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Moving metals V: The question of shared copper sources between Scandinavia and Hungary 1700–1500 BC

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ABSTRACT

The remarkable typological parallels between Carpathian and Scandinavian metalwork, especially from around 1700 to 1500 BC, have long been stressed as evidence that the Carpathian tell communities supplied the Scandinavians with copper. Thus, this study's main objective was to investigate if Bronze Age societies in Scandinavia and the Carpathian basin utilized the same copper sources. To test this hypothesis, analyses, comprising lead isotopes and trace elements, were executed on bronzes from Scandinavia and Hungary. In the current study, the Hungarian data set of 31 artefacts from the famous Százhalombatta hoard and its nearby settlement, is in detail compared to 62 Scandinavian artefacts of various types. The outcome points to that Scandinavia and Hungary partly shared copper sources between 1700 and 1500 BC. The most potential sources are the ones from the Slovak Ore Mountains and Mitterberg in Austria. However, the Scandinavian artefacts from this period also show consistency with additional copper sources, such as Great Orme in Wales and in the Italian Alps. The findings of this study support both the traditional theory, which stated that metal supplies and metalworking traditions were closely related, and the more recent insight, which suggests that style and content may have entirely separate origins. As a result, the intricacy of the production, exchange, and consumption patterns of metal throughout Bronze Age Europe cannot be explained by a simple model that equates stylistic influence and metal suppliers.

1. Introduction and theoretical background

Traditionally, it has been emphasized that clear typological similarities exist between Carpathian and Scandinavian metalwork, particularly from c. 1700–1500 BC and that this indicates that metal was traded between these regions in the Bronze Age (Hachmann 1957; Kristiansen 1998:374-375; Engedal 2002:49-56; Fischl et al. 2013:364–365, Fig. 8; Pernicka 2010; Vandkilde 2014). The fact that metal artefacts crafted in the Carpathian Basin have been found in Scandinavia has stimulated the formulation of different models of interaction, alliances and trade. Danish metalwork with similar compositions as metal found in the Carpathian Basin was identified by Liversage and attributed to a not yet identified Transylvanian or Slovakian ore source (Liversage 1994, 2000:62:81–82). It is generally considered that the spread of Carpathian metalwork to Scandinavia indicates an expansion of the Carpathian trade networks into northern Europe (Vandkilde 2014; Meller 2019). However, it must be underlined that provenance ascription of copper and copper alloys to the Carpathian Mountains have both been difficult and inconclusive due to the few archaeological traces of mining in this region. Another problem has been the lack of lead isotopes analyses in combination with geochemical analyses from both regions. However, the situation has recently improved significantly. Against previous assumptions of a one-to-one relationship between copper sources and metalworking styles, new provenance studies have both forwarded and complicated the picture (Pernicka et al. 2016a–b; Melheim et al. 2018; Ling et al. 2019; Nørgaard et al. 2019, 2021; Berger et al. 2022). The outcome of these studies is that the Carpathian tell communities were partly dependent on external

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supplies of copper, which to some extent and in addition to copper from other sources also reached Scandinavia. Can we still assume that there was a strong connection between the two areas in terms of metal trade? Or, are other models of exchange involving other regions, forces and agents more feasible? In what forms were metals traded? As raw materials in the form of ingots of copper and/or bronze, as finished objects, or both?

The aim of the here presented study is to test the theory of interaction between the two areas and to further discuss the character of this relation by comparing copper alloy objects from archaeological sites in Hungary dated to 1700–1500 BC with Scandinavian objects dated to the same period. What distinguishes this comparative study from the previous ones is that:

- We analyse copper alloys from the Százhalombatta-Földvár tell settlement that has been contextually investigated with state-of-the-art archeological methods
- We analyse copper alloys from the contemporaneous Százhalombatta-Földvár (Téglagyár) Hoard II, in an equivalent manner
- We compare the signatures of metals from the settlement and the hoard, and further, we compare these with signatures found in Scandinavian metalwork
- Based on this and the unique combination of objects (debris, small tools and ornaments, ingots, and prestige items), we are able to differentiate between the various types of metals and the forms they circulated in, and to identify patterns related to find contexts

The metals in every-day use by the tell communities themselves add important information to ongoing discussions about the origins of the copper used by metalworkers in the Carpathian Basin, which is still unresolved (Kiss 2020:319). The Hungarian data set comprises 16 bronzes from the Százhalombatta-Földvár tell settlement and 15 objects from Százhalombatta Földvár (Téglagyár) Hoard II (Figs. 1 and 2). All 31 objects were analysed metallographically, 25 of them were analysed for trace element compositions and 17 of these were selected for lead isotope analysis. This data set is in detail compared to 62 Scandinavian items, some of which have been published previously (Ling et al. 2014, 2019; Melheim et al. 2018), and others which are being published for the first time in this study. A more general comparison is made with other recently published Scandinavian data sets, mainly comprising Danish items (Nørgaard et al. 2019, 2021). Due to different chronological systems, the Middle Bronze Age in Hungary coincides with the Early Bronze Age in Scandinavia. To avoid confusion, we shall use 'Nordic Bronze Age' or NBA to denote the latter (see Table 1).

In the following, we will give an account of the contexts and the chronology of the Hungarian metalwork, and the corresponding Scandinavian metalwork selected for comparison. Thereafter, the results of the analytical work including the comparison between the metal signatures of the Scandinavian and Hungarian samples will be presented. We will also evaluate how our interpretations line up against provenance ascriptions made by other teams regarding copper alloys from the Carpathian basin and Scandinavia (Pernicka et al. 2016a–b; Nørgaard et al. 2019, 2021; Berger et al. 2022). In the last section, we shall return to the main topic and discuss the outcome of this study in relation to the hypothesis of shared copper sources between Scandinavia and Hungary in the Bronze Age.

2. Material and methods

2.1. Hungarian artefacts from Százhalombatta-Földvár – An introduction to the tell settlement and the hoard

Százhalombatta-Földvár is located 30 kms south of Budapest on the elevated western bank of the Danube River. The tell settlement was founded during the late part of the Early Bronze Age (c. 2200 BC; end of EBA 2/Rei. A0) (Kiss et al. 2019) on the edge of the high loess plateau. The site dominates its surroundings and there is an excellent view over the Danube and further towards the east. During the Bronze Age, small water gullies were skirting the site from the north and west. The southern side was bordered by a creek and via this the inhabitants of the tell had direct access to the Danube. The site was continuously occupied from the Early Bronze Age (EBA) (c. 2200 BC), for some 800 years, until the end of the Middle Bronze Age (MBA) (c. 1500/1450 BC). It seems to have been abandoned during the same phase as the other tell settlements in the Carpathian Basin (Raczky et al. 1992; Jaeger & Kulcsár 2013; Kulcsár & Szeverényi 2013; Kiss et al. 2015, 2019).

The Százhalombatta site is one of the most investigated fortified tell settlements of the so-called Vatya culture complex in Hungary. During the 20th century, several excavation campaigns and surveys were conducted on the site (Nováki 1952; Kovács 1969; Poroszlai 2000). The current international archaeological research of the Százhalombatta site started in 1998, with the aim of applying modern excavation methods and new theoretical approaches to the investigation of the settlement; its inner structure and its social implications (Earle & Kristiansen 2010; Poroszlai & Vicze 2004; Uhnér 2010; Vicze et al. 2014, 2017). The excavation trench is located near the middle of the 200 m long, and 50 m wide preserved part of the original tell. Pre-excavation prospecting showed that the cultural layers are the thickest here, i.e. 5 m (Varga 2000; Vicze 2005). Until 2017, approximately 3.5–4 m thick cultural layers were uncovered.

The excavation of the Százhalombatta Bronze Age tell settlement is continuing and up until 2021 the earliest MBA phase of the settlement was reached, representing the transition between the MBA and EBA layers (2000/1900 BC). So far, four phases (I–IV) have been identified based on major changes in settlement structures. Each phase comprises a series of characteristic levels (numbered from top to bottom) that on their own present different sub-phases of the settlement. Phase I corresponds to the gradual abandonment of the site where the inner structure of the settlement changes from level to level, reflecting how the society and its traditions were gradually declining. Chronologically it can be identified as the Late Koszider Period, c. 1500–1450 BC. Phase II represents a longer and continuous period when the settlement structure was defined by the use of a main road dividing the site into an eastern and western area of houses (Vicze & Sørensen 2023; Vicze 2013b). Chronologically this comprises the Early and Classical Koszider Phase of the Vatya Culture (Kovács 1984; Vicze 2011, 2013a), between c. 1700/1600 and 1500 BC.[1] Phase III is identified as the Early and Classical phase of the Vatya culture, chronologically corresponding to MBA 1–2 (2000/1900–1700 BC). Phase IV represents the EBA phase of the settlement and is not yet firmly dated or recovered. In Table 2 the samples have been listed according to the order of their relative chronological position within the layers of the tell settlement. In the case of bronze objects, it is a rare opportunity to be able to work with such a fine-tuned chronological sequence, based on the gradual accumulation of the remnants of a dynamic daily life. The samples presented here were selected from the excavation seasons conducted between 1998 and 2014.

2.2. The typology of the analysed bronzes from the settlement in Százhalombatta

All the selected bronzes are typically poorly preserved and fragmented in nature, which is normal for finds coming from settlement contexts. Usually, the objects are small and prone to having been lost. In the case of the complete artefacts (awl, dagger or chisel, Fig. 3) it is assumed that they were lost or forgotten by their owners, rather than having been intentionally deposited. Most of the analysed bronzes are

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[1] The dates used here are based on the most recent results of more than 100 radiocarbon dates from Hungary in Kiss et al. 2019.

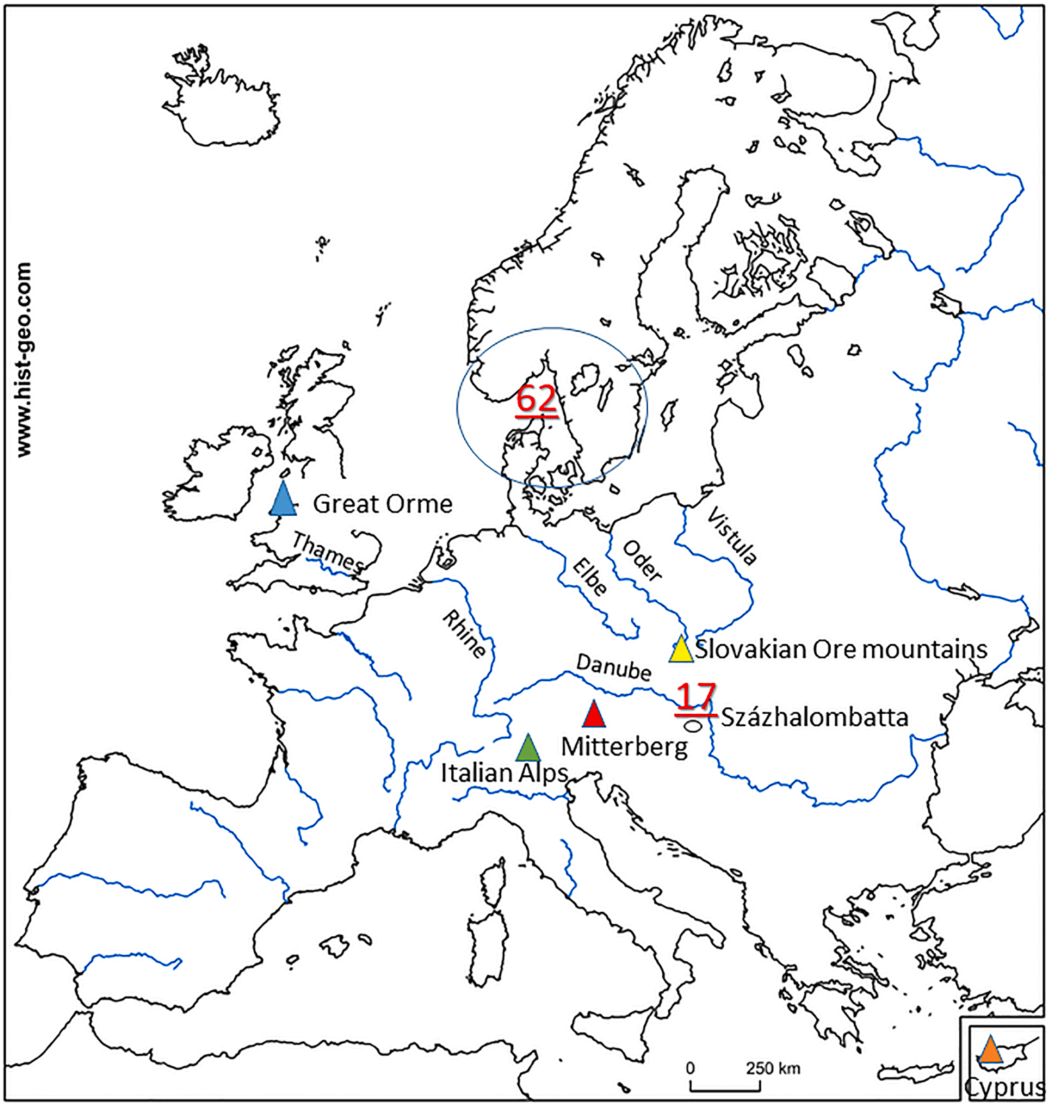

Fig. 1. Map showing the most potential sources of copper (denoted with triangles) for the analysed objects from Hungary as well as from Scandinavia in this study. The highlighted red numbers in Százhalombatta as well as Scandinavia shows how many objects per region we have analyzed. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

fragments or melted pieces. Only six objects could be identified and linked to artefact categories that can be divided into three groups: 1) tools and weapons with cutting edge/s; 2) other small tools (awl); 3) ornaments.

2.2.1. *Tools with cutting edge or edges*

The dagger (**Sz5**) is of the so-called triangular type (Vladár 1974, Type 84). These are usually decorated, but in this case this is uncertain due to the extensive corrosion of the piece. The type has been in use throughout the MBA, particularly during the Koszider period, c. 1700/1600–1500/1450 BC (Kemenczei 1988: 10-14). This dagger type is well known from Vatya settlement, cemetery and hoard contexts and were widely in use within the Carpathian Basin (Bóna 1975; Fokkens & Harding 2013; Neugebauer1994; Szeverényi & Kiss 2018).

The exact parallel of the chisel (**Sz16**, Fig. 3) can be found in the Dunaújváros-Kosziderpadlás Hoard I (Mozsolics 1967; Csányi & Tárnoki 1992:201). These chisels are considered to be the earliest examples and precursors of the later widely known and used socketed axes of the Late Bronze Age (Mozsolics 1967, 1973:37-38).

2.2.2. *Other small tools: Awl*

The awl (**Sz6**) has traces of its original wooden handle and is a complete piece. This type of artefact mostly appears as a grave good in single burials of the contemporary Füzesabony culture in North-Eastern Hungary and Eastern Slovakia (Bóna 1975; Schalk 1992). However, as this find shows, such awls were used in Vatya settlements as well. They are conventionally dated to the second half of the MBA (1700–1450 BC).

2.2.3. *Ornaments*

The third group comprises ornaments that are believed to be pendants or hangers: one spiral coil, one crescent-shaped pendant and one disc-shaped hanger. All three ornament types were widely used within the MBA (2000/1900–1450 BC) in the Carpathian Basin. The spiral coil (**Sz3**, Fig. 3) is part of the so-called spectacle pendant type that was made from a piece of wire coiled on both ends, forming two small discs with a loop in the middle. This type was introduced during the Copper Age from the south but became one of the most frequent jewellery types of the MBA Vatya culture (Bóna 1965, 1975; Girić 1971; Jankovits 2017; Vicze 2011). However, during the MBA it became widely distributed in the northern and western parts of the Carpathian Basin as well (Furmánek, 1980; Kiss, 2012; Honti and Kiss, 2013; Neugebauer and

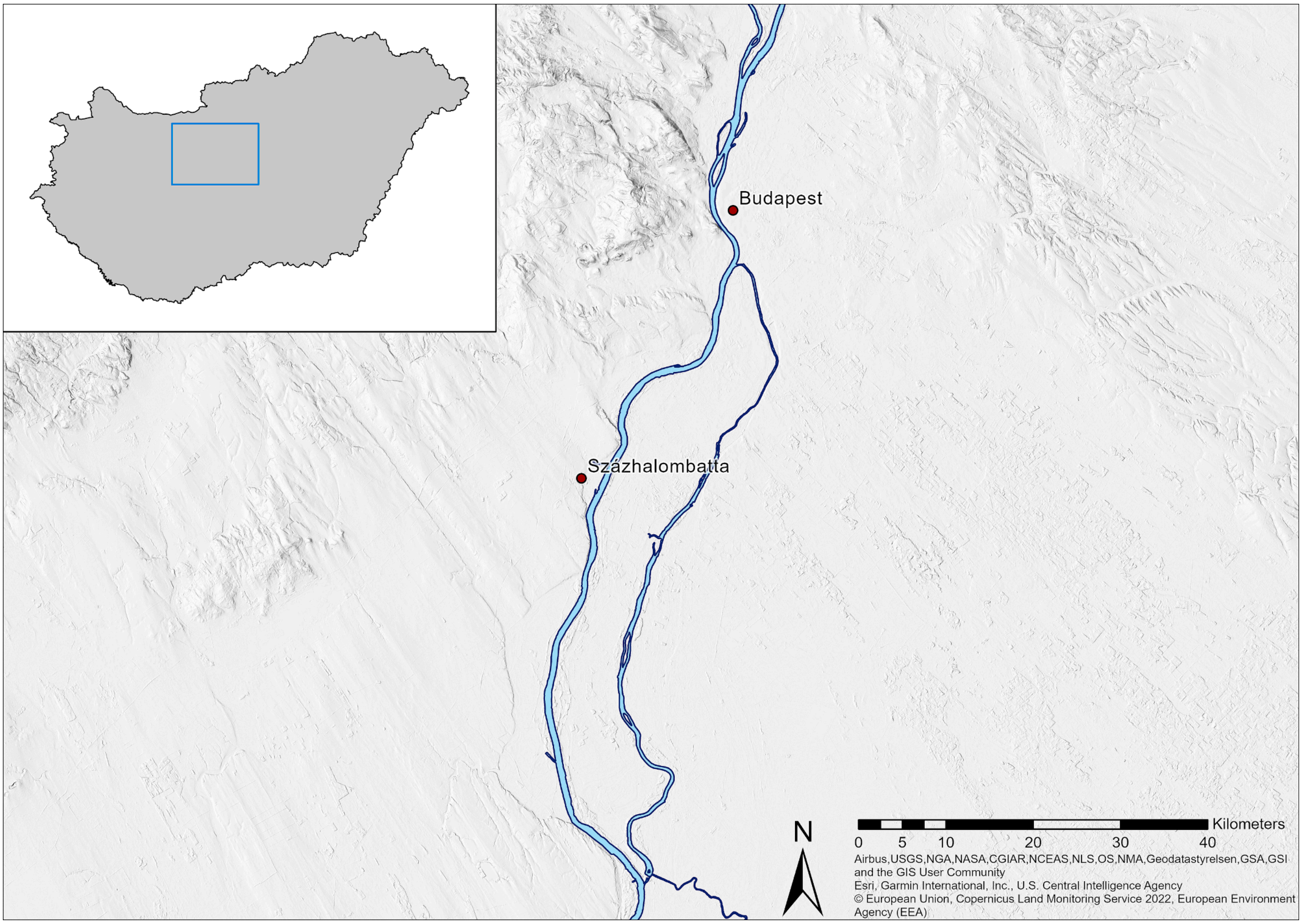

Fig. 2. Map showing the location of Százhalombatta, situated 30 km south of Budapest on an elevated western bank of the Danube River.

