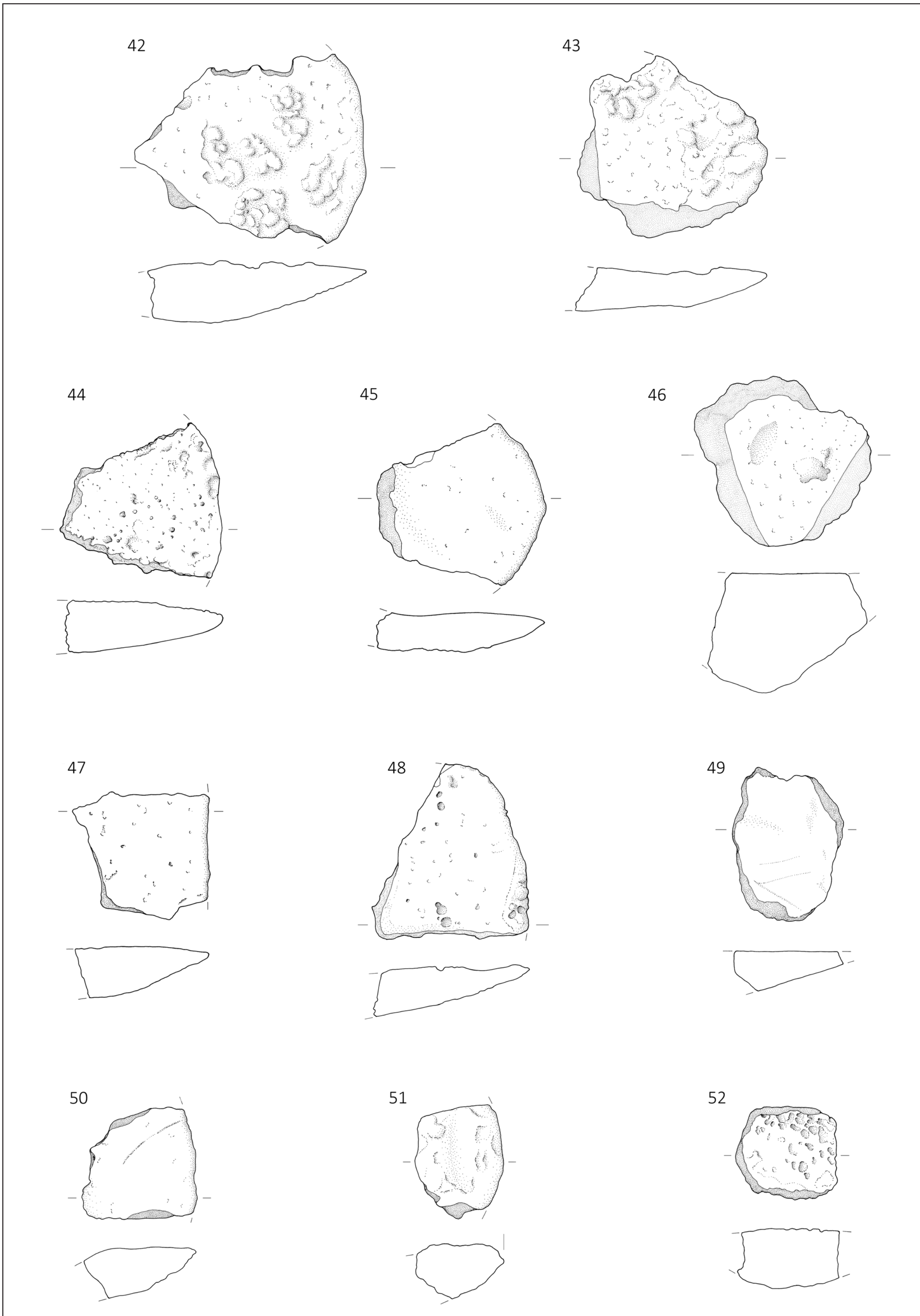


*Pl. 7:* Dragomelj, Hoard I; copper or copper alloy. Scale = 1:3.
*T. 7:* Dragomelj, depo I; baker oz. bakrova litina. M = 1:3.




*Pl. 8:* Dragomelj, Hoard I; copper or copper alloy. Scale = 1:3.
*T. 8:* Dragomelj, depo I; baker oz. bakrova litina. M = 1:3.




*Pl. 9:* Dragomelj, Hoard I; 46 bronze, others copper or copper alloy. Scale = 1:3.
*T. 9:* Dragomelj, depo I; 46 bron, preostalo baker oz. bakrova litina. M = 1:3.

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*Illustrations*: *Fig. 2–5* (elaborated by: Vesna Svetličič). - *Fig. 1,18* (photo: Tomaž Lauko). - *Pl. 1-9* (drawing: Vesna Svetličič, Ida Murgelj, Milan Sagadin; design: Vesna Svetličič).
*Slikovno gradivo: Sl. 2–5* (izdelava: Vesna Svetličič). - *Sl. 1,18* (foto: Tomaž Lauko). – *T. 1-9* (risba: Vesna Svetličič, Ida Murgelj, Milan Sagadin; postavitev: Vesna Svetličič).

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