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

Alžběta Danielisová*a, Daniel Bursák*, Ladislav Strnadb, Jakub Trubačb,
Hana Čižmářová*, David Daněčekac, Kamil Smišek*

*aInstitute of Archaeology CAS, Prague, Letenská 4, 118 01, Prague 1, Czech Republic
bInstitute of Geochemistry, Mineralogy and Mineral Resources, Faculty of Science, Charles University, Albertov 6, 128 43, Prague 2, Czech Republic
cStředočeské muzeum v Roztokách u Prahy, Zámek 1, 252 63, Roztoky, Czech Republic
dMoravské zemské muzeum, Archeologický ústav, Zelný trh 6, 659 37, Brno, Czech Republic

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; Pič, 1903).

In central Europe, a significant concentration was observed at the oppidum of Stradonice (Figure 1; Pič, 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 (Čižmárová, 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 (Čižmárová, 2014). The basic and typologically most homogeneous group comprises the eight-spoked wheels.
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 1. Types of wheel amulet from the La Tène period (the oppidum of Stradonice), after Plč, 1903.

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\textsubscript{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\textsubscript{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     | Trísov   | oppidum    | 4-ray          |
| 14  | A33041-01  | Trísov   | oppidum    | 4-ray          |
| 15  | A33162     | Trísov   | oppidum    | 4-ray          |
| 16  | ZAV7       | Závist   | hallstatt hillfort | 4-ray   |
| 17  | ZAV8       | Závist   | hallstatt hillfort | 4-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  | Trísov   | oppidum    | 8-ray          |
| 25  | A33164     | Trísov   | 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 % | Zn % | As % | Sn % | Bi ppm | Total % | Analytical total % | 4-ray |
|-----|------------|----------------|------|------|------|------|------|--------|----------|-------------------|-------|
| 1   | ZAV1       | 4-ray          | 0.02  | 0.07 | 0.13 | 0.04 | 0.02 | 0.02   | 90.19    | 100 65.90         |
| 2   | ZAV2       | 4-ray          | 0.03  | 0.03 | 0.30 | 0.04 | 0.06 | 0.09   | 97.43    | 100 84.04         |
| 3   | ZAV5       | 4-ray          | 0.03  | 0.03 | 0.50 | 0.04 | 0.06 | 0.09   | 97.43    | 100 84.04         |
| 4   | ZAV6       | 4-ray          | 0.03  | 0.03 | 0.50 | 0.04 | 0.06 | 0.09   | 97.43    | 100 84.04         |
| 5   | ZAV7       | 4-ray          | 0.03  | 0.03 | 0.50 | 0.04 | 0.06 | 0.09   | 97.43    | 100 84.04         |
| 6   | ZAV8       | 4-ray          | 0.03  | 0.03 | 0.50 | 0.04 | 0.06 | 0.09   | 97.43    | 100 84.04         |
| 7   | ZAV9       | 4-ray          | 0.03  | 0.03 | 0.50 | 0.04 | 0.06 | 0.09   | 97.43    | 100 84.04         |
| 8   | ZAV10      | 4-ray          | 0.03  | 0.03 | 0.50 | 0.04 | 0.06 | 0.09   | 97.43    | 100 84.04         |
| 9   | ZAV11      | 4-ray          | 0.03  | 0.03 | 0.50 | 0.04 | 0.06 | 0.09   | 97.43    | 100 84.04         |
| 10  | ZAV12      | 4-ray          | 0.03  | 0.03 | 0.50 | 0.04 | 0.06 | 0.09   | 97.43    | 100 84.04         |
| 11  | ZAV13      | 4-ray          | 0.03  | 0.03 | 0.50 | 0.04 | 0.06 | 0.09   | 97.43    | 100 84.04         |
| 12  | ZAV14      | 4-ray          | 0.03  | 0.03 | 0.50 | 0.04 | 0.06 | 0.09   | 97.43    | 100 84.04         |
| 13  | ZAV15      | 4-ray          | 0.03  | 0.03 | 0.50 | 0.04 | 0.06 | 0.09   | 97.43    | 100 84.04         |
| 14  | ZAV16      | 4-ray          | 0.03  | 0.03 | 0.50 | 0.04 | 0.06 | 0.09   | 97.43    | 100 84.04         |