Table 1
A. Chronology of the Middle Bronze Age and Late Bronze Age in Hungary (after Kiss et al. 2019). B. Chronology of the Late Neolithic, Middle Bronze Age and Late Bronze Age in Scandinavia (after Goldhahn 2019).

Absolute dates	Hungarian (EBA/MBA)	Reinecke/Müller-Karpe	Chronological phases
2000/1900–1700/1600 calBC	MBA 1–2	Br A2	Middle Bronze Age
1600–1450 calBC	MBA 3	Br B1(Br B2)	
1500/1450–1400 calBC	LBA 1	Br B2	Late Bronze Age
1400–1300 calBC		Br C	
1300–1200 calBC	LBA 2	Br D	
1200–1100 calBC		Ha A1	

Absolute dates	Nordic Bronze Age (NBA)	Montelius	Chronological phases
1950–1700 calBC	LN II	LN 2	Late Neolithic
1700–1600 calBC	NBA IA	1A	Early Bronze Age
1600–1500 calBC	NBA IB	1B	
1500–1330 calBC	NBA II	II	Middle Bronze Age
1330–1100 calBC	NBA III	III	

Neugebauer, 1997; Novotná and Novotny, 1984).

The crescent-shaped pendant (**Sz9**, Fig. 3) is considered to be the invention of the Vatya Culture. It has been used from its earliest period (Bóna 1975:53-54) through the Koszider period (see Hoard II, Kovács & Raczky 1999) and even later during the LBA (Jankovits 2008, 2017). The use of this jewellery or garment decoration piece has spread widely from the Vatya territories within the Carpathian Basin from the Lower Danube region (see Schumacher-Matthäus 1985) to the territories of Slovakia (Furmánek, 1980; Furmánek et al., 1999).

The small disc-shaped hanger (**Sz10**, Fig. 3) typically belongs to the ornamental tradition of the Transdanubian Encrusted Pottery culture, however, can also be found on Vatya sites, both in settlements, cemeteries and hoards (Bóna 1975; Honti & Kiss 2013; Kiss 2012; Jankovits 2017; Vicze 2011).

2.3. *The typology of the analysed bronzes from hoard II*

Over the last 120 years two bronze hoards have come to light at Százhalombatta-Földvár, both found by amateurs. The first hoard (Hoard I) was purchased by the Hungarian National Museum from the widow Jánosné Fejérváry for 40 crowns in 1902. This acquisition originally contained 201 MBA bronze artefacts (shaft-hole axes, spearheads and different types of ornaments) and 8 beads along with additional objects dated to the Roman period and the Early Iron Age (Inventory Book of the Hungarian National Museum 1902.45.1–118). Most researchers identified the MBA objects as part of one hoard assemblage, following József Hampel (Hampel 1902:424, Pl. I-III; Bóna 1975:71, Fig. 14). However, Mozsolics questioned the theory that all finds

Table 2
Metal objects from the excavation of the settlement at Százhalombatta-Földvár. Presented from top (Phase I) to bottom (Phase III). Descriptions made by Magdolna Vicze. The samples presented here were selected from the excavation seasons conducted between 1998 and 2014. Analyses made are: M = metallographic, C = chemical, L = Lead isotope analyses.

Phase	Level	Sample No	Object	Analyses	Feature/Context
I	2	Sz1	Tip of a dagger	M	Pit No. 588. The piece is from the bottom layer of the Late Bronze Age pit that cut into Middle Bronze Age layers.
I	4	Sz2	Oval disc like object. Function unknown	M	A 2 m × 2 m excavation unit (eu 1372), within the general fill of the temporary residential area of Level 4.
I	6	Sz4	Tip of a sickle	M	The 2 m × 2 m excavation unit (eu 3027) is within a typical open area type of accumulated fill (id 3019).
II	9	Sz16	Chisel	M, C, L	The chisel was found in a 1 m × 1 m excavation unit (eu 3170) from House id 3181. It was within the stone packing of an open heart with other finds like an amber bead.
II	10	Sz5	Dagger with broken tip	M, C, L	Found within one of the excavation units (eu 3143) of the main road on the E side of House id 3181. Sz5 and Sz7 (eu 3676) were found approximately 1 m apart from each other in the same fill.
II	10	Sz7	Midsection of a pin	M	See Sz5
II	10	Sz3	Spiral pendant fragment	M, C, L	The fragment was found within one of the excavation units (eu 3133) of the main road on the W side of House id 3497. The fill is the same as in the case of Sz5 and Sz7.
II	10	Sz6	Awl	M, C, L	The awl was found in a heap of debris (eu 3671) outside House id 3497.
II	11/12	Sz8	Small rod	M, C, L	The small rod comes from the fill (eu 4563) of a small narrow alley between the Houses id 4651 and id 4080.
II	13	Sz11	Melt piece	M, C, L	The fragment is from the excavation unit (eu 6020) in the thin burnt black organic layer that could belong to a possible temporary building.
II	14	Sz9	Crescent-shaped pendant	M, C, L	Sz9 and Sz12 came from a 2 m × 2 m excavation unit (eu 5616) within an earlier phase of the main road (id 5597).
II	14	Sz12	A small rectangular bronze bar (ingot?)	M, C	See Sz 9
II	14	Sz10	Disc-shaped pendant. Complete piece	M	The pendant was found in an excavation unit (eu 5779) from the fill of the alley SE of House id 5047.
II	15	Sz13	Crumpled bronze sheet, broken	M	The find is from the excavation unit (eu 6691) in the open area, id 6565 that is characterised by lots of ash and working pits.
III	16	Sz14	Melt piece	M, C, L	Sz14 and Sz15 were found within the remnants of a house floor id 6722.
III	16	Sz15	Sheet of bronze	M, C	See Sz14

Fig. 3. Collage of artefacts from the settlement at Százhalombatta-Földvár. Top, from left to right: disc-shaped pendant (sample Sz10), spiral pendant fragment (sample Sz3) and crescent pendant (sample Sz9). Bottom: chisel (Sz16). Photo by the authors.

belonged to a single assemblage (Mozsolics 1967:130, Pl. 6.3, Pl. 17.6). The other bronze hoard (Hoard II) was found by a local farmer in Százhalombatta-Földvár (Téglagyár). These objects had been deposited in a ceramic pot. The samples in the current study are all from Hoard II, most of which is on display in the permanent exhibition of the Hungarian National Museum (Szathmári 2005; Kemenczei 2002:44, Fig. 17).

All artefacts from Hoard II (Fig. 4) date to the Koszider period (c. 1700/1600–1500/1450 BC) (Mozsolics 1984:67; Kiss et al. 2015, Fig. 5; Fischl et al. 2013; Kiss et al. 2019). The complete assemblage has never been published; it is a part of Tibor Kovács's scientific legacy (Mozsolics 1984:67, Pl. 2.1–19, Pl. 3.1–3; Kovács 1999, Fig. 28; Szathmári 2005,

Fig. 4. Objects from the famous Százhalombatta-Földvár (Téglagyár) Hoard II. Prehistoric Collection, Hungarian National Museum, Photo: Ádám Vágó.

Fig. 60; V. Szabó 2015, 119, III.37; Kemenczei 2002:44, Fig. 17). However, most of the ingots from the hoard were published in 1984 (see Mozsolics 1984). The sampled and analysed artefacts from the hoard can be divided into four groups: 1) weapons, 2) tools, 3) ornaments and 4) ingots and/or raw material (Table 3).

2.3.1. *Weapons*

The spearhead fragments (Tab. 3.1–3) are hard to classify precisely due to their fragmented state caused by intentional prehistoric destruction by blunt implements, probably hammers. In the Carpathian Basin, spearheads from the Koszider period are usually small compared to spearheads from the Late Bronze Age. Most of them have midsize or short socket and a leaf-shaped or a slightly flame-shaped blade (Mozsolics 1967:61–62; Hänsel 1968:74–76, Bader 2015:373–374). Two fragments (Tab. 3.1–2) may be part of such weapons. The fragment No. 3 is an unclassifiable object inserted into the broken socket of No. 2. It can be a fragment of the spearhead itself or a completely different object. Such combinations are characteristic for spearheads (Soroceanu & Szabó 2001:219–220, Fig. 4.2; Tarbay 2021:110, Fig. 12.F) and socketed axes deposited in hoards (see with further references Dietrich & Mörtz 2019). No. 2 is a richly decorated specimen without exact parallels, while no. 1 has related finds among the local material, e.g., Sárszentlőrinc-Uzd (Mozsolics 1967, Pl. 58.6, 8).

2.3.2. *Tools*

The half sickle fragment is of a type often described as a knife-like sickle (Hänsel 1968:51–53, Map 7.33a; Petrescu-Dîmboviţa 1978:8–13; Primas 1986:46–48; Furmánek–Novotná 2006:8–11; Mozsolics 1967:66) (Tab. 3.4). In the Carpathian Basin, these agricultural tools are characteristic for the Koszider period when they appeared in contemporary hoard material, e.g., Budapest-Békásmegyer, Kölesd-Nagyhangos, Sárbogárd, Vyškovce nad Ipľom (Mozsolics 1967, Pl. 27.16, Pl. 31.8, Pl. 36.3; Furmánek–Novotná 2006, Pl. 1.1).

2.3.3. *Ornaments*

The cone-shaped pin head most likely belonged to a sickle-shaped pin (Germ. Sichelnadel) (Tab. 3.6). This type of ornament usually occurs in hoards and burials. It can be considered as a widely distributed type, its representatives are known from an area spanning the Carpathian Basin and the western part of Central-, e.g., Czech Republic, Austria, Southern Germany as well as the Northern Balkans. In the territory of Hungary, it can be considered as a characteristic pin type during the Koszider period (Bóna 1958:232–234, Fig. 5; Mozsolics 1967:83–84; Hänsel 1968:77–82, Fig. 3, List 67–73; Říhovský

Table 3
Metal objects from the Százhalombatta Földvár (Téglagyár) Hoard II. Descriptions made by János Gábor Tarbay. Analyses made are: M = metallographic, C = chemical, L = Lead isotope analyses, uncl = unclassifiable.

Cat. no.	Number	General typology	Object	Type	Analyses	Description
1	HNM 76.3.21 [A]	Weapon	Spearhead	uncl.	M, C, L	Blade fragment of a spearhead with leaf-shaped blade. Its midrib is rhomboid sectioned. Hammer impact related to partitioning present on the midrib.
2	HNM 76.3.21 [Ba]	Weapon	Spearhead	uncl.	M, C	Blade fragment of a spearhead with the part of the midrib. The blade is decorated with two, cast outline ribs. Chased dots are visible along the crushed midrib.
3	HNM 76.3.21 [Bb]	Weapon	Spearhead (?)	uncl.	M, C	Inserted to the broken socket of No. 2 HNM 76.3.21 [Ba]. Part of the spearhead or from other object.
4	HNM 76.3.22	Tool	Sickle	Knife-shaped sickle	M, C, L	Fragment of a sickle with straight base and a hammered back.
5	HNM 76.3.23	Ornament	Spiral anklet/ armlet	Regelsbrunn type	M, C, L	Bent fragment of a spiral anklet or armlet with cast rib.
6	HNM 76.3.12	Ornament	Pin	Sickle-shaped pin	M, C, L	Undecorated head fragment of a pin, maybe a sickle-shaped pin. With a central a cast hole and rhomboid-shaped shaft.
7	HNM 76.3.27	Ingot	Tongue-shaped ingot	Tongue-shaped ingot	M, C, L	Upper part of a double tongue-shaped ingot.
8	HNM 76.3.28	Ingot	Tongue-shaped ingot	Tongue-shaped ingot	M, C, L	Upper part of a tongue-shaped ingot.
9	HNM 76.3.29	Ingot	Tongue-shaped ingot	Tongue-shaped ingot	M, C, L	Tongue-shaped ingot with casting mismatch defect.
10	HNM 76.3.36 [B]	Ingot	Tongue-shaped ingot	Tongue-shaped ingot	M, C	Middle part of a tongue-shaped ingot.
11	HNM 76.3.34	Ingot	Tongue-shaped ingot	Tongue-shaped ingot	M, C	Lower part of a tongue-shaped ingot.
12	HNM 76.3.24	Ingot?	Bar ingot?	Bar ingot?	M, C	Quadratic-sectioned bar ingot fragment (or possibly fragment of a ring or spiral).
13	HNM 76.3.35	Ingot	Plano-convex ingot	Százhalombatta type	M, C, L	Quarter fragment of a flat, plano-convex ingot with shrinkage defect.
14	HNM 76.3.36 [A]	Ingot	Plano-convex ingot	Százhalombatta type	M, C, L	Middle fragment of a partitioned plano-convex ingot. Hammer mark is visible in the middle.
15	HNM 76.3.30	Ingot?	Casting debris/ Ingot	uncl	M, C	Slightly quadratic lump or non-standardised ingot form

1979:17–20; Říhovský 1983:3–5; Innerhofer 2000:63–72).

The narrow, ribbed sheet metal fragment (Tab. 3.5) was most likely part of a large spiral anklet or armlet with spiral terminals. These ornaments are eponymous types of the Koszider period (Bóna 1958, Fig. 5; Mozsolics 1967:76; Hänsel 1968:105–106). Intentional partitioning of these ornaments is a custom observed in several Koszider hoards from the territory of Hungary (See Mozsolics 1967: Pl. 14.4, Pl. 27.14, Pl. 50.16, Pl. 67.3). Due to its fragmented state, the Százhalombatta fragment cannot be assigned to a particular type. However, it is very likely that it may represent a Regelsbrunn type of leg-spiral which was distributed between the Carpathian Basin and West Central Europe during the Koszider Period. (Hachmann 1957:116, Hänsel 1968: 105–106, 215–216, List 104, Map 23; Rittershofer 1983:252–265, Fig. 21–32, Lists 17–20; Koledin 2019:179–181). The wearing customs of these ornaments are known from eponymous inhumation burials like Velebit 80 or Wien-Sulzengasse 23 (See Hahnel 1994:29–32, Figs. 1–3; Koledin 2019:177–179, Figs. 1–2).

2.3.4. *Ingots and/or raw material*

The ingot group can be further divided by shape: tongue-shaped ingots, plano-convex ingots, bar ingots, and atypic ingots (or debris). A majority are of the so-called tongue-shaped ingots (Germ. Zungenbarren) (Tab. 3.7–11). In Hungary, ingots of this type are almost exclusively found in hoards dated to the Koszider period (Mozsolics 1967:96–98, Fig. 29, 1984:31; Primas & Pernicka 1998:50–52; Czajlik 2006:52, 2012:73). Clay casting moulds used for producing two, three or five ingots at once are well-known from Dunaföldvár (Tolna County, Hungary) (Rómer 1866:28–29; Czajlik 2012:72–73). According to Zoltán Czajlik, tongue-shaped ingots are also known from France, Austria and Switzerland (Czajlik 2006, 52). Specimen no. 9 from Hoard II shows a casting defect typical for this production technology (Tab. 3.9). Tongue-shaped ingots constitute a common form of ingot, although it has been discussed whether it is an ingot or not. Eugen Friedich Mayer proposed that these may have been as-casts of axes (Mayer 1977:69). This suggestion was debated by Amália Mozsolics (Mozsolics 1984:32, see also Primas & Pernicka 1998:50–52). Recently, Alexandra Găvan interpreted some of the specimens from Százhalombatta Hoard II as casting jets, i.e. by-products of casting (Găvan, 2015:61-62, see also Mozsolics 1984:31). We cannot support this interpretation as it is based on the misidentification of partitioned tongue-shaped ingots. However, the possibility should not be excluded that some of the tongue-shaped ingots with tin content were made from the metal surplus left in the crucible after casting (Schubert & Schubert 1967; Czajlik 2012:72–73, 91). Some of the ingots presented extensively by Mozsolics (Mozsolics 1967, 1984), were chemically analysed by Schubert & Schubert (1967), and also part of the *Stuttgarter Metallanalysenprojekt* and included in the SAM-database (Junghans et al. 1974).

Two divided plano-convex ingots (Tab. 3.13–14) were also selected for analysis. The two fragments represent Zoltán Czajlik's Százhalombatta type of ingot dated to the Koszider period (Czajlik 2006:52; Czajlik 2012:67). Towards the end of the MBA, plano-convex ingots are considered to be rare. Many of them have individual shapes which suggest that this type had not yet became standard at this time (Mozsolics 1967:97–98; Mozsolics 1984:35–39; Czajlik 2006:52; Czajlik 2012:67).

Bar ingots belong to a common and well-distributed type during the Bronze Age. Regarding the Carpathian Basin, the earliest representatives of this type emerged in the MBA, particularly during the Koszider period. They are also common during the LBA, mainly between the Br D–Ha A1 period. Their manufacturing technology is known based on preserved stone moulds and macroscopic traces (Mozsolics 1984:32–33; Kovács 1986: Fig. 3.3; Mozsolics 1973, Pl. 111.1a; Mozsolics 1985:32; Czajlik 2012:74; (Tarbay, 2014):218-219, List. 19, (Tarbay, 2019): Fig. 40; 8, Fig. 12.4; Găvan, 2015, Tab. 2).

