Circulation Patterns of Copper-Based Alloys in the Late Iron Age *Oppidum* of Třísov in Central Europe

Alžběta Danielisová, Ladislav Strnad and Martin Mihaljevič

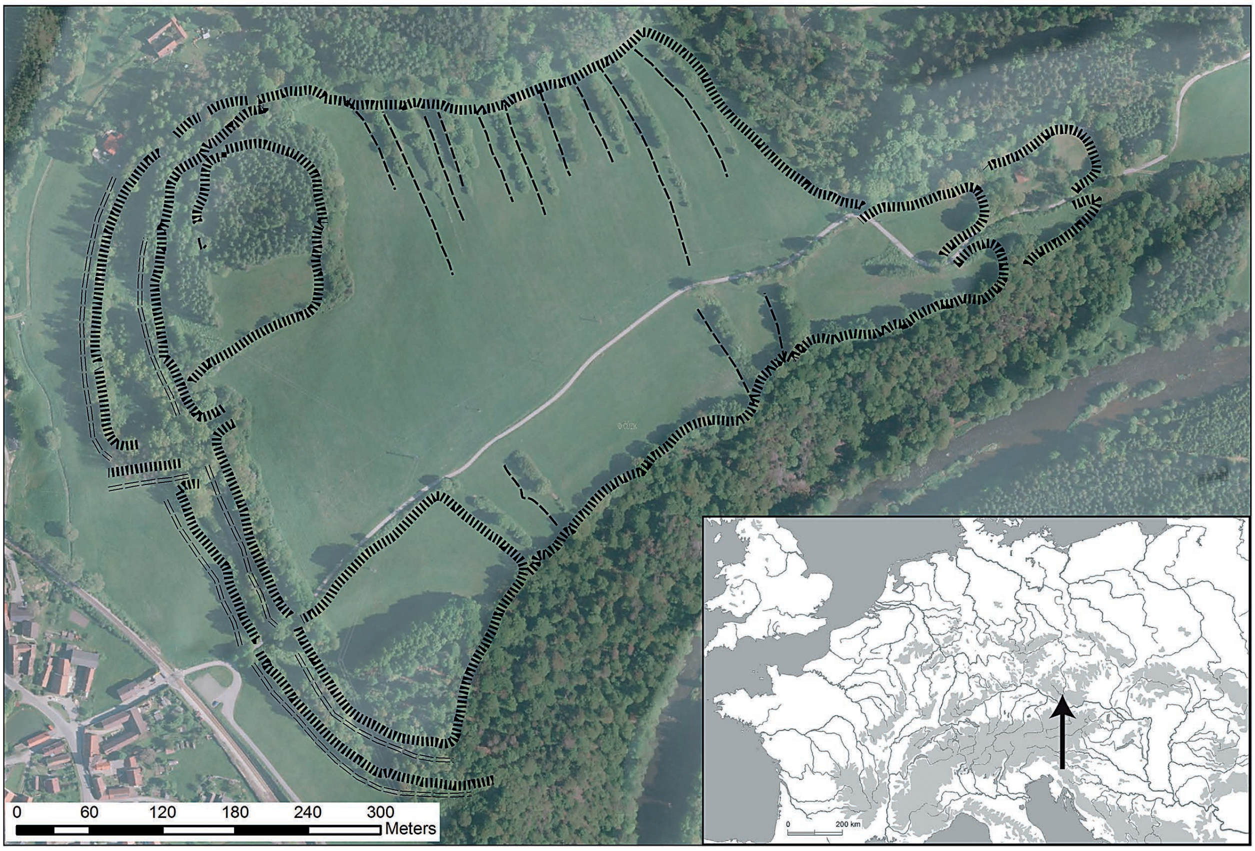
Keywords

Late Iron Age, *oppida*, copper alloys, provenance, lead isotopes

Abstract

This article presents an insight into the sourcing and circulation of copper alloys during the Late La Tène period in Central Europe where the specialised production of metals is regarded as complex and conducted chiefly within the bounds of the *oppida*. Contrary to the logical, though not necessarily data-based, assumption that local raw materials for the production of bronze were mostly used from the local primary deposits, we argue that an advanced and complex economy of Late Iron Age allowed for the steady and consistent material