Rituals, Hoards and Travellers? Archaeometry of the Iron Age Bronze Wheel Amulets

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ABSTRACT

This paper aims to discuss the origin and significance of the so-called spoked-wheel amulets from the late Iron Age (3rd to 1st century BC). The type with eight spokes, which most resembles a real chariot wheel, was discovered to be made of a specific alloy containing a large amount of lead and a significant amount of antimony, plus traces of silver and arsenic. This combination of elements signifies the use of a copper known as *fahlore* (tetrahedrite). Its use in Bohemia after the early Bronze Age is rarely observed, if at all. These amulets are therefore a conspicuous exception. Research in Bavaria has revealed other objects made from *fahlore* copper. Another connection to Bavaria may be indicated by coin hoards accompanied by bronze closure rings of a similar alloy design. Other cases may suggest that antimony was added as a separate component. Here we discuss the composition and provenance of these objects from the perspective of compositional and lead isotope analysis.

1. Introduction

Wheel rings or spoked-wheel amulets are a ubiquitous and popular part of the material culture of the La Tène period. They occur from the 5th century BC onwards, from France to Hungary, across the vast territory of the La Tène culture. The symbolism of wheel amulets remains unexplained. They are usually associated with Sun symbology, as chariots or wheels represented the Sun carriage from the Bronze Age (Green, 1984). Another common association is with other celestial bodies or phenomena, typically thunder (Green, 1986).

In material culture, spoked wheels were most probably used in personal jewellery, perhaps as amulets or special symbols, as is suggested by their depiction on Celtic coins (*e.g.* Manching, *cf.* van Endert, 1991) and evidence from burials since the early La Tène (Werner, 1979; Hecht *et al.*,

1991; Stöckli, 1975). They were often worn as pendants on necklaces or suspended from brooches on bronze chains (*e.g.* numerous finds from the oppidum of Stradonice; Píč, 1903).

In central Europe, a significant concentration was observed at the oppidum of Stradonice (Figure 1; Píč, 1903; Kysela and Venclová, 2018), and at Manching (van Endert, 1991), which suggested that the amulets were typical oppida objects; they had first been described as such in Déchelette's well-known comparative table (1914). In recent years, however, they have been observed in increasing numbers in the countryside, largely as a result of the increased use of metal detectors (Čižmářová, 2014; Danielisová *et al.*, 2018a). They are now known to be present at almost every site from the middle to the late La Tène period (*i.e.* 3rd to 1st century BC) with a particular profusion during the "oppida period" (2nd to 1st century BC).

The spoked wheels differ in size, shape, and number of spokes (Čižmářová, 2014). The basic and typologically most homogeneous group comprises the eight-spoked wheels

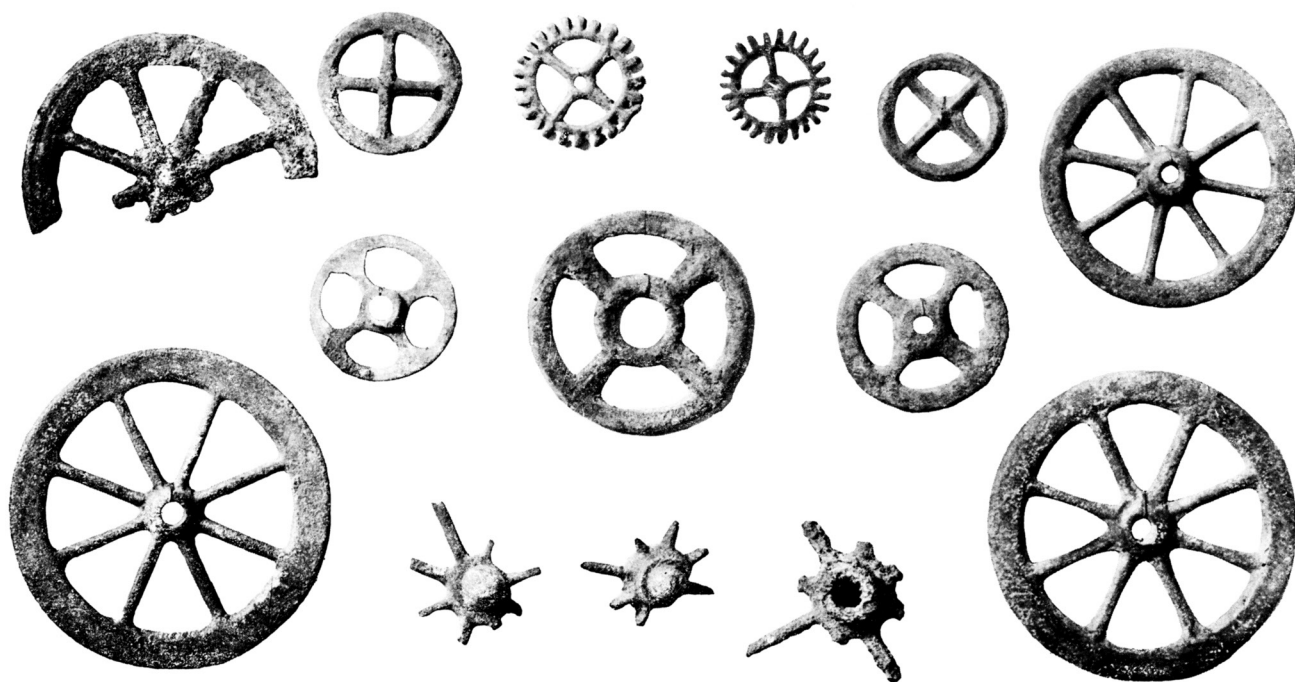*Corresponding author. E-mail: danielisova@arup.cas.cz

Figure 1. Types of wheel amulet from the La Tène period (the oppidum of Stradonice), after Píč, 1903.

which imitate chariot wheels. They are usually made entirely from lead or from a heavily-leaded alloy (Schwab, 2011). The eight spokes are a regular feature; sometimes there are multiples of eight, as with the sixteen-spoked wheel depicted on a Gundestrup cauldron (Green, 1986). Four- and six-spoked wheels make up a larger and more heterogeneous group. These wheels appear only to suggest rather than imitate chariot wheels and have a simpler design that is perhaps more decorative in the context of late La Tène art.

Archaeometric analysis of large assemblages from the La Tène period revealed the recurrence of a particular material composition of the eight-spoked wheels (Danielisová *et al.*, 2018b), which included a large amount of lead, unusually large amounts of antimony, and increased amounts of arsenic

and sometimes silver. It was noteworthy that this chemical composition was found only in these amulets and not in the other types of object. West of Bohemia, however, particularly in Bavaria, antimony bronzes have regularly been recorded and associated with the alloying of *fahlore* copper (Schwab, 2011; 2014a; 2014b). It was not until we detected the same composition in two bronze rings with a rhombic section, used as a closure mechanism in the context of a Celtic coin hoard from Libčice nad Vltavou (Figures 2 and 3), that the connection with Bavaria became worth considering.