Ingot no. 12 has a regular rectangular cross-section which is uncharacteristic (Tab. 3.12). One possibility is that the object was a bar ingot, manufactured further by hammering, which is supported by the micro-texture observed on a polished sample in the current study (not shown). On the other hand, it may have been a fragment of a finished product, possibly some sort of ornament like an arm ring or a spiral. Among the analysed samples there is also a quadratic shaped object with rounded edges and irregular surfaces (Tab. 3.15). Based on its more or less regular shape, it is possible that it represents an ingot of unstandardized shape (as indicated below, the low tin content seems to support that it is a form of raw material).

2.4. *Scandinavian artefacts for comparison*

Primarily utilized for comparison were a number of Scandinavian items with accessible lead isotope and trace element signatures (Ling et al. 2014, 2019; Melheim et al. 2018). The selection was governed first by chronology, next by typology. As part of the current study of the Carpathian bronzes, we also present new and unpublished data for Scandinavian bronzes. Moreover, new reference data on both ores (Pernicka et al. 2016a; Williams 2018; Williams et al. 2019; Artioli et al. 2016) and more analyzed artefacts (Pernicka 2013; Pernicka et al. 2016b; Bunnefeld 2016a,b; Mehofer & Jung 2017; Nørgaard et al. 2019, 2021, 2023) have implied a re-evaluation of some the provenance ascriptions made earlier by our team (Ling et al. 2014).

2.4.1. *The typology of the Scandinavian artefacts*

The selected Scandinavian bronzes date to c. 1700–1500 BC, Nordic Bronze Age (NBA) IA–IB (Vandkilde 2014) and are hence contemporaneous with the sampled objects from Százhalombatta, dated to the Koszider period (1700/1600–1500/1450 BC). Most of the analysed Scandinavian bronzes from this phase consist of axes, spearheads, and blades of typical Nordic forms, such as *Valsømagle*, *Fårdrup* and *Bagterp*. The data set from the current team used for comparison consists of in total, 16 flanged axes (Fig. 5), 18 shafthole axes (Figs. 6–7), 16 spearheads (Figs. 8–9), 10 swords (Fig. 10) and daggers, and two chisels (Table 4).

2.4.2. *Flanged axes*

The flanged axes (Fig. 5) dated to NBA IA–IB (c. 1700–1500 BC) were cast locally in the Nordic region (Vandkilde 1996) but show strong typological links to flanged axes of Central and East-Central European origin. Out of the 16 analysed Nordic flanged axes in the current study, five can be dated to the NBA IA (c. 1700–1600 BC) and eleven to the NBA IB (c. 1600–1500 BC). Comparison is made with analysis of 52 flanged axes from the NBA IA (c. 1700–1600 BC) and nearly 140 flanged axes from NBA IB, from several Danish sites (Nørgaard et al. 2019, 2021). Although flanged axes were also common in the Carpathian Basin (Mozsolics 1967:63–65; Găvan 2015:88–89; Pernicka et al. 2016b; Szabó et al. 2018), none from the Százhalombatta settlement site or hoard were sampled for the current study.

2.4.3. *Shafthole axes*

Characteristic Nordic massive shafthole axes of type *Fårdrup* and *Valsømagle* are key among the Scandinavian reference objects (Figs. 6–7). Although chronological and/or geographical differences in distribution have long been discussed (most lately by Nørgaard et al. 2023), both types date to NBA IB, c. 1600–1500 BC (Vandkilde 1996:227, 238). There is no direct parallel to these typical Nordic shafthole axes in Central or East-Central Europe, although the ornamentation on many *Fårdrup* axes shares strong links with the shafthole axes of disc-butted type from the Hajdúsámson-Apa horizon in the Carpathian basin (Mozsolics 1967; David 2002; Pernicka et al. 2016b). Around 75 *Fårdrup* axes have been found in Denmark (60 analysed by Nørgaard et al. 2021), 38 in Sweden and 6 in Norway. Also, 3 axes of the *Fårdrup* type (out of 11) from Mecklenburg in northernmost Germany have been analysed (Nørgaard et al. 2023). Apart from the eponymous Fårdrup hoard these mostly occur as single finds (Malmer 1989;

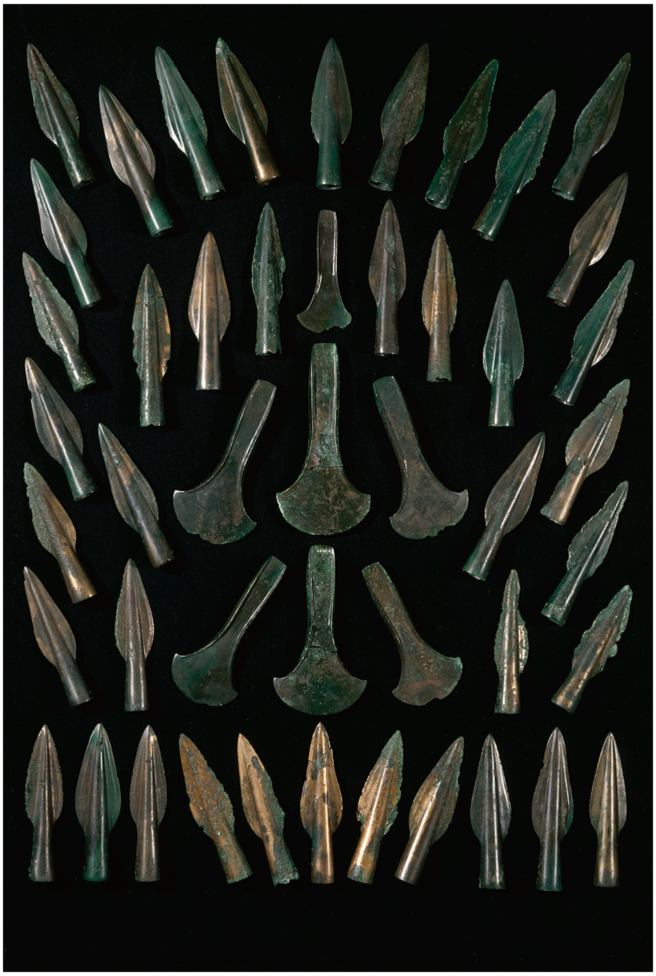

Fig. 5. Flanged axes and spearheads dated to 1700–1600 BC (NBA IA), from the major Bronze Age hoard from Bondesgårde, Torsted, Denmark. Photo by Lennart Larsen. License CC-BY-SA. Source: Danmarks Oldtid, Nationalmuseet.

Fig. 6. Shafthole axe of Fårdrup type from Holtegård, Denmark, dated to 1600–1500 BC (NBA IB) (Photo Kit Weiss, National Museum of Denmark).

Fig. 7. Shafthole axes of Valsømagle type found in Sweden, dated to 1600–1500 BC (NBA IB). Top: HM 9802, from Halland (Hallands länsmuseer), middle: SHM 1665, FID 1182897 from Scania (National Historical Museums, Sweden) and bottom: SHM 1477, FID 1182894, from Uppland (National Historical Museums, Sweden). Photo by the authors.

Fig. 8. Spearheads of Bagterp type, dated to 1600–1500 BC (NBA IB). Top: KLM 01438 from Öland (Kalmar Läns Museum, Sweden), and bottom: 1 M16 4491 from Västergötland (Västergötlands museum, Sweden). Photo by the authors.

Vandkilde 1996; Liversage 2000; Engedal 2010:90, for previous analysis see Cullberg 1968). The *Valsømagle* type is not as common, with only 8 known examples from Denmark (7 analysed by Nørgaard et al. 2021) – mainly from hoards – and about 26 from Sweden, mostly as single finds (Vandkilde 1996: 238; cf. Oldeberg 1974). In addition, 1 of the 9 axes of *Valsømagle* (or similar) type from Mecklenburg is also analysed (Nørgaard et al. 2023). So far, there are no finds of the *Valsømagle* type in Norway (Engedal 2010). Finds of these axes have also been made across the Baltic Sea on Rügen and in adjoining parts of mainland Mecklenburg (Vandkilde 1996:238). In the current study, 18 shafthole axes are included, of which 12 are of the *Fårdrup* type and 6 of the *Valsømagle* type.

Fig. 9. Spearheads of Valsømagle type, dated to 1600–1500 BC (NBA IB). Top: ÖM 1757 from Scania (Österlens Museum, Sweden), and bottom: 1 M16 4489 from Västergötland (Västergötlands museum), Sweden. Photo by the authors.

2.4.4. Spearheads

Among the spearheads selected for the comparative study, we have analysed 8 of the *Bagterp* type and 7 of the *Valsømagle type* (Figs. 8–9). The *Bagterp* type is related to the *Fårdrup* horizon and is a rather common spearhead, especially in Sweden (79) but also in Denmark (62, of which 3 are analysed by Nørgaard et al. 2021). However, a few have also been found in Norway (9) (Jacob-Friesen 1967; Oldeberg 1974; Vandkilde 1996; Engedal 2010:127–129). In Denmark, these spearheads are mainly found in hoards, as single finds and in burials. In Sweden and Norway, they are found as single finds and in hoards, but very seldom in burials. The other type of spearheads, connected to the *Valsømagle* horizon, is the *Valsømagle* spearhead. *Valsømagle* spearheads have been found in Sweden (56) and in Denmark (34) but none in Norway although a few specimens show stylistic traits (Engedal 2010:69). In Denmark they are usually found in burials and hoards. In Sweden they mostly appear as single finds and in hoards (Jacob-Friesen 1967:117; Vandkilde 1996:232-235; Oldeberg 1974).

2.4.5. Swords and daggers

Early types of metal-hilted *swords and daggers* from Scandinavia date to around 1600 BC, and comprise, among others, metal-hilted swords which are similar to swords found in the Carpathian Basin (Vandkilde 1996, 2016; Engedal 2002:49-56, 2016; Schwab et al. 2010; Bunnefeld 2016a,b, Ling et al. 2019). In general, many of the earliest Scandinavian swords (Fig. 10) show strong typological links to swords from the Hajdúsámson hoard in Hungary and the Apa hoard in Romania. Some of the Danish swords and at least one of the Swedish, are considered to be crafted in and directly imported from the Carpathian Basin (Lomborg, 1960):70. Other swords found in Denmark, Sweden and Norway are understood as Nordic derivatives of the Carpathian Basin sword types that were cast locally in Scandinavia (e.g. Oldeberg 1974:229; Vandkilde 1996:224–227; Engedal 2002:54; Bunnefeld 2016b; Melheim 2015:70). Seven, i.e. a majority, of the 10 analysed swords and daggers, are of the metal-hilted type and four of these belong to the Nordic Hajdúsámson-Apa type. Three of these are from the Dystrup hoard in Denmark (Melheim et al. 2018), and one from a lake in Norway (Melheim 2015:70–71; Melheim and Horn 2014). Among the analysed metal-hilted swords are also two samples from Sweden connected to the indigenous Valsømagle type. Included in our comparative study, are also analytical data of one hilt-plated sword from Norway and one hilt-plated dagger from Sweden, both of the Sögel type. Another analysed hilt-plated dagger, from Denmark, is of the Wohlde type (Ling et al. 2019).

2.5. Methods

2.5.1. Sampling procedure

All new samples, from Százhalombatta as well as from Scandinavia, were cut or drilled from various parts of the artefacts, generally adjacent to previous defects in order to minimize the damage. The samples were divided, and one half was mounted in resin, ground and polished. An optical microscope with polarised reflected light was used for metallographic analyses in order to define the structure and texture and prepare for succeeding electron microprobe analysis (EPMA).

2.5.2. Analytical methods

Wavelength dispersive analyses (WDS) were made using the JEOL JXA-8530F at the Centre for Experimental Mineralogy, Petrology and

Fig. 10. Photo of some of the swords from the famous Dystrup hoard in Denmark, dated to 1600–1500 BC (NBA IB). Photo by John Lee. License CC-BY-SA Source: Nationalmuseet Denmark.

Table 4
Analysed metal objects from Scandinavia presented in detail in the current study, dating to c.1700–1500 BC, i.e. Nordic Bronze Age (NBA) IA–IB.

Type	*Number*
Flanged axe	**16**
Shafthole axe	**18**
Fårdrup	12
Valsømagle	6
Spearhead	**16**
Bagterp	8
Valsømagle	7
Other	1
Metal-hilted sword	**7**
Nordic Hajdusámson-Apa	4
Valsømagle	2
Other	1
Hilt-plated sword	**1**
Sögel	1
Hilt-plated dagger	**1**
Sögel	1
Dagger	**1**
Wohlde	1
Chisel	**2**
Total	***62***

Geochemistry at Uppsala University, as point analyses of individual phases as well as in area scans (maximum 50 by 50 μm). Due to the heterogeneity of copper alloys, multiple area scans were made, and mean values calculated. Two in-house reference bronze samples were included in the analytical sessions; one sample with very low, but detectable, concentrations of impurities and one with high concentrations (fahlore-matrix). Operating conditions during runs involved an acceleration voltage of 20 kV and an electron beam current of 20nA. The obtained analytical data were related to standards (oxides, sulphides, metals) and ZAF corrected.

The other half of the sample was used for the lead isotope analysis. Prior to dissolution they were leached for a few minutes in HNO_3 at room temperature in order to remove possible surface contamination and some of the alteration products such as malachite and subsequently digested in hot 6 M HNO_3. After dissolution, the lead was extracted on anion exchange columns. The isotope ratios measurements were performed with the high-resolution Multi-Collector Inductively Coupled Plasma Mass Spectrometer (MC-ICP-MS) of the type Nu Plasma II, hosted by the Vegacenter facility at the Department of Geosciences at the Swedish Museum of Natural History. The SRM NBS-981 Pb standard was run at regular intervals, and all samples were analysed in duplicate. The obtained numbers for the standard are within error of those given by Todt et al. (1996), and the external reproducibility is estimated to be between 0.04% ($^{206}Pb/^{204}Pb$) and 0.08% ($^{208}Pb/^{204}Pb$), whereas the other listed ratios have uncertainties of 0.05% or better. The external precision for unknowns is of a similar order, but in order to account for errors arising also during the chemical treatment in the clean laboratory, accepted overall uncertainty for all independent lead isotope ratios is ± 0.10%.

2.5.3. *Analysed samples*

Metallographic analyses were done on all 31 samples from the Százhalombatta-Földvár settlement and from hoard II (Tables 2 and 3). Some of the samples from the settlement were, however, severely corroded and were not further analysed. After further assessment of various parameters, 25 samples were selected for elemental analyses: 15 samples from the hoard and 10 from the settlement (9 objects), from Phase II and Phase III. Among these 25, 17 were selected for lead isotope analyses; nine from the hoard and eight from the settlement (Tables 2–3). Only the samples with analytical data (elemental or combined elemental and lead isotope) are treated further. For all the 29 Scandinavian samples selected for the current study, metallographic, elemental and lead isotope analyses were carried out.

2.5.4. *Databases for interpretation*

The interpretation of data is a difficult process that involves comparing sets of lead isotope ratios and trace elemental compositions. These comparisons must be made in light of previous research on the history of mining in the relevant regions as well as the archaeological context (e.g., Pernicka et al. 1993; Stos-Gale et al. 1997; Niederschlag et al. 2003; Höppner et al. 2005; Ling et al. 2014; Pernicka et al. 2016a). Our current interpretations of lead isotope and trace elemental data are based on comprehensive databases; e.g. the Alpine ArchaeoCopper Database for the Alpine area (Nimis et al. 2012; Artioli et al. 2016), which has been merged into the extensive databases based on (OXALID) and more recent data for ores from the Italian Alps (Canovaro et al. 2019), Spain (Garcia de Madinabeitia et al. 2021), Great Orme in Wales (Williams 2018, Williams et al. 2019) as well as Slovakian Ore Mountains (Schreiner 2007) and the Austrian Mitterberg ores (Pernicka 2013; Pernicka et al. 2016a). Recently most of these lead isotopic data are also compiled by Tomczyk (2022).

3. A background to the evaluation and assessment of data

Previous studies have identified two major areas, the Austrian Mitterberg ores and the Slovak Ore Mountains as probable sources for objects from the Hajdúsámson-Apa horizon in the Carpathian Basin, based on combined elemental and lead isotope data (e.g. Pernicka 2013; Pernicka et al. 2016b, Berger et al. 2022). These attributions were chosen as a key point of departure for the examination of possible ore sources for the bronzes from Százhalombatta. During assessment of the current data set, ore data from these regions as well as data from many other potentially relevant ore regions were included for comparison.

Although each of these ore regions has characteristic signatures that enables a discrimination between them, their lead isotopic fields are partly overlapping, which obscures a conclusive distinction. Therefore, the trace element signatures were simultaneously evaluated. However, some of the trace elements, e.g. nickel and silver show partially overlapping patterns for the Slovakian Ore Mountains, generally characterised by fahlores and the Austrian Mitterberg ores with mainly chalcopyrite, which impairs the differentiation between these ores. (Berger et al., 2022; Pernicka et al., 2016a; Schreiner, 2007).

A similar approach was applied to the Scandinavian data set, although this emerged as more complex. For clarity ore regions that are found less likely as sources are not presented further if not required (for discussion, however, see more details in Melheim et al. 2018).

Bearing this in mind, it is also important to treat and interpret the combination of lead isotope and geochemical signatures not only for individual objects but for groups of objects. When it comes to our interpretations of the origin of the copper, it may be that from a statistical point of view an individual sample might have a better match to one ore region, but when elemental signatures, context and chronology are considered, another option might be more plausible.

4. Results

4.1. *General results and characteristics of the analysed bronzes from Százhalombatta*

From the analytical results (Tables 5–6), some compositional groups can be distinguished within the settlement site and hoard respectively. Subdivisions can also be made with respect to settlement or hoard, or to stratigraphy/chronology at the settlement site and/or object category, whether the artefacts represent bronze casting (e.g. ingot or debris) or functional objects (as weapons, tools and ornaments).