supply even from distant areas and that such pattern was possibly commonly practised by the *oppida* sites. Concurrently, we do not argue against the possibility of the exploitation and processing of the locally mined metal, we only point out that in provenance studies the evidence for that is yet difficult to find. We back our hypothesis by archaeometric analysis of the assemblage of bronze objects from the *oppidum* of Třísov (Czech Republic) collected during the long-term investigations of this site. The selection of objects for analyses covers the spectrum from the local

Figure 1. *Oppidum* of Třísov in Southern Bohemia. Graphics: A. Danielisová.



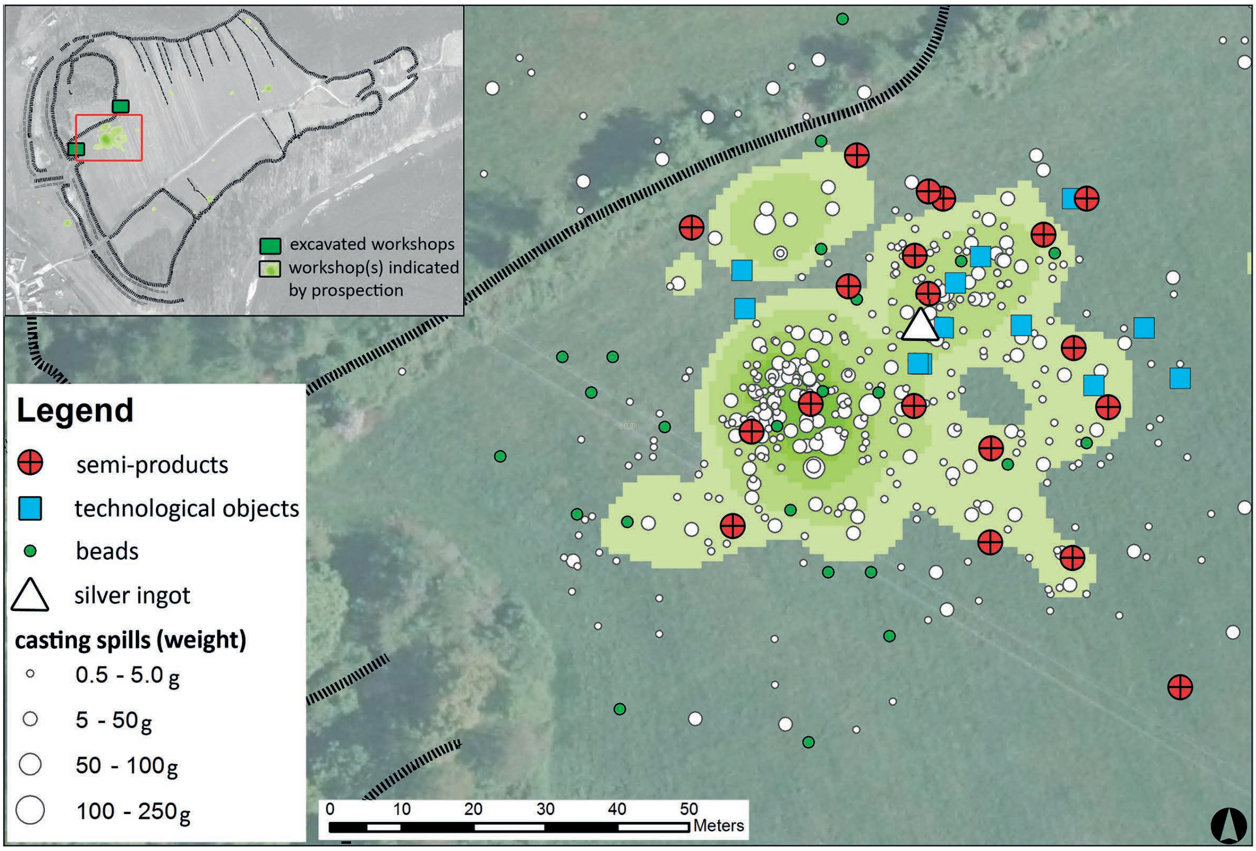


Figure 2. Position of the 'craft district' below the North acropolis of the Třísov oppidum. Graphics: A. Danielisová.