We therefore decided to give more attention to this matter and to investigate the alloy design and provenance of these objects and to explore the broader socio-cultural or political implications. In addition to "official" commercial
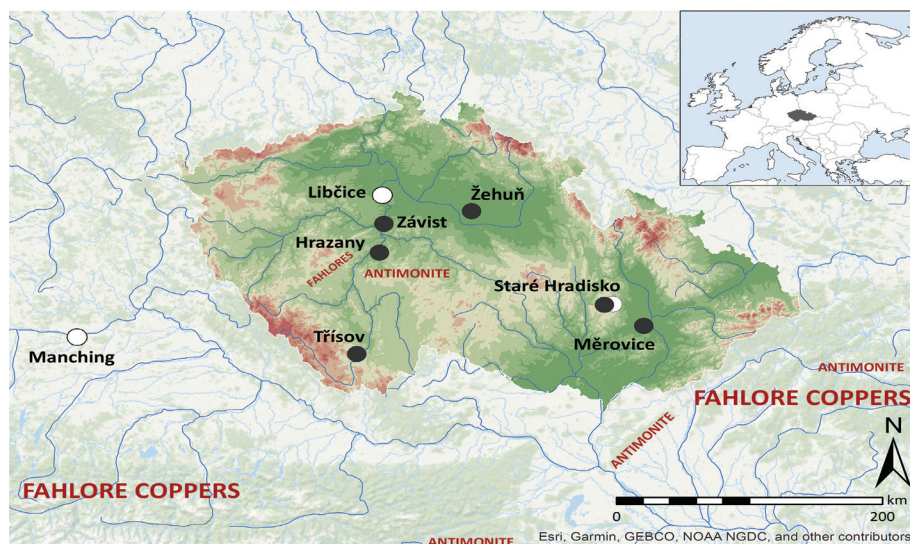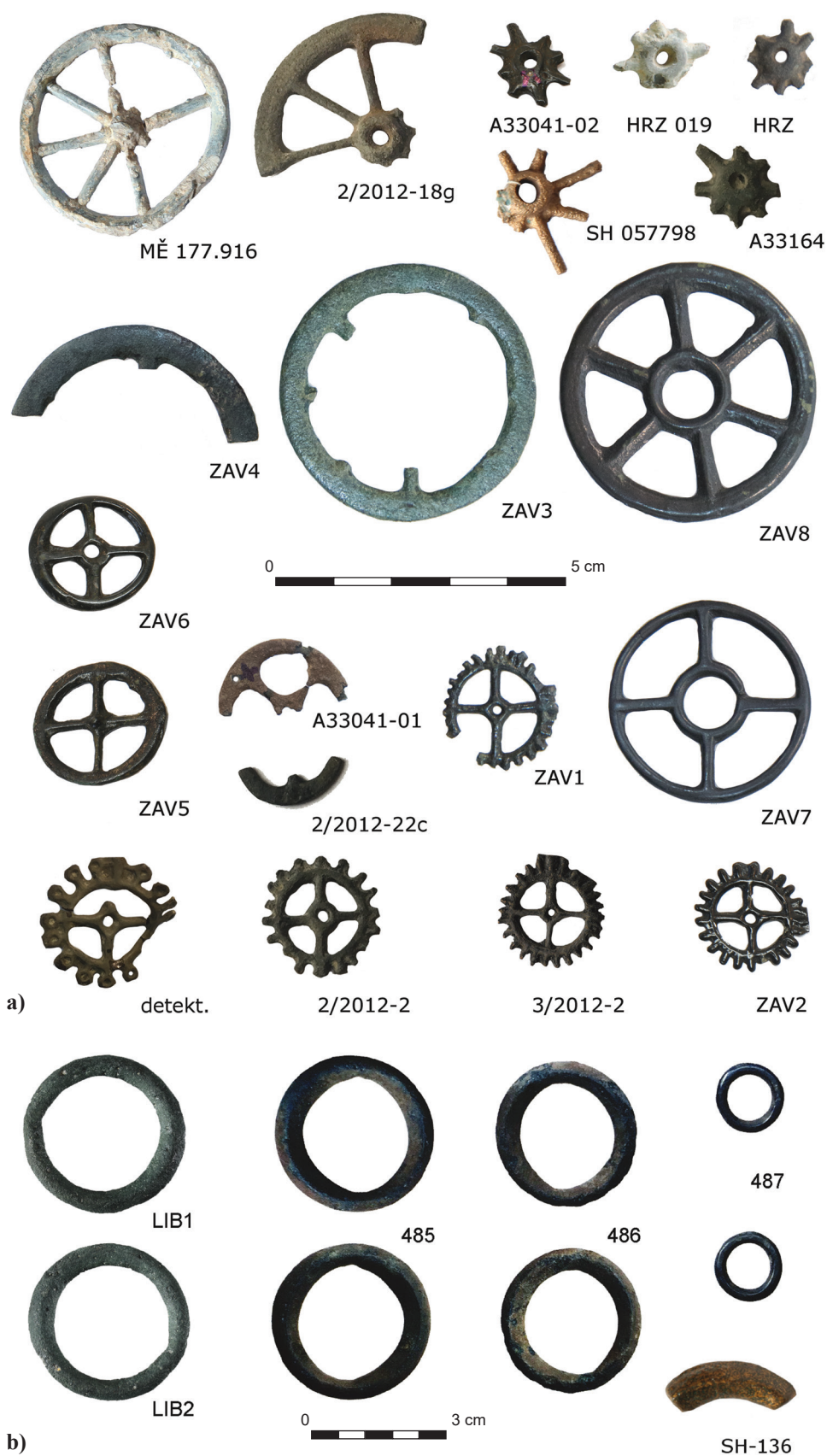

Figure 2. Map of sites mentioned in the text and main deposits of *fahlore* coppers and antimonites in central Europe. Filled symbols: wheel amulets; hollow symbols: rings with a rhombic section; sites represent coin hoards, oppida, and lowland settlements.

Figure 3. a) Analysed spoked-wheel amulets from selected sites (*cf.* Figure 2). The numbers in the picture correspond to the numbers in Table 1 (some objects were not available for documentation). Photo by D. Bursák and A. Danielisová. b) Rings with a rhombic section from coin hoards at Libčice (LIB1–2) and Manching (485–486), and a ring of the same composition from the oppidum of Staré Hradisko (SH 136). Photo by D. Bursák and D. Daněček (LIB1–2); Manching rings (485–486) from Zieghaus, 2013.

connections in these areas, which can be seen from the common material culture and the exchange of coins, subtler social mechanisms based on personal mobility or an elusive world of rituals may have also been at play.

2. Materials and Methods

We were able to sample a total of 28 eight- and four-spoked bronze ring amulets and rings (*cf.* Table 1, Figure 3a, 3b), from seven sites (Figure 2), selected from an assemblage of La Tène period objects analysed under a project looking at copper alloys of the later Iron Age. We obtained data on the composition of all 28 objects; further analysis was carried out on 22 of them to determine their lead isotopic signature. Samples were drilled to the metal core in order to avoid the corrosion layers (*cf.* Lutz and Pernicka, 1996) and to collect the minimum amount of material necessary for analysis.

The objects were small and highly corroded, so the sample weight varied between 0.01 and 0.05 g.