First of all, the functional objects from the settlement as well as the hoard, have in general a higher tin content (Fig. 11), generally distributed between 7 and 10 % Sn. A sickle-shaped pin (No. 6) has lower

Table 5

Chemical composition (in %) of the samples from (a) Százhalombatta-Földvár settlement and Hoard II, and (b) of the Scandinavian samples. Note: 1 = previously unpublished data, 2 = from Ling et al. (2014), 3 = from Melheim et al. (2018) and 4 = from Ling et al. 2019. Two artefacts (a sword and a dagger) have two analyses, hence the deviating number of samples. Average values are calculated from multiple area scans (n = number of areas in current study). The detection limits are around (or <) 0.01 % for Ni, As, Ag, Sb, Co and Fe, and around 0,02 % for Bi. Point analyses are made in phases that normally are enriched in certain trace elements (e.g. Sb and Ag) to confirm (or dismiss) bulk data with values near detection limits, and also lower average values are presented. The range of variability for the major elements as Cu and Sn, and trace elements important for defining metal groups, e.g. Ni, As, Ag and Sb is in the order of the last digit. Reported values for Pb are generally not mainly dependent on detection limit but the heterogenous distribution of lead in microscale, occasionally causing substantial standard deviations. The average lead concentrations should therefore be regarded more in the order of magnitude (also confirmed when measured during lead isotope measurements).

No.	Mus No/ Phase/Level	General typology	Object	S	Fe	Co	Ni	Cu	Zn	As	Ag	Sn	Sb	Au	Pb	Bi	n	Note
1	HNM 76.3.21A	Weapon	Spearhead	0.65	0.10	0.01	0.42	88.9	0.05	0.19	0.02	7.1	n.d.	0.01	0.02	0.01	20	1
2	HNM 76.3.21Ba	Weapon	Spearhead	0.29	0.03	0.01	0.42	90.4	0.04	0.07	0.02	7.2	n.d.	0.01	0.01	0.01	10	1
3	HNM 76.3.21Bb	Weapon	Spearhead (?)	0.26	0.03	0.01	0.44	89.9	0.05	0.08	0.02	7.5	n.d.	0.00	0.02	0.01	10	1
4	HNM 76.3.22	Tool	Sickle	0.51	0.11	0.03	0.57	86.8	0.05	0.86	0.03	7.6	0.00	0.01	0.01	0.00	20	1
5	HNM 76.3.23	Ornament	Spiral anklet/armlet	0.35	0.01	0.01	0.47	84.0	0.04	0.14	0.01	11.8	n.d.	0.01	0.01	0.01	20	1
6	HNM 76.3.12	Ornament	Pin	1.12	0.05	0.00	0.25	92.1	0.01	0.19	0.03	5.5	0.00	0.02	0.03	0.01	8	1
7	HNM 76.3.27	Ingot	Tongue-shaped ingot	1.00	1.11	0.05	2.02	90.8	0.05	0.36	0.03	2.9	0.09	0.01	0.02	0.00	20	1
8	HNM 76.3.28	Ingot	Tongue-shaped ingot	0.52	0.10	0.03	0.36	93.3	0.05	0.84	0.04	2.2	0.00	0.01	0.02	0.01	20	1
9	HNM 76.3.29	Ingot	Tongue-shaped ingot	0.50	0.20	0.02	0.40	93.7	0.04	0.19	0.02	2.0	0.00	0.01	0.02	0.01	18	1
10	HNM 76.3.36B	Ingot	Tongue-shaped ingot	0.30	0.08	0.01	0.29	93.5	0.04	0.71	0.04	4.5	n.d.	0.01	0.00	0.01	7	1
11	HNM 76.3.34	Ingot	Tongue-shaped ingot	0.60	0.33	0.03	0.38	94.9	0.05	1.27	0.05	0.8	0.03	0.01	0.02	0.01	14	1
12	HNM 76.3.24	Ingot?	Bar ingot	0.14	0.30	0.07	0.75	92.1	0.05	0.47	0.03	5.2	n.d.	0.01	0.03	0.00	10	1
13	HNM 76.3.35	Ingot	Plano-convex ingot	0.41	0.12	0.04	0.72	95.2	0.06	0.99	0.04	1.3	0.03	0.01	0.01	0.01	17	1
14	HNM 76.3.36A	Ingot	Plano-convex ingot	0.89	0.00	0.00	0.06	97.4	0.05	0.01	0.03	0.0	0.00	0.01	0.02	0.01	20	1
15	HNM 76.3.30	Ingot?	Casting debris/Ingot	1.07	0.01	0.01	0.43	95.3	0.00	0.22	0.02	2.6	0.01	0.04	0.03	0.01	12	1
Sz 16	II/9	Tool	Chisel	0.17	0.02	0.01	0.38	87.4	0.04	0.42	0.03	9.0	n.d.	0.01	0.05	0.01	17	1
Sz 5	II/10	Tool	Dagger	0.13	0.00	0.00	0.04	86.7	0.05	0.04	0.04	9.5	n.d.	0.01	0.02	0.01	18	1
Sz 3	II/10	Ornament	Spiral pendant	0.26	0.06	0.01	0.67	85.5	0.04	0.45	0.02	9.6	n.d.	0.01	0.01	0.01	18	1
Sz 6	II/10	Tool	Awl	0.09	0.01	0.01	0.32	88.4	0.05	0.16	0.04	8.2	n.d.	0.01	0.05	0.01	18	1
Sz 8	II/11–12	Ingot	Rod	0.27	0.07	0.03	0.53	93.8	0.06	0.29	0.03	3.6	n.d.	0.01	0.01	0.01	10	1
Sz 11	II/13	Debris	Melt	0.08	0.01	0.01	0.07	89.4	0.05	0.25	0.34	7.3	0.17	0.02	0.02	0.02	18	1
Sz 9	II/14	Ornament	Crescent-shaped pendant	0.18	0.00	0.01	0.34	87.4	0.04	0.12	0.04	8.6	n.d.	0.01	0.02	0.01	20	1
Sz 12	II/14	Ingot?	Bar/ingot	0.01	0.09	0.01	0.12	91.9	0.03	0.83	0.73	4.7	0.67	0.01	0.02	0.04	10	1
Sz 14	II/16	Debris	Melt (bronze)	0.17	0.00	0.00	0.05	95.0	0.05	0.19	0.65	1.6	0.27	0.01	0.03	0.02	20	1
Sz 15	II/16	Debris	Sheet of bronze	0.29	0.03	0.01	0.32	93.2	0.05	0.23	0.03	4.6	n.d.	0.01	0.02	0.01	10	1

Unr/FID	Country	Site	Object	S	Fe	Co	Ni	Cu	Zn	As	Ag	Sn	Sb	Au	Pb	Bi	n	Note
NMK 346: B1486	Denmark	U	Chisel	0.20	0.04	0.02	1.13	88.0	0.00	0.83	0.09	9.3	0.25	0.04	0.07	0.02		3
NMK 343: B9391	Denmark	Svendborg South Funen	Flanged axe	0.10	0.02	0.01	0.37	90.7	0.00	0.27	0.18	8.0	0.27	0.01	0.05	0.00		3
NMK 357: B15139	Denmark	Ringkøbing-Skjern Torsted	Flanged axe	0.11	0.02	0.01	0.38	91.2	0.00	0.24	0.14	7.7	0.21	0.01	0.03	0.01		3
NMK 358: B15148	Denmark	Ringkøbing-Skjern Torsted	Flanged axe	0.04	0.01	0.00	0.26	91.2	0.00	0.39	0.16	7.6	0.24	0.02	0.05	0.02		3
NMK 359: B15148	Denmark	Ringkøbing-Skjern Torsted	Flanged axe	0.11	0.00	0.01	0.25	91.0	0.01	0.38	0.16	7.8	0.24	0.00	0.03	0.00		3
B12125	Norway	Møre og Romsdal Ålesund	Low-flanged axe Langquaid	0.05	0.00	0.00	0.23	88.2	0.10	0.11	0.08	10.8	0.09	0.06	0.02	0.01	13	1
NMK 347: B4405	Denmark	U	Chisel	0.37	0.01	0.03	1.00	87.2	0.00	0.95	0.05	10.1	0.22	0.00	0.03	0.01		3
B7830	Denmark	Ringkøbing	Dagger Wohlde	0.34	0.07	0.02	1.19	89.2	0.05	0.37	0.06	7.2	0.12	0.06	0.04	0.02		4
NMK 321: B5892	Denmark	Holbæk Finnerup	Flanged axe	0.10	0.02	0.00	0.02	71.2	0.00	0.27	0.00	5.9	0.56	0.00	0.02	0.02		3
NMK 327: B12365	Denmark	Viborg Hvorslev	Flanged axe	0.16	0.00	0.01	0.49	89.9	0.00	0.44	0.25	8.6	0.09	0.06	0.20	0.02		3
NMK 323: B10027	Denmark	Holbæk Kundby	Flanged axe	0.39	0.01	0.01	0.08	88.0	0.00	0.05	0.00	11.4	0.00	0.00	0.02	0.00		3
NMK 322: B11103	Denmark	Frederiksborg Oppe-Sundby	Flanged axe	0.17	0.01	0.01	0.43	90.1	0.00	0.40	0.03	8.8	0.09	0.00	0.02	0.02		3
NMK 339: B5962	Denmark	Vejle Randbøl	Flanged axe	0.06	0.03	0.01	0.45	92.8	0.01	0.17	0.00	6.4	0.05	0.03	0.04	0.03		3
NMK 657: B 9036	Denmark	Hjørring St. Hans	Flanged axe	0.17	0.05	0.03	0.35	88.1	0.10	0.25	0.00	7.4	0.00	0.00	0.00	0.06		3
NMK 658: B 9037	Denmark	Hjørring St. Hans	Flanged axe	0.17	0.04	0.03	0.72	91.1	0.04	0.37	0.03	6.4	0.06	0.00	0.26	0.09		3
4: SHM 971151	Sweden	Dalsland Färgelanda	Flanged axe	0.11	0.01	0.03	1.01	83.9	0.04	0.72	0.48	9.1	0.82	0.08	0.07	n.a.		2
5: SHM 971153	Sweden	Småland Gamleby	Flanged axe	0.30	0.03	0.02	0.37	89.6	0.04	0.16	0.04	7.9	0.05	0.08	0.10	n.a.		2
9: VM 21916	Sweden	Värmland Östra Fågelvik	Flanged axe	0.08	0.02	0.03	0.11	87.5	0.03	0.15	0.04	10.0	0.21	0.06	0.15	n.a.		2
UMF2285	Sweden	Uppland Åkerby	High-flanged axe Oldendorf	1.85	0.07	0.06	3.30	84.4	0.03	0.60	0.03	9.4	0.01	0.03	0.02	0.01	15	1
ÖM863	Sweden	Skåne Gladsax	Hilt-plated dagger Sögel	0.61	0.09	0.05	0.71	84.0	0.04	0.24	0.03	12.3	0.04	0.01	0.13	0.00		4
ÖM865	Sweden	Skåne Gladsax	Hilt-plated dagger Sögel	0.05	0.05	0.05	0.78	85.8	0.06	0.22	0.04	12.7	0.03	0.01	0.13	0.01		4

(*continued on next page*)

Table 5 (*continued*)

Unr/FID	Country	Site	Object	S	Fe	Co	Ni	Cu	Zn	As	Ag	Sn	Sb	Au	Pb	Bi	n	Note
B5469a	Norway	Vest-Agder Farsund	Hilt-plated sword Sögel	0.09	0.03	0.03	0.42	88.2	0.07	0.32	0.01	9.7	0.24	0.03	0.10	0.01		4
1: B17618	Denmark	Randers Ørum	Metal-hilted sword Nordic Hajdusámson-Apa	0.40	0.01	0.02	0.51	89.7		0.38	0.03	7.3	0.00	0.02	0.14	0.03		3
2: B17622	Denmark	Randers Ørum	Metal-hilted sword Nordic Hajdusámson-Apa	0.50	0.01	0.02	0.54	90.1		0.58	0.03	7.7	0.02	0.02	0.29	0.04		3
3: B17623	Denmark	Randers Ørum	Metal-hilted sword Nordic Hajdusámson-Apa	0.12	0.66	0.93	0.03	95.7		0.00	0.02	3.2	0.01	0.02	0.05	0.03		3
ALM 25: C54227	Norway	Oppland Jevnaker	Metal-hilted sword Nordic Hajdusámson-Apa	0.07	0.07	0.04	0.07	88.6	0.00	0.13	0.01	10.9	0.02	0.04	0.02	0.00		4
ALM 26: C54227	Norway	Oppland Jevnaker	Metal-hilted sword Nordic Hajdusámson-Apa	0.08	0.07	0.00	0.13	88.1	0.03	0.30	0.02	10.7	0.45	0.02	0.00	0.01		4
SHM617282	Sweden	Småland Hagby	Metal-hilted sword Valsømagle	0.14	0.01	0.01	0.01	89.4	0.05	0.06	0.02	8.4	0.00	0.01	0.01	0.01		4
6: UM 40280_3006	Sweden	Uppland Viksta	Metal-hilted sword Valsømagle	0.33	0.04	0.03	0.31	85.9	0.04	0.31	0.03	10.2	0.38	0.07	0.19	n.a.		2
UM29218_458A	Sweden	Bohuslän Tanum	Metal-hilted sword	0.50	0.11	0.04	1.04	81.6	0.04	0.27	0.03	13.6	0.00	0.01	0.02	0.00		4
18,154	Denmark	Vejle Jerlev Herred	Shafthole axe Fårdrup	0.77	0.01	0.01	0.40	89.6	0.05	0.21	0.02	7.6	0.00	0.02	0.04	0.01	9	1
NM26013	Denmark	Sorø Slagelse herred Tårnborg	Shafthole axe Fårdrup	0.10	0.03	0.01	0.75	88.7	0.04	0.45	0.04	8.5	0.01	0.05	0.15	0.01	18	1
NMK 345: NM 16892	Denmark	København Søllerød	Shafthole axe Fårdrup	0.13	0.09	0.02	0.54	89.4	0.00	0.62	0.04	9.1	0.07	0.04	0.13	0.02		3
S3664	Norway	Rogaland Sola	Shafthole axe Fårdrup	0.38	0.15	0.03	0.69	89.3	0.04	0.23	0.02	9.2	0.00	0.04	0.01	0.00	19	1
B3389	Norway	Hordaland Ullensvang	Shafthole axe Fårdrup	0.02	1.17	0.15	0.67	88.6	0.10	0.27	0.07	7.4	0.10	0.05	0.04	0.00	10	1
T14733	Norway	Nord-Trøndelag Inderøy	Shafthole axe Fårdrup	0.02	0.17	0.02	0.35	87.3	0.09	0.51	0.03	10.0	0.00	0.04	0.43	0.01	18	1
SHM1182894	Sweden	Uppland Simtuna	Shafthole axe Fårdrup	0.30	0.04	0.06	0.60	87.1	0.05	0.47	0.02	10.0	0.09	0.01	0.17	0.01	13	1
SHM1182900	Sweden	Skåne Flädie	Shafthole axe Fårdrup	0.12	0.99	0.46	0.46	92.3	0.06	0.20	0.03	4.0	0.00	0.00	0.02	0.01	11	1
SHM1182902	Sweden	Västmanland Fellingsbro	Shafthole axe Fårdrup	0.28	0.04	0.02	0.64	89.6	0.04	0.47	0.03	7.8	0.10	0.01	0.03	0.01	14	1
3: GAM 1255	Sweden	Dalsland Frändefors	Shafthole axe Fårdrup	0.12	0.03	0.03	0.46	88.0	0.02	0.31	0.03	8.1	0.05	0.09	0.11	n.a.		2
7: AM 786	Sweden	Värmland Ny	Shafthole axe Fårdrup	0.58	0.15	0.03	0.09	92.2	0.02	0.33	0.04	4.3	0.05	0.06	0.11	n.a.		2
2: GAM 5289	Sweden	Bohuslän Ödsmål	Shafthole axe Fårdrup	0.74	0.11	0.03	0.47	85.8	0.04	0.39	0.04	9.5	0.10	0.07	0.09	n.a.		2
B11534	Denmark	Sorø Magleby	Shafthole axe Valsømagle	0.05	0.01	0.01	0.09	89.7	0.04	0.12	0.02	8.7	0.12	0.05	0.03	0.01	22	1
NMK 344: B16780	Denmark	København Roskilde	Shafthole axe Valsømagle	0.52	0.32	0.02	0.18	88.0	0.00	0.25	0.03	10.0	0.63	0.03	0.11	0.00		3
SHM1182897	Sweden	Skåne Nosaby	Shafthole axe Valsømagle	0.39	0.12	0.02	0.25	86.2	0.05	0.06	0.01	11.5	0.00	0.01	0.02	0.01	13	1
SHM362528	Sweden	Västergötland Finnerödja.	Shafthole axe Valsømagle	0.03	0.01	0.02	0.03	88.2	0.05	0.14	0.02	10.3	0.00	0.01	0.04	0.01	16	1
HM 9802	Sweden	Halland Snötorp	Shafthole axe Valsømagle	0.10	0.01	0.01	0.01	85.7	0.07	0.15	0.02	11.5	0.00	0.02	0.01	0.01	14	1
10: KM 33_465_10	Sweden	Öland Löt	Shafthole axe Valsømagle	0.11	0.02	0.03	0.33	84.6	0.04	0.29	0.04	11.8	0.40	0.08	0.11	n.a.		2
B14565	Denmark	Sorø Eskildstrup	Spear head Bagterp	0.24	0.02	0.01	0.25	88.3	0.04	0.32	0.02	9.1	0.11	0.05	0.25	0.01	14	1
B18091	Denmark	København Søllerød	Spear head Bagterp	0.14	0.01	0.01	0.54	88.1	0.04	0.51	0.04	8.3	0.04	0.02	0.07	0.01	13	1
T12112	Norway	Sør-Trøndelag Meldal	Spear head Bagterp	0.83	0.00	0.01	0.18	87.1	0.06	0.11	0.12	10.6	0.06	0.06	0.04	0.01	13	1
1M16 4491	Sweden	Västergötland Vara	Spear head Bagterp	0.42	0.00	0.01	0.57	90.1	0.01	0.57	0.05	6.9	0.04	0.04	0.04	0.02	6	1
UMF4566	Sweden	Uppland Lena	Spear head Bagterp	1.15	0.08	0.01	0.54	88.5	0.04	0.26	0.02	9.1	0.00	0.05	0.08	0.02	21	1
KLM 002,900	Sweden	Öland Gärdslösa	Spear head Bagterp	0.18	0.50	0.05	0.51	85.6	0.07	0.88	0.02	9.4	0.00	0.05	0.86	0.01	19	1
KLM 14,348	Sweden	Öland Bredsätra	Spear head Bagterp	0.11	0.01	0.02	0.38	87.1	0.07	0.39	0.02	9.0	0.00	0.03	0.07	0.01	13	1
8: SHM 884944	Sweden	Värmland Ölme	Spear head Bagterp	0.19	0.04	0.06	0.50	91.2	0.01	0.49	0.38	5.5	1.25	0.10	1.30	n.a.		2
UMF974	Sweden	Uppland Gamla Uppsala	Spear head Luneburger II	0.67	0.03	0.05	0.35	88.9	0.05	0.12	0.05	8.8	0.01	0.07	0.12	0.02	21	1
B11350	Denmark	København Smørum. Sengeløse	Spear head Valsømagle	0.80	0.36	0.07	0.90	89.7	0.05	1.23	0.05	5.4	0.40	0.02	0.04	0.00	12	1
B15175	Denmark	Sorø	Spear head Valsømagle	0.27	0.07	0.03	0.36	90.5	0.04	0.30	0.03	6.8	0.22	0.03	0.10	0.02	13	1
1M16 4489	Sweden	Västergötland Friggeråker	Spear head Valsømagle	0.25	0.01	0.13	0.42	87.0	0.05	0.53	0.24	9.1	0.67	0.03	1.26	0.03	29	1
SHM1182901	Sweden	Södermanland Bärbo.	Spear head Valsømagle	0.45	0.05	0.01	0.34	84.4	0.04	0.13	0.01	12.2	0.07	0.01	0.02	0.01	18	1
UMF3183	Sweden	Uppland Uppsala-Näs	Spear head Valsømagle	0.83	0.02	0.00	0.20	89.6	0.04	0.13	0.02	8.6	0.04	0.05	0.05	0.01	21	1
UMF5507	Sweden	Uppland Uppsala-Näs	Spear head Valsømagle	0.56	0.03	0.01	0.35	88.3	0.04	0.22	0.04	9.5	0.23	0.03	0.05	0.01	16	1
ÖM1757	Sweden	Skåne Ö Herrestad	Spear head Valsømagle	0.38	0.11	0.04	0.45	83.9	0.04	0.09	0.02	11.7	0.00	0.01	0.01	0.01	16	1

Table 6
Lead isotopic composition of the samples from (a) Százhalombatta-Földvár settlement and Hoard II, and (b) of the Scandinavian samples. Note: 1 = previously unpublished data, 2 = from Ling et al. (2014), 3 = from Melheim et al. (2018) and 4 = from Ling et al. 2019. Two artefacts (a sword and a dagger) have two analyses, hence the deviating number of samples.