products to potentially imported items. A provenance study based on the analysis of lead isotopes and chemical composition has shown rather homogeneous pattern of lead isotopic values and, on the contrary, quite a variability among the chemical composition of the individual artefact groups suggesting thus 1) standardised technological procedures for individual types of objects, 2) common recycling of the materials used and/or 3) contamination of low-leaded alloys from highly leaded bronzes.

Introduction

There are quite numerous studies on the provenance and metallurgy of the copper and its alloys in periods from the beginnings of metallurgy or from the specific areas like Mediterranean or the Alps, however, the case for Late Iron Age (2nd - 1st century BC) remains largely obscure. For decades there was an assumption that primarily local deposits were exploited and the proximity to sources of polymetallic ores significantly influenced the settlement network. However, there is no evidence among, now quite abundant, material assemblages of how the copper, tin, or lead were exploited or economically managed; there is only evidence of very intensive and well organised local bronze working. The *oppida* are widely perceived as developed cosmopolitan centres with long distance economic networks that made possible imports of various materials from even very distant areas; a well-documented trade in raw glass imported from the Eastern Mediterranean is a good example of this (cf. Roymans, et al., 2014, pp. 223-225; Venclová, 2016, pp.116-118).

In this contribution, we would like to draw attention to the outcomes of the analyses of non-ferrous metal artefacts assembled during the long-term surface prospections of the South Bohemian *oppidum* of Třísov (Figure 1).

The surveys have produced more than three thousand metal objects that have significantly expanded the existing inventory of finds, curiously though, no evidence regarding the procurement of the raw or fresh metals was discovered. This naturally raises the question of the metal supply pattern of this site that, due to this exceptional abundance of finds, indeed constitutes a 'metallic site': a rich settlement with numerous evidence of an intensive local bronze working and circulation of prestige objects obtained through the long distance trade. Several specialised workshops have been discov-