Analysis of the chemical composition and lead isotopes was performed at the Institute of Geochemistry, Mineralogy and Mineral Resources, Charles University, Prague. Mass spectrometry (ICP-MS) and lead isotope analysis (MC-ICP-MS) were applied in order to determine the chemical composition and possible provenance of the artefacts. The major elements (Cu, Sn, Pb) and trace elements (Sb, Ag, As, Zn, Ni, Co, Fe, Bi) were determined using modified digestion in mineral acids (HNO_3+HCl, 3:1), followed by conventional solution nebulization ICP-MS iCAPQ (Thermo, Bremen) and/or ICP OES Agilent 5110 (Agilent, USA). Approx. 0.01–0.02 g of each sample was digested in 2.5 ml of the acid mixture (HNO_3+HCl, 3:1) in PTFE vessels (Savillex, USA) on a hot plate (100°C for 1–2 hours) and transferred to a 25 ml volumetric flask. All the samples and procedural blanks were further diluted one thousand-fold

Table 1. List of the analysed objects, their types, and contexts ("4-ray": four-spoked wheel amulets; "8-ray": eight-spoked wheel amulets; "ring": bronze ring with a rhombic section).

Id.	Inv. number	Site	Context	Type of amulet
1	ZAV1	Závist	oppidum	4-ray
2	ZAV2	Závist	oppidum	4-ray
3	ZAV5	Závist	oppidum	4-ray
4	ZAV6	Závist	oppidum	4-ray
5	detekt.	Žehuň	settlement	4-ray
6	2/20012-22a	Žehuň	settlement	4-ray
7	2/2012-22b	Žehuň	settlement	4-ray
8	2/2012-22c	Žehuň	settlement	4-ray
9	2/2012-5	Žehuň	settlement	4-ray
10	2/2012-2	Žehuň	settlement	4-ray
11	3/2012-2	Žehuň	settlement	4-ray
12	2/2013-4	Žehuň	settlement	4-ray
13	A33038	Třísov	oppidum	4-ray
14	A33041-01	Třísov	oppidum	4-ray
15	A33162	Třísov	oppidum	4-ray
16	ZAV7	Závist	hallstatt hillfort	4-ray
17	ZAV8	Závist	hallstatt hillfort	6-ray
18	ZAV3	Závist	oppidum	8-ray
19	ZAV4	Závist	oppidum	8-ray
20	MĚ 177.916	Měrovice	settlement	8-ray
21	SH 057798	Staré Hradisko	oppidum	8-ray
22	HRZ 019	Hrazany	oppidum	8-ray
23	2/2012-18g	Žehuň	settlement	8-ray
24	A33041-02	Třísov	oppidum	8-ray
25	A33164	Třísov	oppidum	8-ray
26	LIB1	Libčice	hoard	ring
27	LIB2	Libčice	hoard	ring
28	SH 136	Staré Hradisko	oppidum	ring

Table 2. Chemical composition of the samples. Data were normalized to 100%. For detection limits see the table (n.d. = below detection limit).

Id.	inv.number	Type of amulet	Co %	Ni %	Cu %	Zn %	As %	Ag %	Sn %	Sb %	Pb %	Bi ppm	Total %	Analytical total %
		detection limit	<0.005%	<0.01%	<0.05%	<0.01%	<0.10%	<0.005%	<0.05%	<0.005%	<0.001%	<50ppm		
1	ZAV1	4-ray	0.025	0.097	65.8	0.64	0.153	0.034	8.24	0.074	24.895	n.d.	100	65.90
2	ZAV2	4-ray	n.d.	0.032	62.4	7.21	0.137	1.308	21.37	n.d.	7.574	n.d.	100	84.04
3	ZAV5	4-ray	n.d.	0.040	71.7	0.03	0.369	0.369	4.98	2.871	19.607	n.d.	100	101.40
4	ZAV6	4-ray	0.111	0.104	72.8	n.d.	0.282	0.060	21.02	0.159	5.495	n.d.	100	102.59
5	detekt.	4-ray	0.091	0.041	72.4	n.d.	0.318	0.098	14.69	0.096	12.299	n.d.	100	95.00
6	2/20012-22a	4-ray	0.043	0.085	76.3	0.18	0.204	0.051	5.99	0.062	17.059	n.d.	100	95.74
7	2/2012-22b	4-ray	n.d.	0.019	85.8	n.d.	n.d.	0.023	6.23	0.034	7.894	n.d.	100	98.19
8	2/2012-22c	4-ray	0.007	0.040	77.8	n.d.	n.d.	0.163	6.11	0.028	15.883	n.d.	100	89.61
9	2/2012-5	4-ray	0.139	0.059	83.7	n.d.	0.261	0.037	11.84	0.023	3.977	n.d.	100	92.18
10	2/2012-2	4-ray	0.033	0.056	84.7	n.d.	0.175	0.044	8.90	0.107	5.996	n.d.	100	92.13
11	3/2012-2	4-ray	0.017	0.213	77.9	0.03	0.148	0.077	10.52	0.080	10.977	n.d.	100	86.25
12	2/2013-4	4-ray	0.025	0.132	71.8	0.10	0.207	0.061	8.83	0.059	18.777	n.d.	100	71.24
13	A33038	4-ray	0.031	0.102	89.5	0.02	0.097	0.023	8.09	0.059	2.080	n.d.	100	98.53
14	A33041-01	4-ray	0.048	0.070	72.3	0.01	0.304	0.232	9.95	0.150	16.891	172.6609	100	94.43
15	A33162	4-ray	n.d.	n.d.	68.0	0.02	n.d.	0.114	11.17	0.650	20.051	n.d.	100	93.75
16	ZAV7	4-ray	0.014	0.077	70.8	n.d.	0.137	0.063	23.37	0.225	5.335	n.d.	100	101.45
17	ZAV8	6-ray	0.017	0.031	58.1	n.d.	0.125	0.045	11.93	0.047	29.745	n.d.	100	83.33
18	ZAV3	8-ray	n.d.	0.063	71.4	n.d.	0.641	0.294	2.77	5.864	18.969	n.d.	100	86.44
19	ZAV4	8-ray	n.d.	0.046	70.8	n.d.	0.722	0.200	1.83	6.995	19.442	n.d.	100	90.09
20	MĚ 177.916	8-ray	n.d.	0.075	0.1	0.18	0.562	<0.005	0.30	7.385	91.419	n.d.	100	103.18
21	SH 057798	8-ray	n.d.	0.036	57.9	n.d.	0.745	0.228	4.50	5.088	31.424	439.6541	100	93.17
22	HRZ 019	8-ray	n.d.	0.256	55.8	0.06	0.716	0.118	5.12	7.884	29.997	n.d.	100	88.37
23	2/2012-18g	8-ray	n.d.	0.094	59.3	0.48	0.368	0.419	4.37	3.496	31.475	n.d.	100	99.02
24	A33041-02	8-ray	n.d.	0.066	52.5	n.d.	0.484	0.381	8.04	5.155	33.379	97.10824	100	103.36
25	A33164	8-ray	n.d.	0.032	63.6	n.d.	0.228	0.700	5.33	3.739	26.334	n.d.	100	94.45
26	LIB1	ring	n.d.	0.088	62.9	0.04	0.314	0.025	2.73	5.166	28.711	44.46928	100	95.87
27	LIB2	ring	n.d.	0.096	55.9	0.01	0.550	0.024	2.02	5.554	35.872	40.18123	100	96.40
28	SH 136	ring	n.d.	0.080	61.3	0.13	0.674	0.090	3.55	5.039	29.176	77.28064	100	97.56

Table 3. Lead isotope data for the wheel amulets and rings with a rhombic section. Data precision (MC-ICP-MS) is better than 0.01% for ratios with [206]Pb in the denominator and better than 0.03% with [204]Pb in the denominator.