No.	Mus No/ Phase/Level	General typology	Object	^{208}Pb/ ^{206}Pb	^{207}Pb/ ^{206}Pb	^{206}Pb/ ^{204}Pb	^{207}Pb/ ^{204}Pb	^{208}Pb/ ^{204}Pb	Note
1	HNM 76.3.21A	Weapon	Spearhead	1.9958	0.79039	19.936	15.758	39.788	1
2	HNM 76.3.21Ba	Weapon	Spearhead	n.a.	n.a.	n.a.	n.a.	n.a.	1
3	HNM 76.3.21Bb	Weapon	Spearhead (?)	n.a.	n.a.	n.a.	n.a.	n.a.	1
4	HNM 76.3.22	Tool	Sickle	2.0498	0.82303	19.069	15.694	39.088	1
5	HNM 76.3.23	Ornament	Spiral anklet/armlet	2.0243	0.80888	19.426	15.714	39.323	1
6	HNM 76.3.12	Ornament	Pin	2.0666	0.83430	18.796	15.681	38.844	1
7	HNM 76.3.27	Ingot	Tongue-shaped ingot	2.0354	0.81237	19.355	15.724	39.395	1
8	HNM 76.3.28	Ingot	Tongue-shaped ingot	2.0613	0.81981	19.172	15.717	39.518	1
9	HNM 76.3.29	Ingot	Tongue-shaped ingot	2.0435	0.81370	19.306	15.709	39.450	1
10	HNM 76.3.36B	Ingot	Tongue-shaped ingot	n.a.	n.a.	n.a.	n.a.	n.a.	1
11	HNM 76.3.34	Ingot	Tongue-shaped ingot	n.a.	n.a.	n.a.	n.a.	n.a.	1
12	HNM 76.3.24	Ingot?	Bar ingot	n.a.	n.a.	n.a.	n.a.	n.a.	1
13	HNM 76.3.35	Ingot	Plano-convex ingot	2.0583	0.81877	19.191	15.713	39.502	1
14	HNM 76.3.36A	Ingot	Plano-convex ingot	2.0699	0.83234	18.862	15.700	39.040	1
15	HNM 76.3.30	Ingot?	Casting debris/Ingot	n.a.	n.a.	n.a.	n.a.	n.a.	1
Sz 16	II/9	Tool	Chisel	2.0864	0.84630	18.512	15.667	38.624	1
Sz 5	II/10	Tool	Dagger	2.0813	0.84548	18.423	15.576	38.344	1
Sz 3	II/10	Ornament	Spiral pendant	2.0381	0.81853	19.158	15.682	39.046	1
Sz 6	II/10	Tool	Awl	2.0867	0.84126	18.632	15.675	38.879	1
Sz 8	II/11–12	Ingot	Rod	2.0579	0.82636	19.000	15.701	39.100	1
Sz 11	II/13	Debris	Melt	2.0908	0.85006	18.416	15.655	38.504	1
Sz 9	II/14	Ornament	Crescent-shaped pendant	2.0536	0.82960	18.869	15.654	38.749	1
Sz 12	II/14	Ingot?	Bar/ingot	n.a.	n.a.	n.a.	n.a.	n.a.	1
Sz 14	II/16	Debris	Melt (bronze)	2.0937	0.85152	18.409	15.675	38.542	1
Sz 15	II/16	Debris	Sheet of bronze	n.a.	n.a.	n.a.	n.a.	n.a.	1

Unr/FID	Country	Site	Object	^{208}Pb/ ^{206}Pb	^{207}Pb/ ^{206}Pb	^{206}Pb/ ^{204}Pb	^{207}Pb/ ^{204}Pb	^{208}Pb/ ^{204}Pb	Note
NMK 346: B1486	Denmark	U	Chisel	2.0911	0.85197	18.337	15.625	38.344	3
NMK 343: B9391	Denmark	Svendborg South Funen	Flanged axe	2.0451	0.82628	18.954	15.663	38.759	3
NMK 357: B15139	Denmark	Ringkøbing-Skjern Torsted	Flanged axe	2.0486	0.82790	18.922	15.665	38.761	3
NMK 358: B15148	Denmark	Ringkøbing-Skjern Torsted	Flanged axe	2.0479	0.82759	18.919	15.661	38.742	3
NMK 359: B15148	Denmark	Ringkøbing-Skjern Torsted	Flanged axe	2.0479	0.82754	18.924	15.664	38.751	3
B12125	Norway	Møre og Romsdal Ålesund	Low-flanged axe Langquaid	2.0608	0.83302	18.865	15.715	38.876	1
NMK 347: B4405	Denmark	U	Chisel	2.0861	0.84966	18.392	15.630	38.361	3
B7830	Denmark	Ringkøbing	Dagger Wohlde	2.0924	0.84929	18.461	15.679	38.631	4
NMK 321: B5892	Denmark	Holbæk Finnerup	Flanged axe	2.0900	0.84855	18.450	15.659	38.557	3
NMK 327: B12365	Denmark	Viborg Hvorslev	Flanged axe	2.0920	0.85279	18.323	15.629	38.331	3
NMK 323: B10027	Denmark	Holbæk Kundby	Flanged axe	2.0310	0.81855	19.183	15.706	38.959	3
NMK 322: B11103	Denmark	Frederiksborg Oppe-Sundby	Flanged axe	2.0780	0.84462	18.524	15.650	38.491	3
NMK 339: B5962	Denmark	Vejle Randbøl	Flanged axe	2.0893	0.84749	18.485	15.672	38.617	3
NMK 657: B 9036	Denmark	Hjørring St. Hans	Flanged axe	2.0914	0.85223	18.340	15.632	38.346	3
NMK 658: B 9037	Denmark	Hjørring St. Hans	Flanged axe	2.0928	0.85268	18.331	15.633	38.352	3
4: SHM 971151	Sweden	Dalsland Färgelanda	Flanged axe	2.0671	0.84002	18.656	15.671	38.564	2
5: SHM 971153	Sweden	Småland Gamleby	Flanged axe	2.0417	0.81669	19.251	15.722	39.305	2
9: VM 21916	Sweden	Värmland Östra Fågelvik	Flanged axe	2.0773	0.84231	18.587	15.656	38.611	2
UMF2285	Sweden	Uppland Åkerby	High-flanged axe Oldendorf	2.0314	0.82293	19.105	15.722	38.806	1
ÖM863	Sweden	Skåne Gladsax	Hilt-plated dagger Sögel	2.1079	0.85843	18.250	15.667	38.472	4
ÖM865	Sweden	Skåne Gladsax	Hilt-plated dagger Sögel	2.1166	0.86653	18.035	15.627	38.175	4
B5469a	Norway	Vest-Agder Farsund	Hilt-plated sword Sögel	2.0949	0.85151	18.407	15.674	38.562	4
1: B17618	Denmark	Randers Ørum	Metal-hilted sword Nordic Hajdusámson-Apa	2.0917	0.85276	18.324	15.626	38.327	3
2: B17622	Denmark	Randers Ørum	Metal-hilted sword Nordic Hajdusámson-Apa	2.0908	0.85216	18.337	15.626	38.337	3
3: B17623	Denmark	Randers Ørum	Metal-hilted sword Nordic Hajdusámson-Apa	2.0866	0.85039	18.350	15.605	38.290	3
ALM 25: C54227	Norway	Oppland Jevnaker	Metal-hilted sword Nordic Hajdusámson-Apa	2.0741	0.83931	18.686	15.683	38.757	4
ALM 26: C54227	Norway	Oppland Jevnaker	Metal-hilted sword Nordic Hajdusámson-Apa	2.0854	0.84548	18.536	15.672	38.655	4
SHM617282	Sweden	Småland Hagby	Metal-hilted sword Valsømagle	2.0647	0.83761	18.609	15.587	38.423	4
6: UM 40280_3006	Sweden	Uppland Viksta	Metal-hilted sword Valsømagle	2.0917	0.84946	18.460	15.681	38.612	2
UM29218_458A	Sweden	Bohuslän Tanum	Metal-hilted sword	2.0635	0.83044	18.884	15.683	38.963	4
18,154	Denmark	Vejle Jerlev Herred	Shafthole axe Fårdrup	2.0885	0.84862	18.454	15.660	38.542	1
NM26013	Denmark	Sorø Slagelse herred Tårnborg	Shafthole axe Fårdrup	2.0928	0.85280	18.336	15.637	38.375	1

(continued on next page)

Table 6 (*continued*)

Unr/FID	Country	Site	Object	$^{208}Pb/^{206}Pb$	$^{207}Pb/^{206}Pb$	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb$	$^{208}Pb/^{204}Pb$	Note
NMK 345: NM 16892	Denmark	København Søllerød	Shafthole axe Fårdrup	2.0903	0.85179	18.347	15.630	38.345	3
S3664	Norway	Rogaland Sola	Shafthole axe Fårdrup	2.0398	0.81895	19.184	15.710	39.131	1
B3389	Norway	Hordaland Ullensvang	Shafthole axe Fårdrup	2.0722	0.83830	18.718	15.692	38.789	1
T14733	Norway	Nord-Trøndelag Inderøy	Shafthole axe Fårdrup	2.0920	0.85296	18.320	15.626	38.325	1
SHM1182894	Sweden	Uppland Simtuna	Shafthole axe Fårdrup	2.0863	0.84569	18.539	15.679	38.681	1
SHM1182900	Sweden	Skåne Flädie	Shafthole axe Fårdrup	2.0901	0.85161	18.348	15.625	38.351	1
SHM1182902	Sweden	Västmanland Fellingsbro	Shafthole axe Fårdrup	2.0516	0.83043	18.871	15.671	38.716	1
3: GAM 1255	Sweden	Dalsland Frändefors	Shafthole axe Fårdrup	2.0076	0.79886	19.678	15.720	39.505	2
7: AM 786	Sweden	Värmland Ny	Shafthole axe Fårdrup	2.0785	0.84109	18.608	15.651	38.677	2
2: GAM 5289	Sweden	Bohuslän Ödsmål	Shafthole axe Fårdrup	1.9488	0.79379	19.824	15.736	38.634	2
B11534	Denmark	Sorø Magleby	Shafthole axe Valsømagle	2.0773	0.84192	18.612	15.670	38.664	1
NMK 344: B16780	Denmark	København Roskilde	Shafthole axe Valsømagle	2.0840	0.84152	18.627	15.679	38.817	3
SHM1182897	Sweden	Skåne Nosaby	Shafthole axe Valsømagle	2.0292	0.80554	19.516	15.721	39.604	1
SHM362528	Sweden	Västergötland Finnerödja.	Shafthole axe Valsømagle	2.0618	0.83203	18.842	15.677	38.849	1
HM 9802	Sweden	Halland Snötorp	Shafthole axe Valsømagle	2.0680	0.83865	18.601	15.600	38.468	1
10: KM 33_465_10	Sweden	Öland Löt	Shafthole axe Valsømagle	2.0775	0.84028	18.664	15.683	38.774	2
B14565	Denmark	Sorø Eskildstrup	Spear head Bagterp	2.0903	0.85185	18.339	15.622	38.334	1
B18091	Denmark	København Søllerød	Spear head Bagterp	2.0919	0.85243	18.344	15.637	38.376	1
T12112	Norway	Sør-Trøndelag Meldal	Spear head Bagterp	2.0460	0.82813	18.886	15.640	38.641	1
1M16 4491	Sweden	Västergötland Vara	Spear head Bagterp	2.0740	0.83547	18.784	15.694	38.960	1
UMF4566	Sweden	Uppland Lena	Spear head Bagterp	2.0886	0.85093	18.354	15.618	38.335	1
KLM 002900	Sweden	Öland Gärdslösa	Spear head Bagterp	2.0918	0.85261	18.331	15.629	38.344	1
KLM 14348	Sweden	Öland Bredsätra	Spear head Bagterp	2.0779	0.84640	18.482	15.644	38.405	1
8: SHM 884944	Sweden	Värmland Ölme	Spear head Bagterp	2.0972	0.85349	18.340	15.653	38.463	2
UMF974	Sweden	Uppland Gamla Uppsala	Spear head Luneburger II	2.1136	0.86277	18.142	15.652	38.344	1
B11350	Denmark	København Smørum. Sengeløse	Spear head Valsømagle	2.0624	0.81171	19.347	15.704	39.903	1
B15175	Denmark	Sorø	Spear head Valsømagle	2.0953	0.85153	18.405	15.673	38.567	1
1M16 4489	Sweden	Västergötland Friggeråker	Spear head Valsømagle	2.0978	0.85342	18.341	15.653	38.477	1
SHM1182901	Sweden	Södermanland Bärbo.	Spear head Valsømagle	2.0724	0.83296	18.839	15.692	39.044	1
UMF3183	Sweden	Uppland Uppsala-Näs	Spear head Valsømagle	2.0846	0.84653	18.467	15.633	38.499	1
UMF5507	Sweden	Uppland Uppsala-Näs	Spear head Valsømagle	2.0804	0.84228	18.605	15.670	38.706	1
ÖM1757	Sweden	Skåne Ö Herrestad	Spear head Valsømagle	2.0878	0.84679	18.521	15.683	38.669	1

(5.5 %) and a spiral armlet (No. 5) higher Sn (12 %) The ingots (mainly from the hoard) and the casting debris (exclusively from the settlement) are in general below, or well below, 6 % Sn. Within the group of ingots, the plano-convex ingots (No. 13–14) are those with lowest, or no, tin, but also one of the tongue-shaped ingots (No. 11) is low in tin. Some objects and ingots may potentially be related in terms of trace element signatures and lead isotope ratios that support a mutual copper ore source, but since the tin content of the ingots generally is too low compared to that of the artefacts, the two cannot be directly related. This means that addition of tin during casting was needed to, hypothetically, achieve similar tin content as in the currently analysed objects.

Secondly, the trace element and lead isotope signatures allow us to define a few major metal types, although there are outliers (Figs. 12–13). *One group* comprises only a few samples, of casting debris (melts Sz 11 and Sz14) and an ingot (Sz12). All these are from level 13 of Phase II, and levels 14 and 16 of Phase III respectively, layers which date to around 1700 BC, i.e. among the earliest analysed samples from the settlement site. They are characterised by Ag (0.3–0.8 %), As (0.2–0.8 %) and Sb (0.2–0.7 %), reflecting a fahlore source, and with low nickel (0.1 %). In addition, a presence of Bi can be noted (0.01–0.04 %). Their lead isotope signatures strongly indicate that the copper originated in the Slovakian ore mountains, which agree well also with the trace element signatures indicating a fahlore source. Corresponding elemental signatures are not observed in any of the currently analysed samples from the hoard nor artefacts from the settlement.

A second type (with potential subgroups) comprises the majority of the samples and is characterised by Ni (average 0.44 %, 0.3–0.8 %) and As (average 0.41 %, with larger variation 0.1–1.3 %), and low or very low Ag and Sb, i.e. signatures that generally reflect chalcopyrite ores. In this group we find most of the artefacts from levels 9–12, but also Sz9 a half-moon pendant from level 14 and Sz 15, a sheet of bronze from level 16. In most of these samples, Ni ≥ As. Their trace elemental signatures are generally within the compositionally overlapping fields that can be assigned to either Mitterberg or Slovakian ores (Pernicka et al., 2016a; Schreiner, 2007, also discussed by Berger et al. 2022).

In terms of lead isotope signatures (Fig. 13), however, some differences can be noted that distinguish them; samples Sz3 (spiral pendant) and Sz8 (rod/ingot) from level 10 and 11/12 respectively have lead isotope signatures consistent with ores from Mitterberg. Among the others, Sz9 (half-moon pendant from level 14), and Sz 16 (chisel from level 9) are consistent with Slovakian ores. An origin from Slovakian ores is probable also for sample Sz6 (from level 10), although ores from Mitterberg might be an option, or a mix of the two.