| 15  | ZAV17      | 4-ray          | 0.03  | 0.03 | 0.50 | 0.04 | 0.06 | 0.09   | 97.43    | 100 84.04         |
| 16  | ZAV18      | 4-ray          | 0.03  | 0.03 | 0.50 | 0.04 | 0.06 | 0.09   | 97.43    | 100 84.04         |
| 17  | ZAV19      | 4-ray          | 0.03  | 0.03 | 0.50 | 0.04 | 0.06 | 0.09   | 97.43    | 100 84.04         |
| 18  | ZAV20      | 4-ray          | 0.03  | 0.03 | 0.50 | 0.04 | 0.06 | 0.09   | 97.43    | 100 84.04         |
| 19  | ZAV21      | 4-ray          | 0.03  | 0.03 | 0.50 | 0.04 | 0.06 | 0.09   | 97.43    | 100 84.04         |
| 20  | ZAV22      | 4-ray          | 0.03  | 0.03 | 0.50 | 0.04 | 0.06 | 0.09   | 97.43    | 100 84.04         |
| 21  | ZAV23      | 4-ray          | 0.03  | 0.03 | 0.50 | 0.04 | 0.06 | 0.09   | 97.43    | 100 84.04         |
| 22  | ZAV24      | 4-ray          | 0.03  | 0.03 | 0.50 | 0.04 | 0.06 | 0.09   | 97.43    | 100 84.04         |
| 23  | ZAV25      | 4-ray          | 0.03  | 0.03 | 0.50 | 0.04 | 0.06 | 0.09   | 97.43    | 100 84.04         |
| 24  | ZAV26      | 4-ray          | 0.03  | 0.03 | 0.50 | 0.04 | 0.06 | 0.09   | 97.43    | 100 84.04         |
| 25  | ZAV27      | 4-ray          | 0.03  | 0.03 | 0.50 | 0.04 | 0.06 | 0.09   | 97.43    | 100 84.04         |
| 26  | ZAV28      | 4-ray          | 0.03  | 0.03 | 0.50 | 0.04 | 0.06 | 0.09   | 97.43    | 100 84.04         |
| 27  | ZAV29      | 4-ray          | 0.03  | 0.03 | 0.50 | 0.04 | 0.06 | 0.09   | 97.43    | 100 84.04         |
| 28  | ZAV30      | 4-ray          | 0.03  | 0.03 | 0.50 | 0.04 | 0.06 | 0.09   | 97.43    | 100 84.04         |
by 2% (v/v) HNO₃ 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 HNO₃ 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).

### 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 206Pb in the denominator and better than 0.03% with 204Pb in the denominator.

| Id. | Inv. number | Type of amulet | 206Pb/204Pb | 208Pb/204Pb | 206Pb/207Pb | 207Pb/204Pb | 208Pb/206Pb |
|-----|-------------|----------------|--------------|--------------|--------------|--------------|--------------|
| 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 | 18.643 | 15.669 | 39.119 |
| 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 |

### 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...
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
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, Almèria), 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). Fahllore 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,Sb and Cu,As. 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 fahl ores 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 fahl ores in Bavaria is seen as evidence of the widespread smelting of local ores from deposits in the Alps and the German Mittelgebirge zone as fahl ores are not observed in the analysis of Mediterranean alloys from the same period (Schwab, 2014b). However, in Bohemia, fahl ores 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 fahl ores. 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 fahl 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
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 Kolin 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 Kolin hoard on the other hand contained only coins of local, i.e. Boian, origin. The composition of the bronze rings from Lauterach and Starý Kolin 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 Marbing 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 fahlores 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”.

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