Id.	Inv. number	Type of amulet	$^{207}Pb/^{206}Pb$	$^{208}Pb/^{206}Pb$	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb$	$^{208}Pb/^{204}Pb$
1	ZAV1	4-ray	0.8376	2.0842	18.711	15.672	38.998
2	ZAV2	4-ray	0.8378	2.0847	18.707	15.673	39.000
3	ZAV5	4-ray	0.8531	2.1005	18.364	15.667	38.573
4	ZAV6	4-ray	0.8346	2.0672	18.779	15.674	38.821
5	detekt.	4-ray	0.8373	2.0721	18.712	15.668	38.773
6	ZAV8	4-ray	0.8377	2.0820	18.712	15.676	38.957
7	2/20012-22a	4-ray	0.8458	2.0824	18.467	15.619	38.456
8	2/2012-22c	4-ray	0.8411	2.0772	18.577	15.624	38.588
9	A33162	4-ray	0.8377	2.0829	18.708	15.671	38.966
10	A33038	4-ray	0.8380	2.0823	18.702	15.670	38.943
11	A33041-01	4-ray	0.8378	2.0828	18.708	15.673	38.964
12	ZAV7	6-ray	0.8372	2.0828	18.722	15.674	38.995
13	ZAV3	8-ray	0.8377	2.0845	18.711	15.675	39.003
14	ZAV4	8-ray	0.8382	2.0849	18.702	15.676	38.991
15	MĚ 177.916	8-ray	0.8478	2.0842	18.405	15.604	38.360
16	SH 057798	8-ray	0.8395	2.0847	18.675	15.677	38.932
17	2/2012-18g	8-ray	0.8410	2.0866	18.630	15.669	38.873
18	A33164	8-ray	0.8392	2.0842	18.673	15.669	38.919
19	A33041-02	8-ray	0.8386	2.0730	18.676	15.661	38.714
20	HRZ 019	8-ray	0.8379	2.0832	18.692	15.662	38.938
21	LIB1	ring	0.8379	2.0831	18.711	15.677	38.975
22	LIB2	ring	0.8378	2.0830	18.713	15.678	38.980

by 2% (v/v) HNO_3 before measurements were taken. All the chemicals used in the dissolution were reagent grade (Merck, Germany) and the acids were double distilled. Deionized water from a Millipore system (Millipore, USA) was used for all dilutions. All solutions were stored in HDPE (Nalgene) bottles. The ICP-QMS analytical protocol and calibration strategy closely followed those described by Strnad *et al.*, 2007 and 2016. The analytical precision of the ICP-MS data for all the analysed elements ranged from 0.3% to 3% relative (*cf.* Table 2).

To determine provenance, the samples for lead isotopic analysis were dissolved in 5 ml of aqua regia (1:1 HNO_3 and HCl). Lead was separated using Sr-spec resin (Triskem) and ultrapure 6M HCl (Romil) as elution media. The isotopic analysis was performed using Neptune MC-ICP-MS (Thermo-Fisher Scientific). Samples were spiked with thallium reference material NIST SRM 997 and the mass bias was corrected with the generalized power law using 203Tl/205Tl = 0.418922 (Košler *et al.*, 2008). The lead isotopic data were corrected using the standard-sample bracketing approach relative to NIST declared values for the SRM 981 reference material. The baseline after wash was each under 0.0004 mV. Relative analytical precision of measurements by MC-ICP-MS are better than 0.005% (RSD) for 206Pb/207Pb and 208Pb/206Pb, and better than 0.01% for 206Pb/204Pb, 207Pb/204Pb and 208Pb/204Pb (*cf.* Table 3).
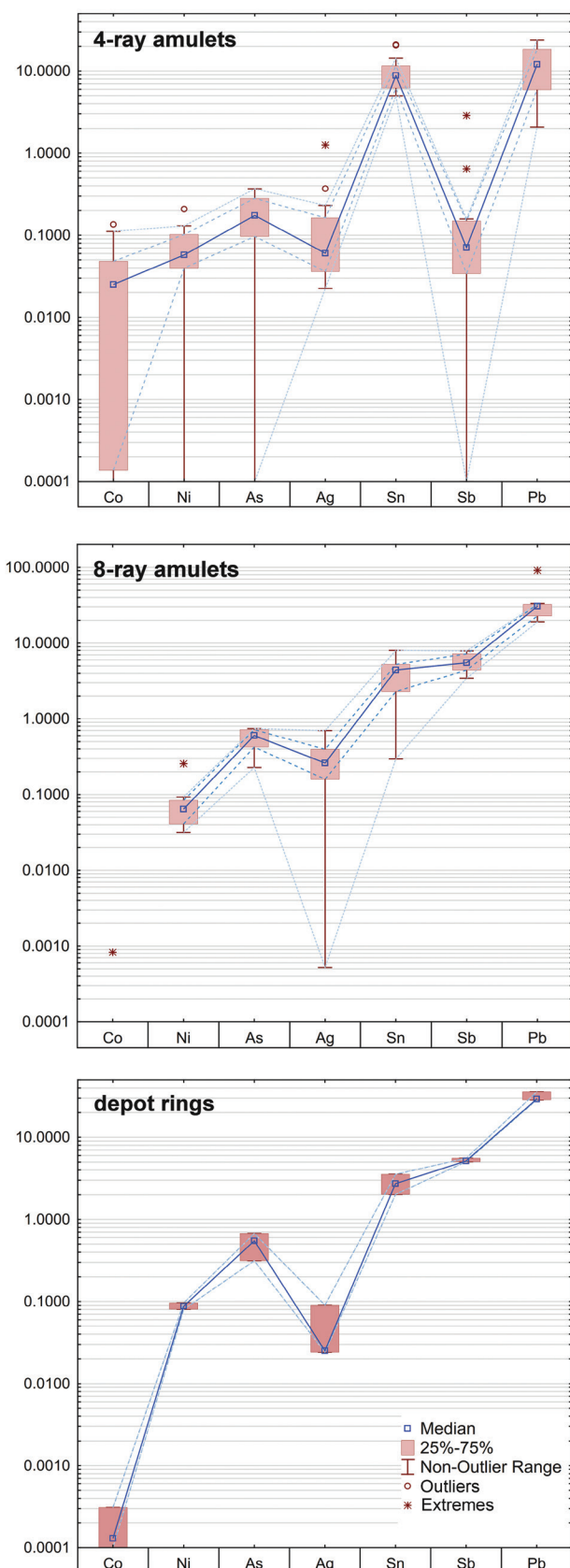
3. Results

### 3.1 Chemical composition – the alloy design

The ICP-MS analysis shows that the amulets are made of tin bronze that always contained at least 2% lead (Table 2). The alloy design was strongly connected to typology. Figure 4 shows the chemical profiles of the typological groups according to the main alloying components (except copper) and the minor and trace elements. The chemical composition of the four-spoked wheels and the materials used to make them are quite diverse; the chemical composition of the eight-spoked wheels and the rings is largely homogeneous. The small variations in the trace elements could be a result of the different origins of the copper in the alloys (no data on the origin of the copper is available). One significant feature of the eight-spoked wheels is the large amount of lead in the alloy, usually between 20% and 30%. A similar lead content was observed in the rings found with the coin hoards; one ring from Libčice contained 28% lead, the other ring 35%.