The majority of the samples from hoard II can also be assigned to the second metal group in terms of trace element composition, characterised by Ni and As, with low or very low Ag and Sb (Fig. 12). Also, among the samples from the hoard, Ni > As, but in three of the tongue-shaped ingots (No. 8, 10, 11) and in a plano-convex ingot (No. 13), As > Ni. Among the samples from the hoard with Ni > As, a slight shift towards lower Ag can be indicated compared to the samples from the settlement. One of the tongue-shaped ingots (No. 7) is deviating from the others with much higher Ni (2 %), however, the isotope ratios (Fig. 13) are coherent with the other tongue-shaped ingots indicating a copper from the Austrian Mitterberg ores.

The isotope ratios for most of the analysed items from the hoard also plot within the isotopic field for Mitterberg. Among these is a spearhead (No. 1) which has Ni and Ag similar to those in the tongue-shaped ingots, but lower As. Two other spearhead samples (No. 2 and 3) have mutually very similar trace element data, also equal to spearhead No. 1, and although lead isotope data is not available for No. 2 and 3, a similar

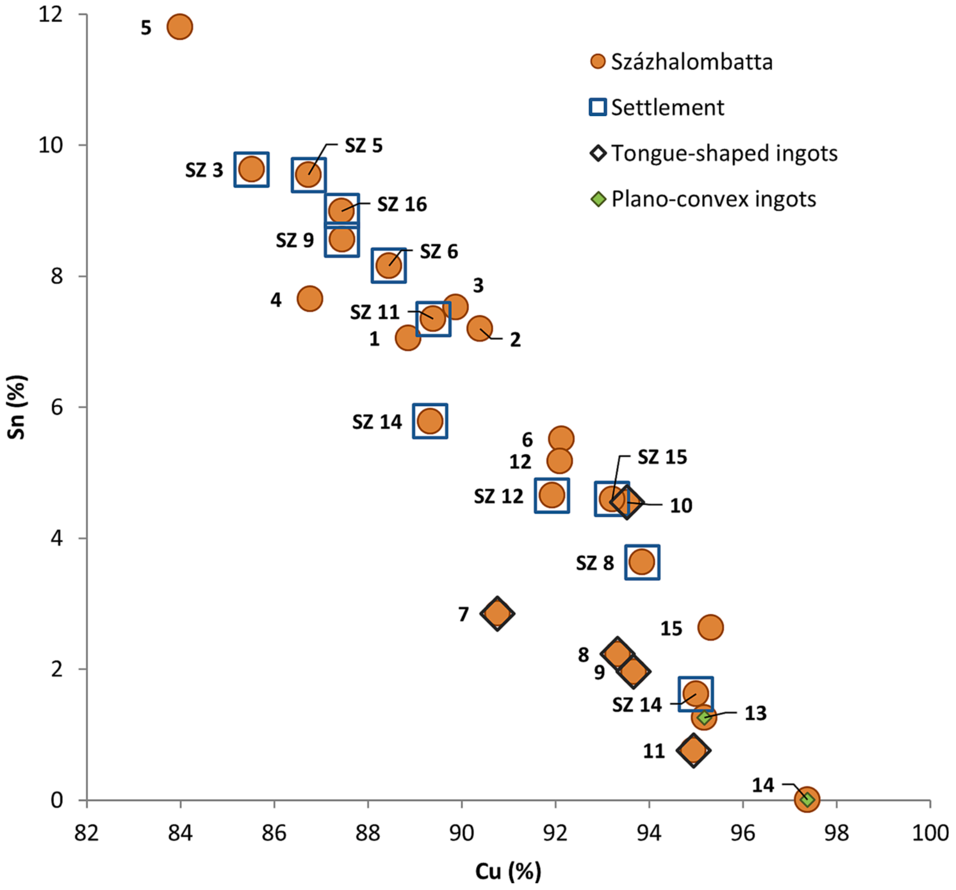

Fig. 11. Cu-Sn in analysed samples from Százhalombatta. Sample lables according to Table 5. In general, the various ingots (mainly from the hoard) including the tongue-shaped ingots, and the plano-convex ingots have tin concentration below, or well below, 6 %. The weapons as well as ornaments, have a higher tin content, generally distributed between 7 and 10 % Sn.

origin may be hypothesized. The compositional similarity of the two latter also supports the potential that No. 3, which was found inserted in the socket of No. 2, may be from the same object.

Furthermore, a sickle-shaped pin (No. 6), with somewhat lower Ni, has lead isotope data that is more difficult to interpret. Considering the full picture, Mitterberg copper ores might be plausible, although Slovakian copper ores must also be considered for this pin.

Finally, two samples, are defined by a low impurity pattern. One of these is the plano-convex ingot of pure copper (No. 14) which has lead isotope ratios that fit best with the Slovakian isotopic field, especially the Slovakian ores that are characterized by relatively high antimony. Despite the low Sb content, a non-specific Slovakian origin is suggested, mainly based on the isotopes. Only one other sample, the dagger Sz5 from the settlement level 10, has similarly low trace element signatures (very low concentrations of Ni, As, and Ag, all below 0.04 %, and Sb below detection limit), but in terms of lead isotope ratios it can be clearly distinguished, not only from the plano-convex ingot (No. 14), but from all other samples. The best match in the database is with Cypriot ores.

In summary, the majority of samples from Hoard II plot within the isotopic field for Mitterberg, while the copper in the objects and casting debris from the settlement in Százhalombatta seems to derive from two major sources: the Slovakian Ore Mountains and the Mitterberg ores. Furthermore, these two sources are present in objects from earlier as well as later levels of the settlement. From the limited data set no distinction in relation to chronology is evident, however, Slovakian ores are more frequent in earlier phases.

When it comes to the casting debris, Slovakian ores are considered to be the most plausible sources. Interestingly, some melts have fahlore signatures with significant Ag and Sb contents, notably in concentrations that have not been observed in any of the currently analysed artefacts. The occurrence of the debris at the site indicates local casting, however, using a metal type that is yet not identified in any of the analysed artefacts from the settlement, but may very well be expected. The metal type characterised by Ni and As is present in artefacts as well as in metal debris. Finally, a dagger with low trace element contents has lead isotope signatures indicating an origin from another source, potentially Cypriot ores.

4.1.1. *Tongue-shaped ingots (Zungenbarren)*

The typical tongue-shaped ingots (Zungenbarren), which are common constituents in hoards merit more attention. Three of the tongue ingots (No. 7–9) from Hoard II in the current study have lead isotope data that plot within the isotopic field for the Mitterberg ores. All three also contain Ni, As (and low Ag), however, in somewhat different concentrations and proportions. Sample No. 7 (double tongue ingot) is in fact one of the samples with highest concentrations (e.g. 2 % Ni) while the other two contain ca 0.4% Ni. Two additional tongue ingots have elemental data (No. 10–11) that is very similar to that of No. 8. These variations in trace elemental patterns of the tongue-shaped ingots are worth noting. Furthermore, their tin contents vary (0.8–4.5 %), and do not follow a standardized pattern, as might be assumed. An even larger compositional variation has been observed in previously analysed tongue-shaped ingots (14 samples) from five other hoards (Schubert & Schubert 1967; Junghans et al. 1974), clearly demonstrating the scattered composition (0–10 % Sn) among them.

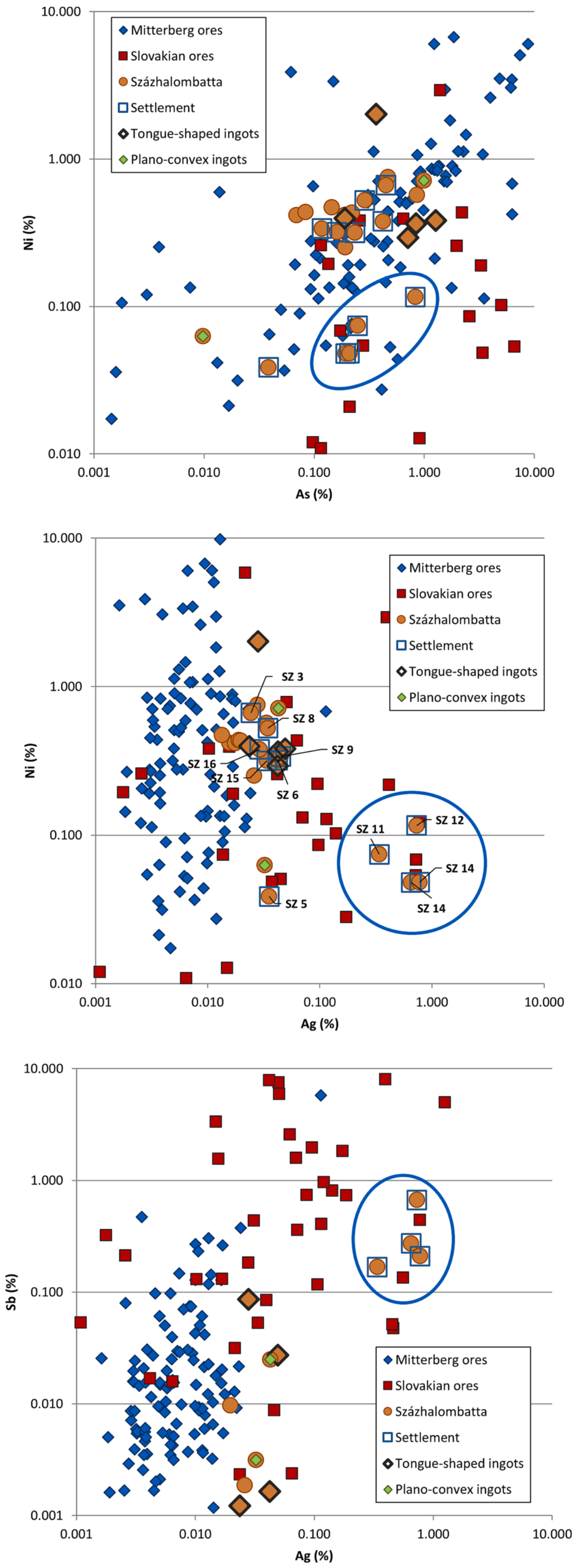

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Fig. 12. Trace element signatures. Comparison of Ni-As, Ni-Ag and Sb-Ag in the current samples from Százhalombatta. One group (indicated by the ellipse) comprises casting debris (melts) and/or ingots from the settlement site with signatures (Ag, Sb, As, low Ni) not observed in any of the currently analysed objects from the hoard. A majority of the samples, including the tongue-shaped ingots, is characterised by Ni and As, with low or very low Ag and Sb (or not detected). Two samples, a plano-convex ingot and a dagger (Sz5), are low in impurities. Normalised ore data for comparison are for Slovakian ores from Schreiner (2007), and Mitterberg ores from Pernicka et al., 2016a. The trace elemental signatures are for many samples within levels that are in compositionally overlapping regions that can be assigned to either Mitterberg or Slovakian ores.

4.1.2. *Comparison with other metal hoards from the Carpathian Basin*

We also compared our findings with combined lead isotope and trace elemental data sets from other Bronze Age hoards, with slightly earlier dating, including the Hajdúsámson, Apa, Téglás, and Vámospércs hoards (Pernicka 2013; Pernicka et al. 2016b; Berger et al. 2022), and with metals from other hoards and settlements, where only elemental data are available (e.g. Junghans et al. 1974; Liversage 1994; Dani et al. 2013).

The most famous and quoted of these hoards are doubtlessly the Hajdúsámson and Apa hoards. The swords and axes from these hoards are commonly regarded masterpieces, due to their practical and aesthetical properties, and are frequently subject to typological comparison and discussion (Pernicka et al. 2016b). Moreover, the fact that similar weapons but also other prominent pieces of metalwork of Carpathian style and origin have been found in many parts of Europe, far from Hungary, as for instance Scandinavia, have stimulated different models and theories of interaction, alliances, and trade. Another striking example of parallel metal work are ritual objects, discs, or drums of so called Balkåkra type found in Scania, Sweden as well in Haschendorf/Hasfalva in Hungary (Pernicka 2010; Szabó et al. 2018). Analyses of the latter concluded that it was made of copper from several different sources (Pernicka 2010). It is generally held that the vast spread of Carpathian metalwork was an effect of the expansion of Carpathian tell communities in Europe, around 1700/1600 BC, following the decline of the previously dominant Únětice culture ((Vandkilde, 2014); Meller 2019). When it comes to provenance ascriptions, all but two of the analysed samples from the Hajdúsámson, Vámospércs and Téglás hoards were interpreted as having been made of copper from the Mitterberg ores (Pernicka 2013, Pernicka et al. 2016b). From trace element analyses of the surface of four other axes and a sword from Hajdúsámson, Dani et al. (2013), however, suggested that these were produced from several metal sources. In addition, two artefacts from Téglás were ascribed to sources in the Slovakian ore mountains, while sources in the eastern Alps could not be excluded. For the analysed swords and axes from the Apa hoard, an origin of the copper from the Mitterberg ores were considered most likely, in contrast to other objects from Romania which mainly have copper from Slovakian ores (Pernicka 2013; Pernicka et al. 2016b).

A succeeding study, incorporating trace elements as well as multi-isotope analysis, has re-analysed many of the artefacts from Hajdúsámson, Apa and Téglás (Berger et al. 2022) and suggests a revised interpretation regarding the provenance. Although single sources are concluded, as Mitterberg ores for some of the items from Hajdúsámson and Slovakian ores for some of those from the Téglás hoard, mixing of metals are suggested for many of the artefacts. This is mostly stressed for the artefacts from the Apa hoard with variations in lead isotope ratios potentially defining a mixing line, and trace elemental overlap (Fig. 14) between the two ore regions in question. For several of the artefacts from these hoards, mixing of ores as well as more complex mixing, or recycling of several bronze batches (and copper), are discussed. However, although mixing is argued for, it is limited to these two major ore sources (Berger et al. 2022).

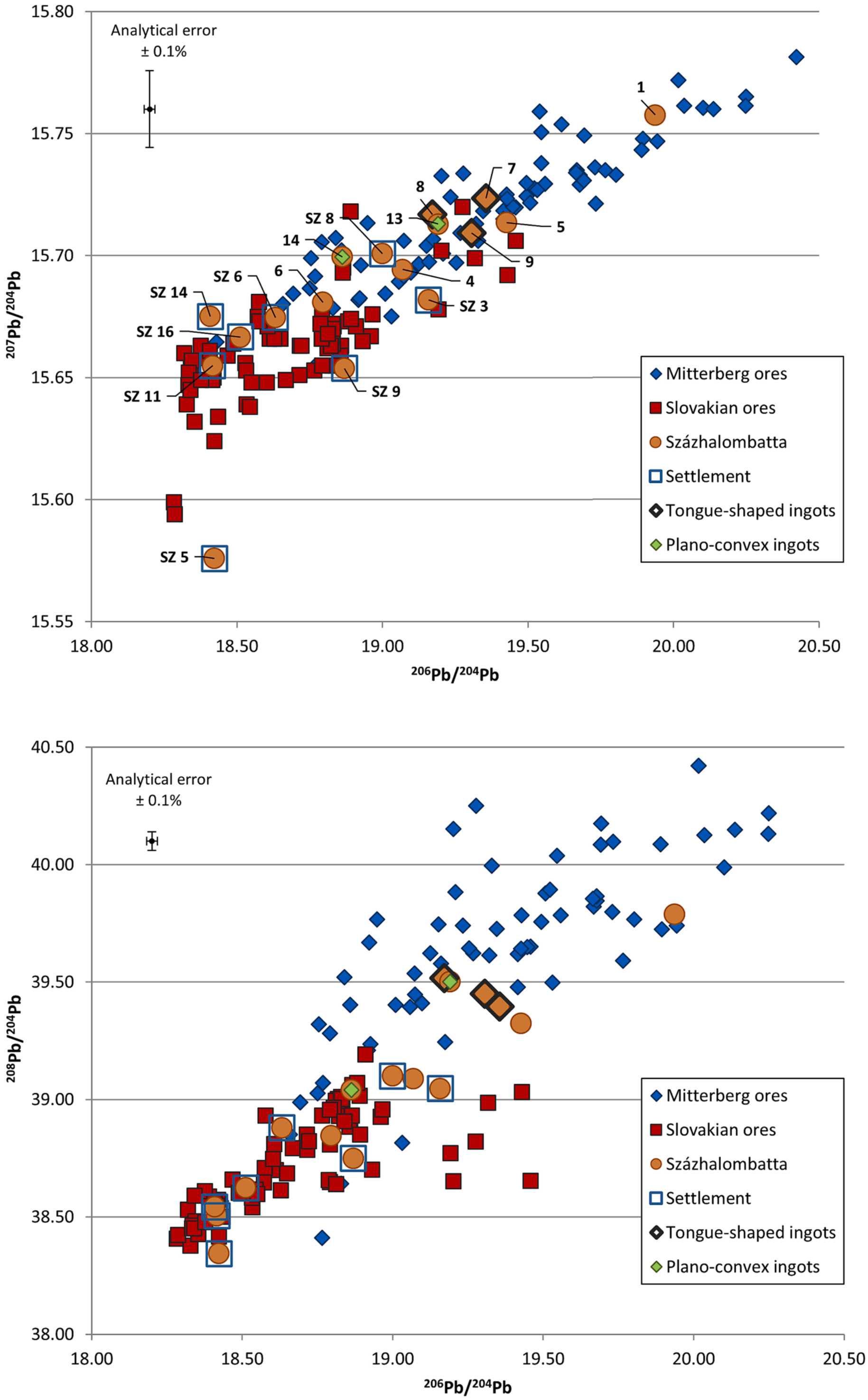

Fig. 13. A. Lead isotope ratios for the current samples from Százhalombatta. Many samples, comprising a majority of the objects from the hoard including the tongue-shaped ingots, have lead isotope signatures that are consistent with ores in the Austrian Alps, e.g. the Mitterberg ores. Many of the samples from the settlement site have lead isotope ratios that are consistent with ores from Slovak Ore Mountains. The latter also includes the casting debris (melts) and/or ingots with fahlore signatures (Sz11, Sz12 and Sz14). A dagger (Sz5) from the settlement is different from all the others and has a ^{207}Pb/^{204}Pb ratio which is lower than the ores from Slovakia. Ore data for comparison are for Slovakian ores from Schreiner (2007), and Mitterberg ores from Pernicka et al., 2016a. B.Ore from Mitterberg and Slovak Ore mountains ores are consistent with the lead isotope ratios of many pf the bronzes from Hungary and from Scandinavia (LNII–IB), apart from the dagger Sz5 (marked by the arrow), which has the ^{207}Pb/^{204}Pb value lower than the ores from Slovakia (in yellow; from three selected areas). However, some of the Scandinavian bronzes have closer affinity with the ores from the Great Orme mine in Wales, rather than with the Spania Dolina ores. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