Another feature that clearly distinguishes the eight-spoked wheels from the four-spoked wheels is the high antimony content (4–8%) in the alloy, and higher readings of arsenic (around 0.5%) (Figure 5). Where the amount of antimony is higher, the tin content decreases proportionally.

Lead-antimony bronzes are not rare in prehistory (Frána *et al.*, 2009; Schwab, 2011). Higher amounts of antimony

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Figure 4. Variability plots of the chemical profiles of the minor and trace elements of the individual types of amulet/ring. The figure shows comparatively larger heterogeneity in the case of four-spoked wheels compared to the uniform designs of the eight-spoked wheels and rings with a rhombic section. Values log-normalized, given in %.
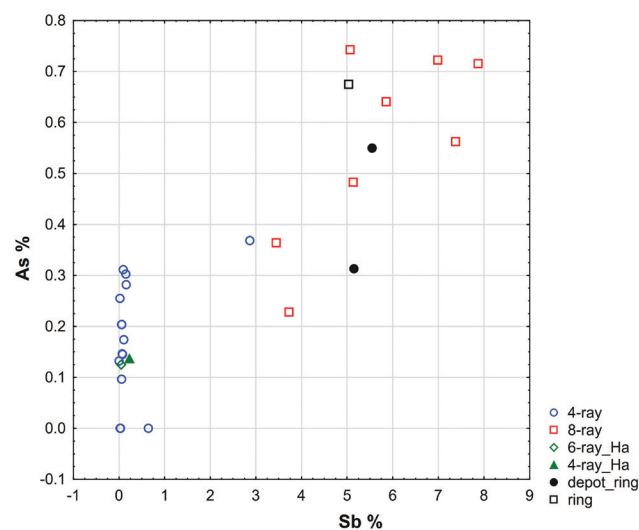
Figure 5. Differences in the alloy composition of the four-spoked and eight-spoked wheel amulets, showing the use of *fahlore* copper for the fabrication of the latter. Rings with a rhombic section were made from the same material, while the (possibly) Hallstatt period amulets from Závist have the same composition as the four-spoked amulets.

together with other characteristic trace elements (As, Ag, sometimes Ni) is attributed to tetrahedrites (commonly referred to as *fahlores*), a high-impurity copper used widely from the beginning of the Bronze Age (Frána *et al.*, 1997; 2009; Niederschlag *et al.*, 2003; Lutz and Schwab, 2014a; Schwab, 2014b; Nørgaard *et al.*, 2019). In the Czech lands, however, this copper becomes scarce after the early Bronze Age (Frána *et al.*, 1997; 2009).

An almost identical case to that described above is the oppidum of Manching (Figure 3b), where rings of the same shape and dimensions were part of a closure mechanism on a container holding a famous hoard of gold coins discovered in the 1990s (Zieghaus, 2013). The analytical values of the major and trace elements were normalized to 100%, but the proportions of the individual alloy components are basically the same as those in the Libčice hoard. In Bavaria, the appearance of an alloy where antimony appears to replace tin is recorded from LT C2 (*i.e.* 2nd century BC) onwards. The presence of antimony as a regular admixture in late La Tène alloys has been observed in numerous types of objects: wheel amulets, belt fittings, ring beads, mirrors, and small figural works of art (Schwab, 2014b). Further west, the antimony was frequently present in bronze-cast coins, the potins (Burkhardt *et al.*, 1994; Haselgrove, 1999; Schwab, 2014b) which circulated widely in Gaul, Belgium, and Britain. It is interesting that in Bohemia and Moravia this alloy has so far been detected only in amulets and rings which served a particular function.

The eight-spoked amulet from Měrovice (MĚ 177.916), found using a metal detector, was exceptional in being almost completely made of lead (91%), plus an admixture of antimony (ca. 7%). Such an alloy is highly unusual, although lead amulets are reported from Germany (Schwab, 2014b). Lead is a soft metal, so antimony could improve

the mechanical properties, or give an item a more silver-like appearance, but the precise reasons for alloying lead with antimony are unknown. The Měrovice case suggests that antimony could have been added to the alloy as a standalone component and not as part of the *fahlore*. Antimony is a grey metalloid and ores are recognizable by their silvery appearance. Antimony usually forms its own minerals (*e.g.* stibnite or pyrargyrite) or can be bound in, for example, an arsenopyrite and/or tetrahedrite structure (*e.g.* Andráš *et al.*, 2010). The processing of antimonite ores was not demanding from the technological point of view as its melting point is 630.6°C (stibnite, the most typical antimony sulphide, has a melting point of 546°C). Antimony mineralization and deposits across central Europe (*cf.* Figure 2) include western Slovakia and the Low Tatra mountains (Andráš *et al.*, 2010), the Rhineland (Wagner and Schneider, 2002), the eastern Alps, and a significant occurrence in the Massif Central (Négrel *et al.*, 2019). Other minor occurrences include the Erzgebirge area, the central part of the Bohemian Massif, and throughout the Alps. Antimony can also be a by-product of copper and silver mining and non-placer gold exploitation. Antimony (Sb-Au mineralization) was intensively mined near Krásná Hora nad Vltavou in central Bohemia until 1991 (Němec and Zachariáš, 2018). An elite La Tène settlement in the surrounding area included finds of bronze objects (including a four-spoked wheel) containing large amounts of antimony (Bursák *et al.*, forthcoming). It is highly probable that these objects were manufactured on site using local raw materials. Knowledge of the occupation of this region could be key to discovering more about the history of the use of antimonite in late La Tène metallurgy.

Antimony-lead alloys are also typical in commercial applications in modern times. It is used as the cast metal for grids and terminals in lead-acid storage batteries, in which the antimony content can reach 8%, with about 0.25% tin and small amounts of arsenic, copper, and silver. The Měrovice sample trace element readings are 0.1% Cu, 0.18% Zn, 0.5% As, and 0.3% Sn, so a modern origin (despite its authentic appearance) is plausible and the interpretation must be treated with caution. Lead isotopic ratios plot this object as an outlier, but within the linear distribution of other samples and close to the isotopic signature of amulets from Wallendorf (see 3.2, Figure 6).

All the other samples with a significant amount of antimony are typical of *fahlores*. Apart from typical deposits of fahlore coppers from the Alpine area and Slovakian Ore Mountains (Nørgaard *et al.*, 2019), several tetrahedrite samples were analysed from the Příbram area in central Bohemia (Frána *et al.*, 2009). This area also bears evidence of late La Tène occupation with tentative attempts to link it to metallurgical activities (Waldhauser *et al.*, 2010).

3.2 Lead isotopes: Provenance
The high lead content in the alloys means each deposit-oriented investigation can only indicate the origin of the added lead. The lead content obscures the Pb isotope signature of the copper in the alloy and thus only the source of the galena can be traced. In the case of recycling, that is, the addition of another lead source, a mixture of the lead added to the new alloy is produced. Both phenomena can be observed in this assemblage (Figure 6).

Unfortunately, a solid corpus of comparative data for the Iron Age is still lacking. Questions of provenance are very
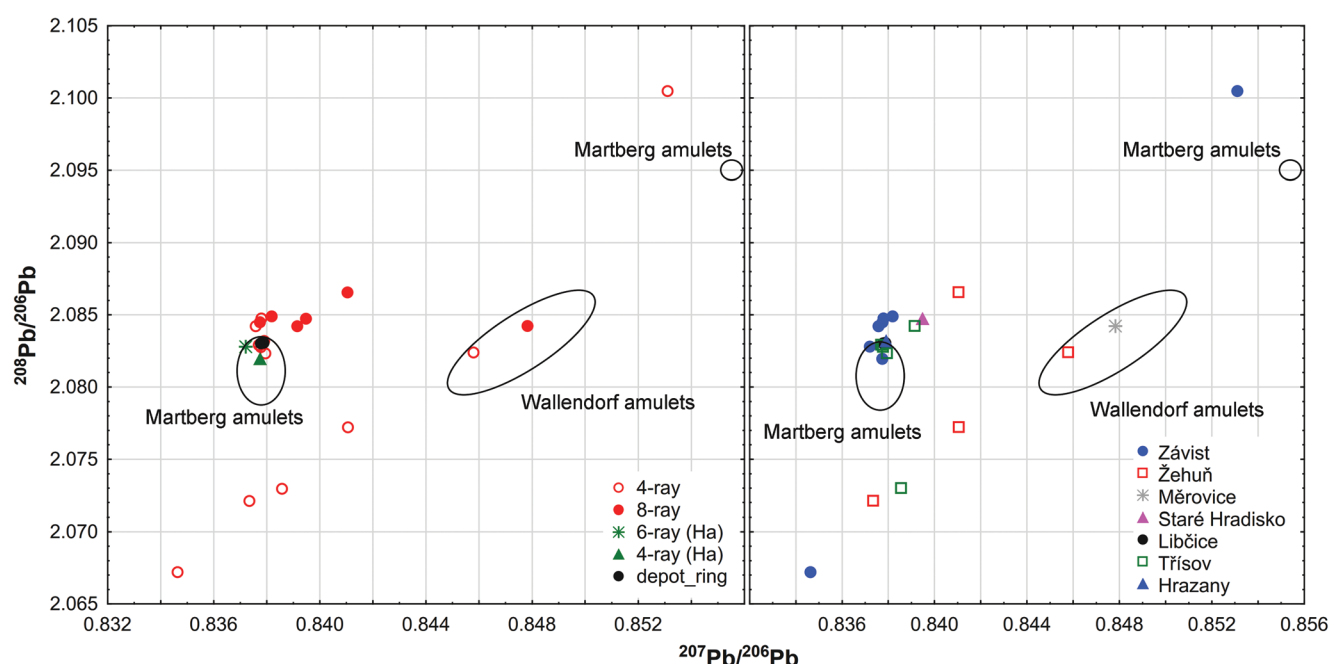
Figure 6. Lead isotopic ratios of the amulets with analysed analogies from Germany (after Schwab, 2014b). The data show the homogeneity of the lead in the eight-spoked wheels compared to the four-spoked wheels which visibly scatter along the line below, which suggests a mixing of sources within different deposits.

Figure 7. Lead isotopic ratios of the amulets projected against known deposits in Germany, Bohemia, Spain, and the Alps. The values do not show an exact match with any of the deposits, but rather suggest a mixing of the Spanish lead with other sources in the case of the eight-spoked wheels, some of the four-spoked wheels, and both of the rings from Libčice. The four-spoked wheels are on the mixing line below and suggest local sources, possibly from the German Mittelgebirge area and the Erzgebirge. Background data from: Bielicki and Tischendorf, 1991; Bode, 2008; Brauns, 1995; Durali-Müller, 2005; Krahn and Baumann, 1996; Lehman, 2011; Leveque and Haack, 1993; Niederschlag *et al.*, 2003; Durali-Müller *et al.*, 2007; Tischendorf *et al.*, 1992; Zwicker *et al.*, 1991; Legierski and Vaněček, 1967; Cattin *et al.*, 2011; Pernicka *et al.*, 2016; Höppner *et al.*, 2005; Artioli *et al.*, 2016; OXALID; Arribas and Tosdal, 1994; Domerque *et al.*, 2012; Hunt-Ortiz, 2003; Klein *et al.*, 2007; Klein *et al.*, 2009; Marcoux *et al.*, 1992; Stos-Gale *et al.*, 1995; Santos Zalduegui *et al.*, 2004; Tornos and Chiaradia, 2004; Trincherini *et al.*, 2001; Trincherini *et al.*, 2009; Velasco *et al.*, 1996.
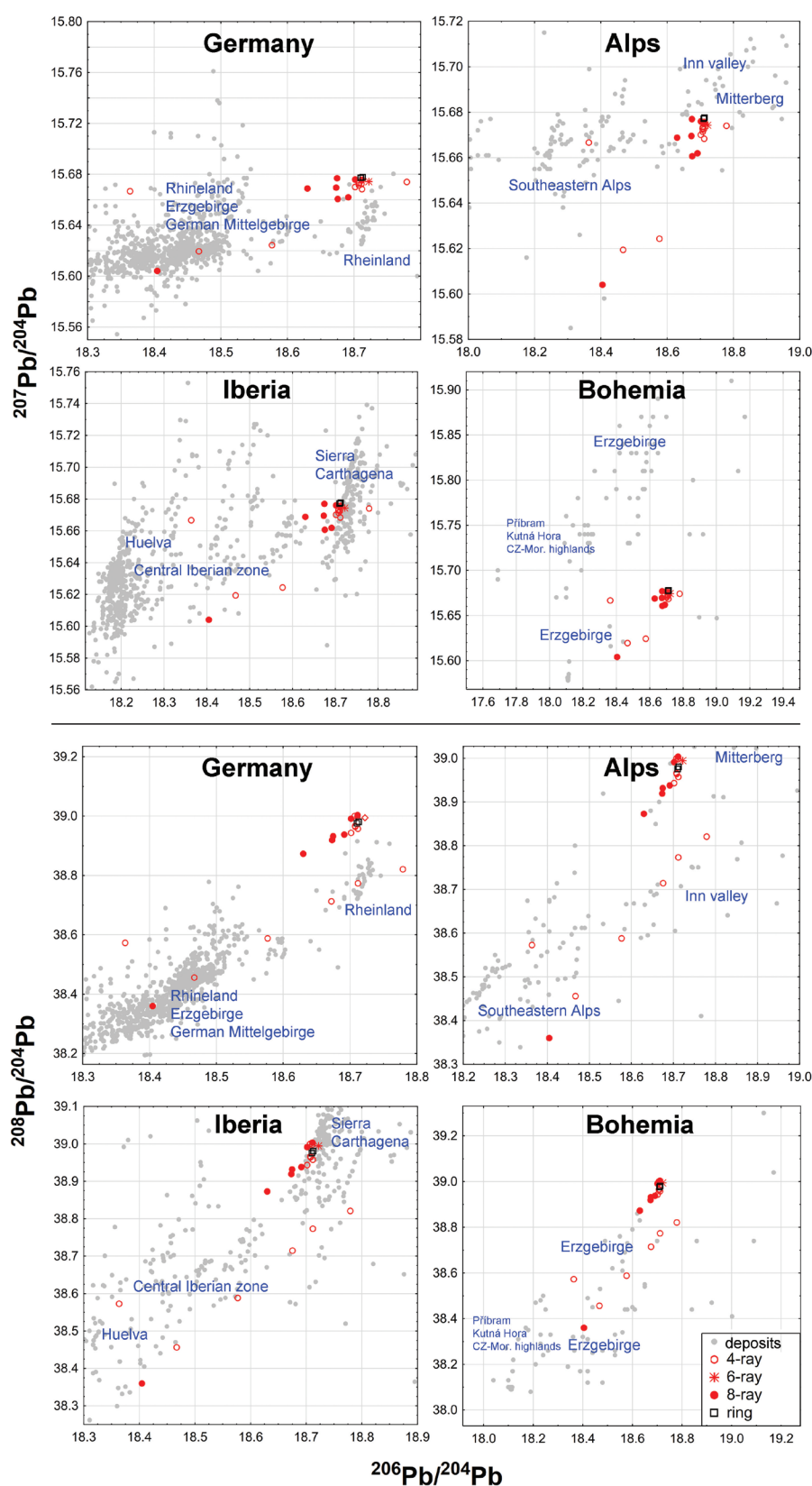
difficult to answer as large mining areas in Europe, such as Mitterberg, had already served their time and were replaced by numerous smaller areas, whose importance for the Iron Age is yet to be adequately assessed (Schwab, 2014b).