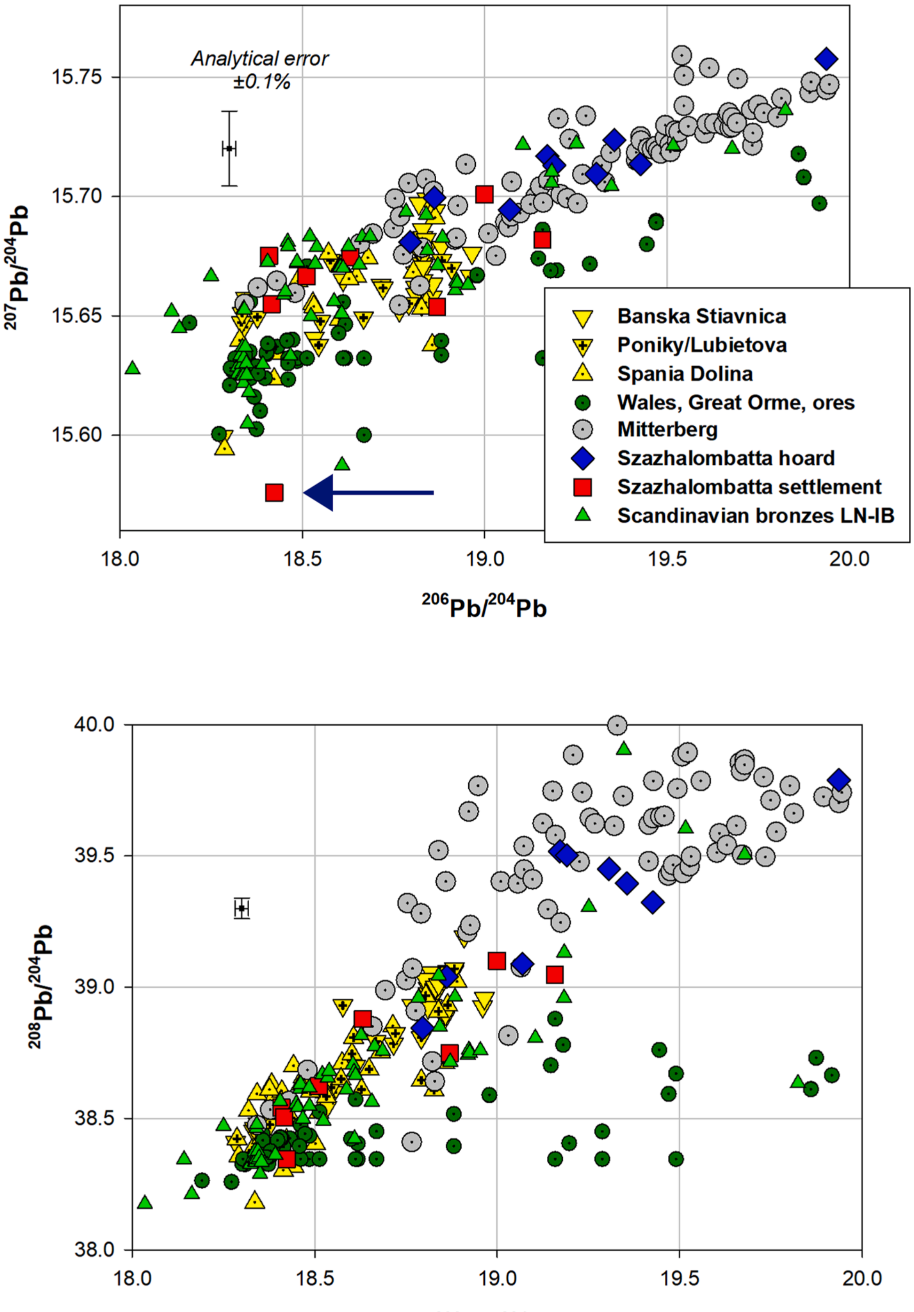

Fig. 13. (*continued*).

4.2. *General characteristics of the contemporaneous Scandinavian bronzes*

4.2.1. *Previous comparable analyses as point of departure*

Previous analyses of objects found within the sphere of the Nordic Bronze Age have identified chronological shifts in the metal supplies that reached Scandinavia. Studies of Danish artefacts indicate that a majority of the flanged axes from NBA IA with fahlore signature were manufactured of copper from Slovakian ores (Melheim et al. 2018; Nørgaard et al. 2019). Three major sources have previously been suggested for a majority of the objects from NBA IB; Slovakian ores, and ores from Austrian Mitterberg and Welsh Great Orme. Melheim et al. (2018) identified ores from Austrian Mitterberg and Slovakian ores as the most probable sources for most Danish metalwork during this phase. In addition, an origin from the Great Orme mine in Wales was suggested for flanged axes as well as shafthole axes from Denmark (Melheim et al. 2018). Recently, Nørgaard et al. (2021) identified the same three major sources for approximately 200 Danish artefacts, primarily axes, from this phase. Also, when it comes to three Nordic Hajdúsámson-Apa type swords from Dystrup in Denmark, a copper origin from Great Orme was argued for (Melheim et al. 2018, also in Ling et al. 2019). However, it should be emphasized that none of the other analysed swords from Norway or Sweden, dating to 1600–1500 BC, were connected to the Great Orme ores; rather, the bulk of them were related to Slovakian ores (Ling et al. 2019, cf. Nørgaard et al. 2023). Similarly, Bunnefeld (2016b) argued for a Slovakian origin for the copper in swords from Denmark, with one exception, a Hajdúsámson-Apa sword suggested to be made of Mitterberg copper. Although Berger et al. (2022) explored mixed ores and/or metals for most of the Apa-Hajdsámson artefacts in their multi-isotope approach, they nevertheless favored either Slovakian or

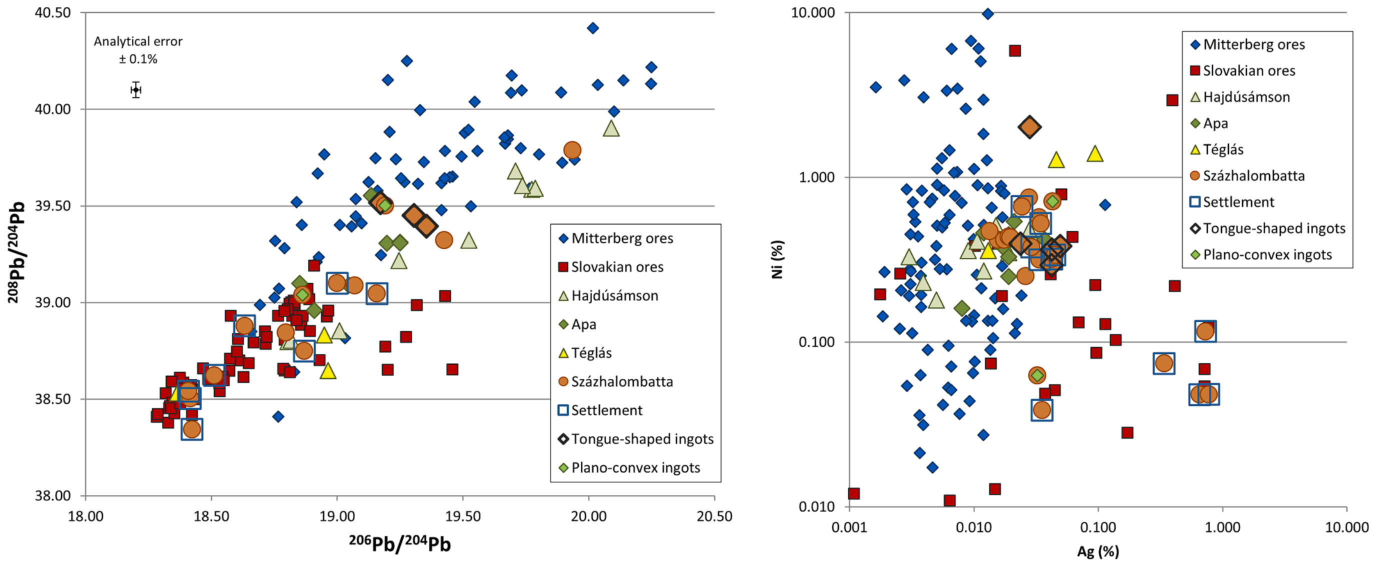

Fig. 14. Current samples compared with artefacts from the Hajdúsámson, Apa and Téglás hoards with both elemental and lead isotope data, displaying similar features with cluster in the Ni-Ag overlapping field of Slovakian ores and Mitterberg ores. However, the samples from Hajdúsámson with low Ag are consistent with Mitterberg ores both in terms of elemental data and lead isotope ratios. Data from Pernicka et al., 2016a,b; Pernicka, 2013; Schreiner, 2007 and Berger et al. 2022.

Mitterberg ores as single origins for most Scandinavian swords included in their analyses.

4.2.2. *Scandinavian bronzes in relation to those from Százhalombatta*

The major features of the comparative study (Tables 5–6) are highlighted here, including the new data from the current research team. In short, the analytical data indicate that there are similarities between the signatures of the Scandinavian and Carpathian objects, but there are also clear differences between the two data sets. There are groups of artefacts within the Scandinavian data set with signatures which are not observed in the current set of samples from Százhalombatta. Correspondingly some signatures observed in samples from the Százhalombatta settlement are not recorded in the contemporaneous Scandinavian data set.

The copper previously interpreted to originate in *Slovakian* ores is identified in objects of various typology, including flanged axes and one Nordic Hajdúsámson-Apa type sword, as well as shafthole axes and spearheads from both Fårdrup and Valsømagle horizons. Their trace elemental signatures (Fig. 15) are characterized by Ni, As, Sb and some Ag. However, the fahlore with low Ni that characterizes some of the casting debris from the Százhalombatta settlement, is not recorded in the current Scandinavian set of samples. Although the lead isotope signatures (Fig. 16) of the metal debris in question strongly indicate a copper ore origin in the Slovakian ore mountains, the distinct trace element signatures imply yet another ore source, not identified in any of the Scandinavian artefacts from 1700 to 1500 BC. However, similar fahlore signatures are common in earlier Scandinavian artefacts dating to the Late Neolithic, c. 2000–1700 BC, although generally with somewhat higher Ni (cf. Nørgaard et al. 2019).

Copper from *Mitterberg* ores is also indicated in the current study, but only in a very few Scandinavian objects (5) from NBA IB (shafthole axes of both Fårdrup and Valsømagle type and a flanged axe), mainly characterised by Ni (average 0,5 %) and As (average 0,4 %) and low Ag and Sb. This region was distinguished by Nørgaard et al. (2021) as a supplier of copper to numerous Danish artefacts.

Areas outside Central Europe, e.g. the *Great Orme* copper mine in Wales, were also substantial providers of copper to Scandinavia during the NBA IB, and Scandinavian metalwork typologically reminiscent of Carpathian bronzes seems to be made out of this copper too. The connection to Wales is strengthened by the new extensive analyses of ores and related British objects (Williams 2018). These new results open up for a larger compositional variation including Ni and As (mainly As > Ni) and low impurities of Sb and Ag (<0.1 and < 0.2 % according to Williams et al. 2019). This is in accordance with the composition of some of the Scandinavian artefacts (average Ni slightly above 0.4 % and As slightly below 0.4 %, in combination with low or very low Sb and Ag) with lead isotope signatures which are consistent with those from the Great Orme ores (Figs. 15–16). Among the Scandinavian metalwork with signatures suggesting copper from Great Orme, are flanged axes and Nordic Hajdúsámson-Apa type swords, previously discussed in detail by Melheim et al. (2018). In the current data set there is an additional ca. ten artefacts, mainly from the Fårdrup horizon with copper likely to originate from Great Orme. This includes Fårdrup shafthole axes and Bagterp spearheads from mostly Denmark and Sweden, but also one or possibly two objects from Norway. This strong impact of copper from Great Orme distinguishes Scandinavian metalwork from the hitherto analysed metalwork from the Carpathian Basin.

The possible identification of Cypriot copper in a dagger from Százhalombatta is intriguing in light of earlier interpretations of two Scandinavian objects with low impurities (Ling et al. 2014), which were held to be consistent with Cypriot ores (Stos-Gale and Gale 1994). This may strengthen the idea of shared sources between the regions.

On the other hand, yet another *additional copper source* has been identified in the Scandinavian data set, which is not present in the data set from Százhalombatta. From lead isotope and trace element data, copper with origin in the Italian Eastern Alps (Southalpine AATV) was tentatively suggested for a hilt-plated dagger (Sögel-type) and two swords (one Sögel-type and one Valsømagle-type) dating to NBA IB (1600–1500 BC), i.e. among the earliest Scandinavian objects with copper from this area, which became a major supplier of copper around 1500 BC (Ling et al. 2019). A copper origin from the Italian Eastern Alps has later also been pointed out by Nørgaard et al. (2021, 2023) for a few flanged axes and shafthole axes dating to NBA IB. Recent radiocarbon dating of Alpine copper smelting sites (Pearce et al. 2019) provides further evidence of copper smelting in this area from 1600 to 1500 BC, and that the so far, few Scandinavian artefacts reflect the rise of the southalpine copper supplier.

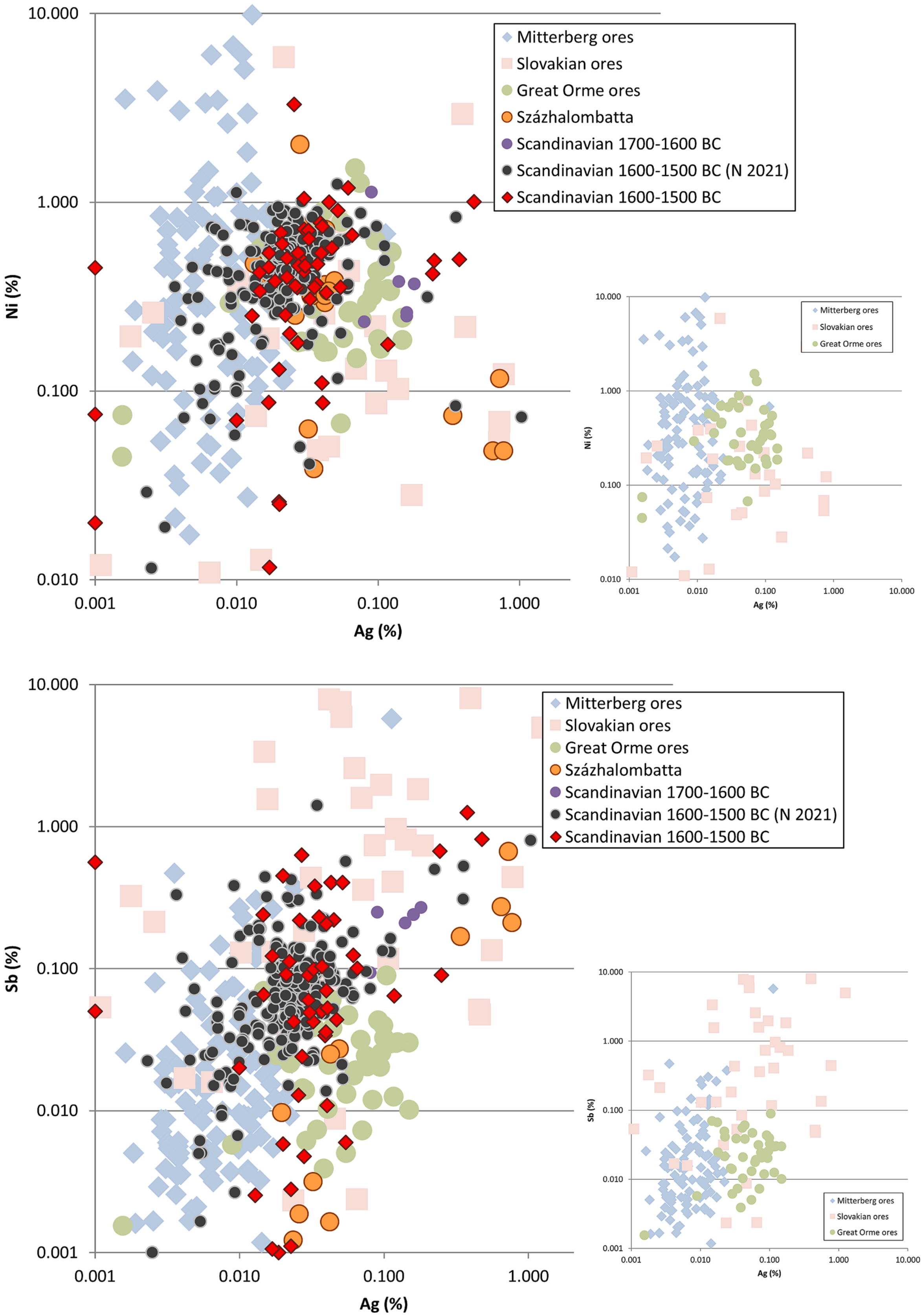

Fig. 15. Trace element signatures. Comparison of Ni-Ag and Sb-Ag in the Scandinavian samples compared to the samples from Százhalombatta. Data for Scandinavian artefacts are 1600–1500 BC (N) from Nørgaard et al. 2021, and 1700–1600 BC and 1600–1500 BC from Ling et al. 2014, Melheim et al. 2018, Ling et al. 2019, and new data (n = 29). Ore data for comparison are Slovakian ores from Schreiner (2007), Mitterberg ores from Pernicka et al., 2016a and ores from Great Orme (Williams 2018, Williams & Le Carlier de Veslud 2019). The same ore data also in the inserted graphs to illustrate their compositional fields more clearly.