Because the amulets were found at settlements with proven connections with other regions, such as Spain, and because of the availability of existing research (*cf.* Danielisová *et al.*, 2018b; Schwab, 2014b), comparison was made with known

deposits in the Czech Republic, the German Mittelgebirge zone (central and southern Germany), the Alps, and Iberia.

From the distribution of the lead isotope ratios, we can make the following observations:

1) The Pb ratios of eight-spoked wheels and rings with a rhombic section are very homogeneous and confirm the results of the chemical composition analysis. Both of the amulets from Závist, dated to the Hallstatt period (ZAV7, ZAV8) plot in this group, which suggests a later dating. The four-spoked wheels scatter along the line below the first group, which suggests a mixing of sources within different deposits (Figure 6).

2) The Pb ratios are also quite consistent with the origin of the amulets. The eight-spoked wheels from Závist, Staré Hradisko and Třísov have similar ratios to the amulets from Martberg (Schwab, 2014b). This suggests a super-regional system which has already been postulated for the late Iron Age supply of metal to the oppida (Danielisová *et al.*, 2018b). The four-spoked wheels plot within the trend of the amulets from Wallendorf, for which a mixing of local (*i.e.* German or Bohemian) sources of lead has been suggested (Schwab, 2014b). The Variscan deposits in the Rhineland, German Mittelgebirge zone or the Erzgebirge (which connect the German and Bohemian objects) can also be considered.

3) The eight-spoked wheels do not greatly overlap any of the predicted deposits (Figure 7). The data show that they are closest to the deposits in southeast Spain (Sierra Cartagena, Murcia, Almería), but not close enough for 100% certainty. The same observation was made with the amulets from Martberg, where a mix of various Spanish lead sources was suggested (Schwab, 2014b). The Pb ratios of the four-spoked wheels, on the other hand, do not seem to be a result of mixing Spanish lead with local geologically older deposits as was suggested for Germany (Schwab, 2014b).

4. Discussion

The use of a high-impurity copper for the production of particular objects, in this case eight-spoked wheel amulets and rings with a rhombic section, may or may not have been a result of requirements for a specific alloy design. It has been suggested that the alloy was designed for the resulting colour: leaded bronze is usually a golden-yellowish colour (Devogelaere, 2017); adding antimony would yield a more silver-like appearance (Schwab, 2014a). *Fahlore* copper with arsenic and antimony has similar properties to tin-rich bronzes: arsenic and antimony can replace part of the tin in the δ eutectoid or form their own intermetallic phases such as Cu_4Sb and Cu_3As. Experiments have shown that the colour spectrum of these alloys is red-brown to gold depending on the antimony and tin content, but that the surfaces are silver-coloured in all cases as a result of inverse ingot segregation after casting (Schwab, 2014b). The alloy composition

does not have ideal mechanical properties (Northover, 2004), which is perhaps why it was used only for smaller decorative objects such as rings, belts, beads and mirrors, and the amulets (Schwab, 2014a). Schwab (2014a) has also suggested that antimony replaced tin in the more expensive alloys – used for mirrors and bronze potin coins – to produce an imitation of silver or a high-tin bronze called *speculum*.

It is yet to be established whether the *fahlore* copper and antimonite were used because of a shortage of tin caused by the repeated recycling of objects, a scarcity of raw materials caused by disruption to the supply, as has been suggested for Bavaria (Schwab, 2014a), or because minerals were available which gave the alloys the desired visual properties. The items from Bohemia show that antimony did not replace tin entirely, but formed another component of the alloy. Evidence of antimony in copper-free objects (Měrovice) and in the area bearing antimony deposits (the region around Krásná Hora nad Vltavou) may also suggest the use of antimony minerals as standalone components, although evidence of the use of *fahlores* also exists.

The common occurrence of antimony bronzes at Manching (Schwab, 2014a), where the antimony content reaches as high as 10%, suggests that it is an intentional alloy. The use of fahlores in Bavaria is seen as evidence of the widespread smelting of local ores from deposits in the Alps and the German Mittelgebirge zone as *fahlores* are not observed in the analysis of Mediterranean alloys from the same period (Schwab, 2014b). However, in Bohemia, *fahlores* were not used past the Bronze Age (Niederschlag *et al.*, 2003; Frána *et al.*, 1997; 2009; Danielisová *et al.*, in print). For this reason, it becomes significant that (with exceptions, *cf.* 3.1) no objects in Bohemia apart from the eight-spoked wheels and the rings found with the coin hoards were made using *fahlores*. This naturally raises the question as to whether this phenomenon is a result of deliberate alloying reserved for particular objects or is a matter of provenance. The latter would lead us to expect the movement of amulets and rings (bound to their owners or in the form of raw material) with the *fahlore* signature from Bavaria to sites in Bohemia and Moravia. Local production would thus become pointless, but the great spread of amulets across different social groups (oppida and the countryside) would suggest either a high level of mobility or the need to reconsider the possibility of local production. When comparing mutual ratios of the selected elements (Figure 8), which show two different rates of depletion of As and Sb relative to Ag, it is clear that it is not the typology but the site that is consistent with the pattern of trace elements. This suggests that the amulets were not produced at a single location, but that at each different site the alloy design particular to each product was always maintained. It may also suggest that each major settlement had its own network of contacts who brought amulets in from particular production sites (the clearest division is that between Závist and Třísov oppida). Site specificity also appears distinctive with respect to Pb isotope ratios (Figure 6).