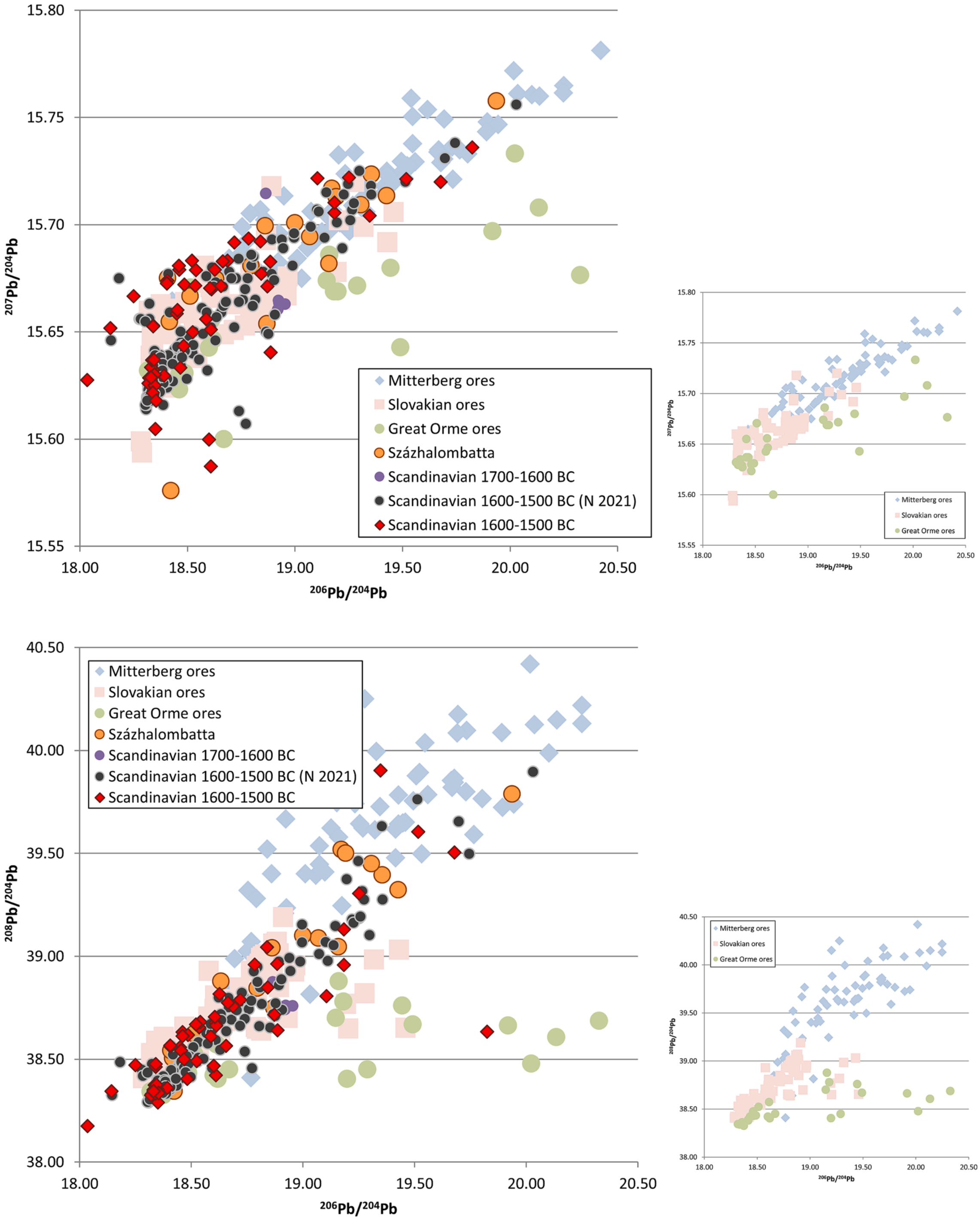

Fig. 16. Lead isotope ratios for Scandinavian samples compared to the samples from Százhalombatta, and ore data, demonstrating similarities as well as differences. Scandinavian samples with ^{207}Pb/^{204}Pb values 15.61–15.64 that are consistent with ores from Great Orme, have no corresponding samples from Százhalombatta. Ore data for comparison (also in the inserted minor graph) are Slovakian ores from Schreiner (2007), Mitterberg ores from Pernicka et al., 2016a and ores from Great Orme (Williams 2018, Williams & Le Carlier de Veslud 2019). Data for Scandinavian artefacts are 1700–1600 BC (N) from Nørgaard et al., 2021, and 1700–1600 BC and 1600–1500 BC from Ling et al. 2014, Melheim et al. 2018, Ling et al. 2019, and new data (n = 29).

5. Discussion

5.1. *The hypothesis of shared copper sources between Hungary and Scandinavia*

The conventional theory that copper was traded from Hungary to Scandinavia in the period in question emerged from the idea of cultural interaction and a transmission of metalworking styles and ideas from the Carpathian Basin to the north (e.g. Kristiansen & Larsson 2005, 204-205; Vandkilde 2014). This hypothesis has typically been supported by trace element data and typological parallels rather than by lead isotope data or other tangible mining-related evidence, rendering it inconclusive. Slovakian copper was considered an important while not substantial supply by Liversage (Liversage 2000:62, 81–82; cf. Liversage 1994:73-74). The application here of lead isotope analysis, represents a possibility to re-evaluate the theories of the origin of the copper, and further substantiate previous provenance studies.

Due to recent advances in provenance studies (Pernicka et al, 2016a–b, Nørgaard et al. 2019, 2021, Berger et al. 2022), and the analytical data genereted from the current study, we are now in a position to forward the overarching issue about shared copper sources between Hungary and Scandinavia 1700–1500 BC. Overall, there seems to have been two major sources of copper to the metals analysed from the Százhalombatta hoard and settlement, ores from Slovakia and Mitterberg, either as single sources or mixed ores. The same sources are evident in the contemporaneous Scandinavian metalwork. A third shared source for e few outliers of Cypriote copper is more challenging. In addition, copper from ores in Wales and the Italian Eastern Alps was identified in Scandinavia 1700–1500 BC, but not in the data set from Százhalombatta. Neither of these sources were identified in the Carpathian metalwork analysed by Berger et al. (2022). Currently, thus, there is no indication that copper from the Italian Eastern Alps circulated in the Carpathian Basin, but again, the data set is quite limited.

In the currently analysed Hungarian material, some interesting trends may be noted. While the majority of the samples from Százhalombatta Hoard II is consistent with Mitterberg copper, copper from both Mitterberg and the Slovakian Ore Mountains, from at least two types of ores, was identified in the metal artefacts and casting debris from the settlement in Százhalombatta. The same two regions were identified as potential sources for other copper-based objects from the Hajdúsámson-Apa horizon in the Carpathian Basin (Pernicka 2013; Pernicka et al. 2016b). Berger et al. (2022) identified the same two major sources but argued for mixing of ores or metals to explain the compositional patterns. Regardless of mixing, the overall picture shows that Mitterberg and Slovakian ores were important suppliers of copper to the Carpathian tell communities during the Bronze Age.

In the current Scandinavian data set, Slovakian copper is more dominant than copper from Mitterberg. The latter source is, however, more prominent in a batch of Danish artefacts analysed by Nørgaard et al. (2021) and hence may be equally significant. They in fact suggest that Slovakian ores are only subordinate and that the variation in lead isotope ratios in combination with homogeneous trace elemental signatures, can be assigned to mixing of ores from Mitterberg and Great Orme in Wales. The theory of mixing argued by Nørgaard et al. (2019, 2021, 2023) is interesting. Especially the case study of shaft hole axes of Fårdrup and Valsømagle type (Nørgaard et al. 2023) illustrates exemplary the ambiguity of identifying copper sources for artefacts with similar trace elemental signatures. A majority of these axes have low impurity patterns mainly characterized by Ni and As, very similar to patterns found in the current study. Since similar impurity patterns are found in all three potential regions, the lead isotope signatures are vital. However, these are also partly overlapping. For some axes, affiliations to copper from either of the three regions are more probable. For others, a more complex alternative including mixing seems possible. For the latter, Nørgaard et al. (2023) argue that the signatures from one single source (Slovakian ores) may be the result of a hypothetical mixing of metals from two sources (from Welsh and Mitterberg ores). Given that copper from several different suppliers circulated within the same communities and workshops, the chance that copper from different sources was mixed, is clearly present. Irrespective of the potential mixing of metals, it seems clear from the above discussion that a few major suppliers of metal are prominent in the analysed Scandinavian bronzes.

5.2. From ore to metal

The patterns found in our research support the central argument presented by Radivojević et al. (2018) that shifts in copper sources were linked to changes in metal flows in the European Bronze Age. Additionally, it has been demonstrated that the intricacies of the production and consumption patterns of metal across Bronze Age Europe cannot be explained by a simple equation between stylistic influence and metal suppliers. While a number of Nordic swords of types inspired by Hajdúsámson-Apa metalwork were in fact made of copper from Slovak ores (Bunnefeld 2016b; Ling et al. 2019; Berger et al. 2022), analytical results remind us that such a connection cannot be taken for granted. Striking examples are the previously mentioned Nordic Hajdúsámson-Apa swords from Dystrup in Denmark, cast in Scandinavia from Great Orme copper on the basis of Carpathian prototypes. Other examples are two blades from Sweden of the Hajdúsámson-Apa inspired Sögel type (Vandkilde 1996:239), suggested to be made of copper from the Italian Alps (Ling et al. 2019). Nørgaard et al. (2023) argued that the majority of Fårdrup style axes in their data set were made of copper from Mitterberg, despite a strong stylistic inspiration from Carpathian metalwork. The Fårdrup axes of the current study are identified as having been made mainly of copper from Slovak and Great Orme, while a minority of the axes match Mitterberg copper. This indicates that even though Scandinavian metalworking traditions were highly influenced by casting techniques and typology from the Carpathian Basin (Vandkilde 2014), this action was not necessarily dependent on copper from ores solely in that region. Instead, the processing and crafting of metals seem to have been less strictly connected to metal supply chains.

Nonetheless, in order to understand these supply chains, we must address the various forms copper (and tin) circulated in. To be traded and transported, copper was transformed into ingots, or metal was exchanged in the shape of crafted artefacts or already alloyed ingots or preforms. Another core problem is alloying practices and how this tied in with production and supply chains (Liversage 2000). An ingot is simply a raw material that has been manufactured to achieve a regular and intentional shape and can be of pure copper, tin or of bronze alloyed with e.g. tin in lower or higher concentrations. An example of the latter are the tongue-shaped ingots from Hoard II, three of which were low-tin ingots. It is striking that no tongue-shaped ingots have yet been identified in Scandinavia, hence metal is likely to have entered this region in other forms. Recent studies have argued that a yet unacknowledged circulation of bronze ingots may explain composition patterns 1600–1500 BC (e.g. Berger et al. 2022:70; Nørgaard et al. 2023).

As already pointed out, the ingots analysed in this study are quite variable when it comes to tin content. The tongue-shaped ingots present in hoard II are all alloyed with tin as their previously analysed counterparts from Hungary (Czajlik 2012:91), although to varying degrees and even larger variability is demonstrated in tongue-shaped ingots from other hoards (Schubert & Schubert 1967; Junghans et al. 1974). Hoards can be understood as reflecting metal valuables and potentially their composition are more likely to reflect the metals that circulated out of the region than those from the settlement site. The pure copper ingots, which were utilized in places like Százhalombatta most likely came directly from the area of the mining districts where they were produced (Czajlik 2012:64–67). At such sites, they were further processed by partitioning and alloying, to be cast into objects. Surplus material in the crucible is likely to have been spared by being poured directly into ingot moulds, as exemplified by the open moulds at the ridge of the workshop from Lovasberény-Mihályvár (Petres and Bandi 1969). By doing this, a transportable 'secondary' raw material is produced, an 'alloyed' ingot, that could be recast or traded. Another possibility is that such ingots were created by melting actual casting waste (such as drops, lumps, etc.) together, as is indicated by archaeological evidence from the Carpathian Basin during the Late Bronze Age (Mozsolics 1981; compare Modl 2019). Százhalombatta is one of the tell sites in the Carpathian Basin where metal crafting is argued to have played an important role, possibly reflecting specialized production (Găvan, 2020). In the ingots from Hoard II a division can be seen between ingots regarding provenance of copper. The tongue-shaped ingots (0.8–4.5 % Sn) and the plano-convex ingot with low tin (1.3 %) are all probably of Mitterberg copper, although mixing with Slovakian ores can be discussed also due to the overlapping elemental data. However, the plano-convex ingot of (nearly) pure copper is more likely of Slovakian origin. Although, overlapping of data in theory may suggest mixing of ores, this is probably less likely in such a pure ingot. This ingot is low in impurities as well, which clearly discriminates it from the copper in the casting debris from the Százhalombatta, with more pronounced concentrations of trace elements. Although this casting debris contain copper from Slovakia, this is from a different type of ore than in the plano-convex ingot. This also means that this casting debris is not related to the plano-convex ingot, unless metal with higher impurity pattern was added sometimes during the process. All these compositional patterns indicate a complex process of casting not only from various regions but from different types of ores.

5.3. Trade relations and geography

The results of combined elemental and lead isotope analyses discussed here indicate a range of copper producers and, potentially, a complex web of trade relations. The identification of Mitterberg copper at the Százhalombatta settlement site and in the hoard is telling. As we saw, a predominance of Mitterberg copper was noted also in another famous hoard finds from the Carpathian Basin. Interestingly, a source of probably Slovakian copper with higher impurities was identified in casting debris from early phases of Százhalombatta tell, dated to around 1700 BC, which is not observed in any of the currently analysed artefacts from Hungary nor contemporaneous artefacts from Scandinavia. In light of these results we can envision three scenarios:

1. Carpathian tells like the strategically situated Százhalombatta served as hubs of trade for trade with Scandinavia.
2. The two areas got copper from some of the same sources but were not themselves exchange partners.
3. Both of these exchange patterns might have coexisted during the Bronze Age.

The cultural impact seen in Scandinavia from the Carpathian Basin suggests that there was a tight connection, in favour of the first scenario. Implicit in this is that communities in the Carpathian Basin controlled the region's copper sources and the trade in metals. On the other hand, the lack of Italian copper in Százhalombatta and the presence here of another type of metal not found in Scandinavia, may suggest that the two areas were not directly involved in trade with each other, and, perhaps, that the Scandinavians also used other exhange routes that bypassed Százhalombatta (but compare Ling et al. 2019), or that these changed through time.

Taken together, there are more arguments in favour for the first scenario. The idea of a direct connection between Hungary and Scandinavia via the Central European rivers was based both on imported items crafted in the Carpathian Basin and an otherwise strong cultural and religious impact from the region observed in Scandinavia from 1700 BC, intensifying c. 1600–1500 BC (Vandkilde 2014). Vandkilde (2014) argued that the Carpathian Basin was a transcultural crossroads, from where new innovations spread and were further creatively transformed in other regions, like the Nordic. Finds of Baltic amber in the Carpathian region may further support the idea of lively trade and contact between the two regions. Amber beads are frequent finds at cemeteries and in some cases hoards of the Mad'arovce-Otomani-Füzesabony horizon (e.g. Furmánek et al. 1999; Harding 2013; Stanczik and Tánoki 1992). A well-worn amber bead (redrilled and further used after initial breaking) from Level 8 and some amber crumbles from the heavy fractions of Levels 7 and 8 indicate the general presence and use of amber at Százhalombatta. Also, it is a fact that Százhalombatta is geographically very well positioned as a catchment area for copper from both Mitterberg and Slovakia.

The traditional idea that Carpathian tells like the strategically situated Százhalombatta were involved in metal trade based on a regional supply of copper must be readdressed in light of the presence at Százhalombatta of not just copper from the Slovakian Ore Mountains but also from Mitterberg. Was access to Mitterberg copper unrelated to trade in copper from the Slovak Ore mountains? Or, did the northerners in fact acquire Mitterberg copper via groups in the Carpathian Basin? When it comes to Mitterberg, (Shennan and Acott, 1995) hypothesized that raw copper was transported downstream by canoe along the Salzach valley to the Danube valley, where the transformation of metal into ingots and other standardized exchange commodities took place. Did the transformation of copper into objects of exchange take place at hubs such as Százhalombatta, or at sites closer to the mines?

Another observation must be stressed in this context, something that shows the exception rather than the rule, but it may also indicate the complexity of the Bronze Age copper trade in prehistoric Europe. A single outlier from the settlement in Százhalombatta, a dagger of a common type from Middle Bronze Age indicates a potential origin from Cypriot ores. Such an origin is challenging, this being a dagger of a type that is common and widely used in the Carpathian Basin during the Middle Bronze Age (Kemenczei 1988; Szeverényi & Kiss 2018). In light of the role played by the tell communities in the copper trade, it's fair to hypothesize that they served as a hub, for copper supplies from both Slovakian and Eastern Alpine mines (Mitterberg), but also, perhaps as a strategic place for the reshipment of Cypriot copper on its way to Northern Europe. This might not be too farfetched since we know that Hungarian tell communities, via the Danube, had close trade ties with groups in the Black Sea region and groups in the Eastern Mediterranean world (Kristiansen 1998; Maran 1998; Vandkilde 2016).

6. Conclusion

This study shows that Bronze Age groups in Scandinavia and Hungary shared copper sources 1700–1500 BC. It confirms the theory that Scandinavian and Hungarian communities had direct or indirect trade relations during this epoch. It should be emphasized, however, that there are other more direct ways from the metal sources to Scandinavia than the direct route to the Middle Danube. As a result, the exchange through the Carpathian tell communities is most likely one of several ways copper was brought to Scandinavia. Moreover, the analyses of Scandinavian bronzes from 1700 to 1500 BC point to the use of a wider range of sources than the Hungarian ones.

Finally, beginning approximately 1700 BC, Hungarian metal networks spread all the way up to Northern Europe, leaving substantial imprints on the Scandinavian bronze-crafting tradition. While the traditional view argued for a close connection between metal sources and metalworking traditions, more recent insight shows that form and content may have totally different origins. Through creative translations metals were continuously transformed: the same workshops used metals from various sources, technologies were borrowed, and styles hybridized. The impact of Carpathian culture in Scandinavia was a result of these innovations and exchanges. Future studies must address in more detail the question of tin and how alloying practices tied in with the copper trade.

Declaration of Competing Interest

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

Data availability

Data will be made available on request.

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