The rings bearing a rhombic section are similar to the eight-spoked amulets in both chemical composition and Pb
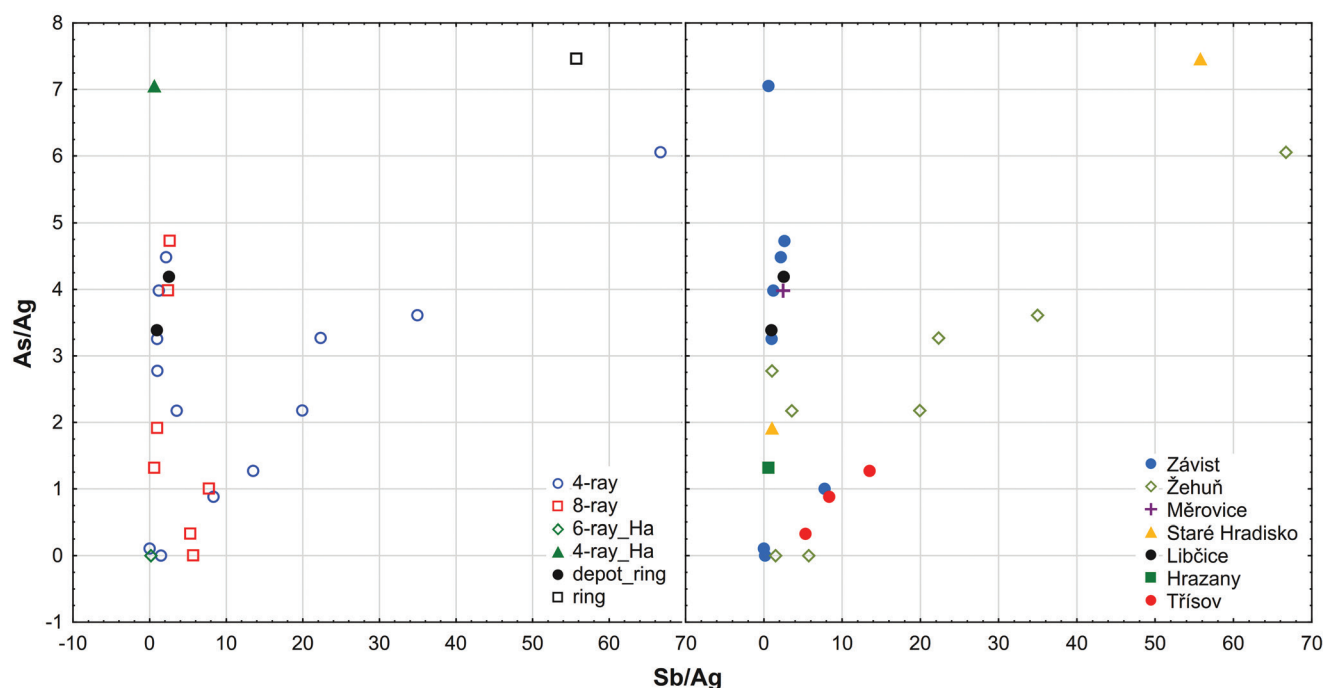
Figure 8. The common denominator (Ag) of the x-axis and y-axis gives rise to a dual linear trajectory showing two trends in the chemical composition. These trends are dependent not on the type of amulet but on the site. This suggests that individual settlements might have been involved in producing their own amulets using different kinds of copper but following the required alloy design. The two linear trajectories could also suggest binary mixing of (yet) unknown end-members.

isotopes (Figure 3b). Such rings were often used as closure systems on organic containers holding coin hoards. A similar bronze ring was found in a depot at Lauterach in the Vorarlberg (Pauli, 1991) and two bronze rings are also reported in the context of the Starý Kolín coin hoard in Bohemia (Militký, 2018). Regarding provenance, it may be significant that coins found in the Libčice hoard were of Thuringian and Bavarian origin, which could explain the use of *fahlore* copper to make the closure rings. A similar explanation can be suggested in the case of Lauterach, not far from Bavaria, in an area of Alpine deposits that also contained *fahlores*. The Starý Kolín hoard on the other hand contained only coins of local, *i.e.* Boian, origin. The composition of the bronze rings from Lauterach and Starý Kolín is unknown. The numerous rings with a rhombic section from Manching (van Endert, 1991) and Staré Hradisko (SH 136) may suggest that the rings were produced at the oppida and were a typical part of the local material culture. Those found with the coin hoards are the only rings whose chemical composition was analysed. The fact that exactly the same alloy was used for the rings and the amulets also suggests that not only the type and shape of an object but also the processes used in its manufacture played a significant role in the ritual life of the late Iron Age.

5. Conclusion

Spoked-wheel amulets are an interesting aspect of the material culture of the middle and especially the late La Tène period. They were used as personal jewellery, possibly with a specific function as a symbol of the Sun. There were various designs, but two basic types prevailed: four-spoked wheels (with numerous sub-variations) and eight-spoked wheels (with few or no variations). It was the latter group that proved interesting with respect to archaeometric analysis and this was because of their specific alloy design. The elevated concentrations of arsenic, silver and especially antimony led to the conclusion that they were made using *fahlore* copper. The use of *fahlores* is almost unknown in Iron Age Bohemia and Moravia but common in Germany (the oppida of Manching and Martberg specifically), where it was used for amulets and other items, perhaps where a silvery appearance was required. Interestingly, the only objects for which the use of *fahlore* copper was detected in Bohemia were these particular types of amulet. More interesting still was the discovery of the same composition in the bronze rings that served as a closing mechanism for sacks containing coin hoards. This all naturally gave rise to questions about the provenance and origin of this alloy design, which according to the lead isotopes is also highly homogeneous. The lead used in the eight-spoked wheels and the closure rings has a common source. It was possibly a mixture of Spanish lead brought to the Transalpine areas as part of the extensive trade in metals which probably involved most of the oppida and other major sites in central Europe (*cf.* Danielisová *et al.*, 2018b; Schwab, 2014b).

The eight-spoked wheels and the rings with a rhombic section may be part of a well-organized production system as they feature Spanish lead but were made locally using *fahlore* copper (and perhaps antimonite). The reasons

behind the choice of materials might have been: (a) purely practical (the availability of raw materials at a specific location); (b) aesthetic (the silvery appearance of the alloy); (c) technological (better workability); or even (d) symbolic (the exact number and ratios of the individual components).

We can create a picture of the wearers of these amulets, who travelled from the oppida in the western part of central Europe where Spanish lead and *fahlore* copper were routinely processed. We can also draw a picture of the special materials being imported to the places of production based on the particular demands of the alloy design. Last, but not least, we can envision locally exploited *fahlores* and antimonites being processed. All three hypotheses are equally plausible but (perhaps excepting the last of the three) lack direct supportive evidence.

Unlike the eight-spoked wheel amulets, the four-spoked wheels show great diversity in their chemical composition and lead isotopes, and these are mostly compatible with their places of origin, thus reflecting local production. It appears that no particular rules were followed when producing these objects. It is perhaps safe to say that unlike the eight-spoked wheels, the four-spoked wheels, which are similar in their symbolism but more "free-hand" in their execution, were a true part of the late La Tène "pop culture".

Acknowledgments

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