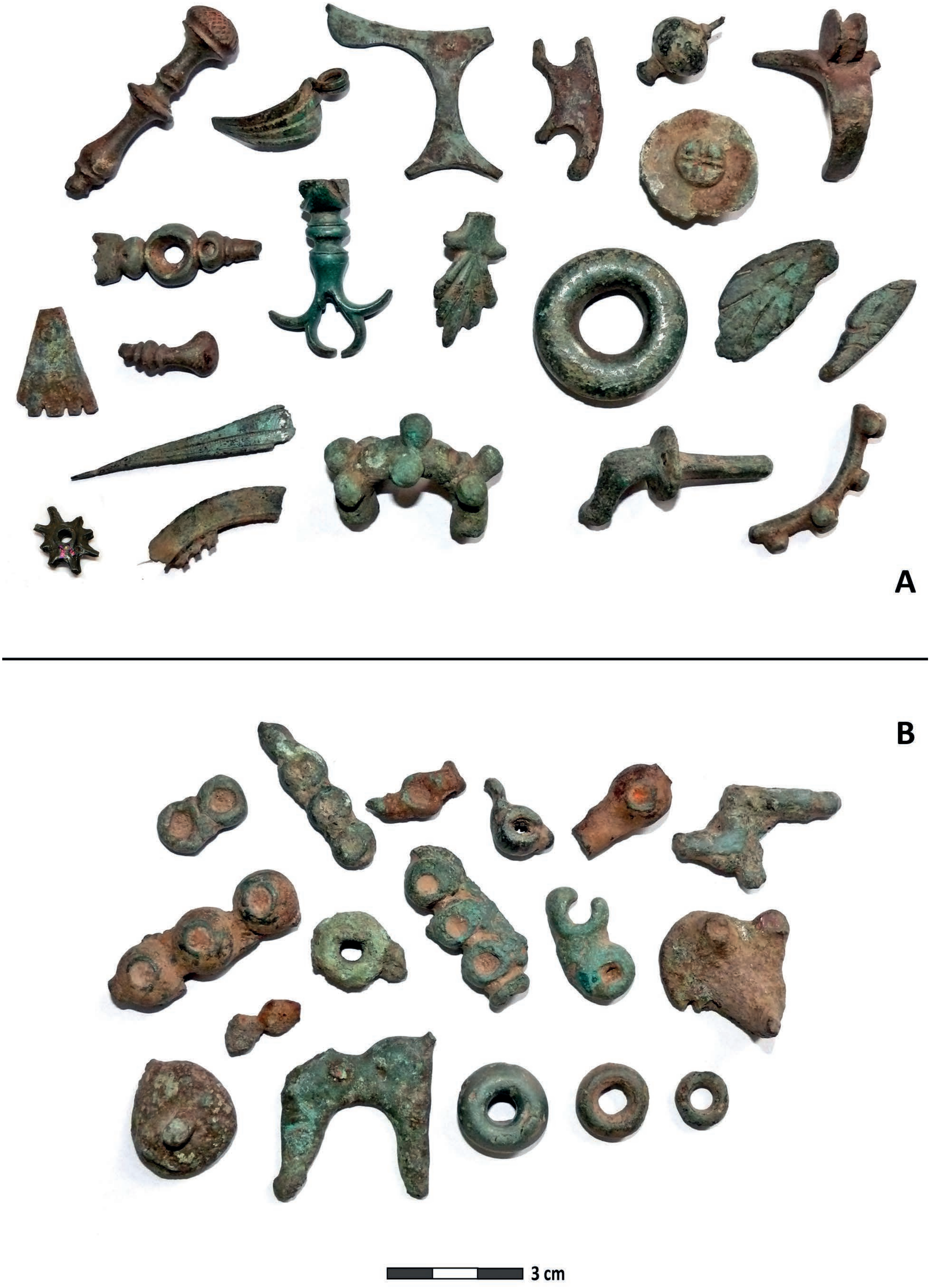


Figure 3. Selection of finds from Třísov that have been subjected to geochemical analyses (A: jewellery, amulets, republican vessels, various fittings; B: *chaîne opératoire* finds from the workshop below the North acropolis). Photo: A. Danielisová.

ered during both excavations and prospections forming an actual 'craft district' known so far only from the *oppida* sites, such as Manching or Bibracte (Figure 2).

Due to this abundance and range of finds, the Třísov *oppidum* represents a good medium for studying the local practices of the metallurgy of copper alloys that may also cast new light on the nature of the specialised production and raw materials supply patterns of the Late Iron Age period in Central Europe.

Methodology

Analyses of chemical composition and provenance analyses through lead isotopic ratios have been conducted on the total assemblage including artefacts, casting spills and technological objects (casting waste and semi-products) (Figure 3). Typically, they should reveal routine treatment of the copper, tin and lead alloys by specialised workers that have included range of various objects.

The selection of samples aimed to represent each major category of artefacts found at Třísov: 'imports' (mostly Roman republican bronze ware, mirrors, jewellery etc.), 'production' (semi-products, technological objects, finished products - beads), 'brooches' (Nauheim, Almgren 65, Mötschwil) and other personal objects (belt fittings), spoked wheels (amulets), bronze spur, and small 'figural' art (cf. Kysela, Danielisová and Militký, 2014, p.574). For comparative reasons more than one object per category has always been selected. Altogether 72 objects from Třísov were analysed for their chemical composition and lead isotopic signatures. The analyses were conducted on drilled corrosion-free samples in order to obtain data from the original metal core of the objects.

The bulk chemical composition was determined following procedures employed for the samples, which are given elsewhere (Ettler, Červinka and Johan, 2009). The decomposition in mineral acids (HCL/HNO_3) were used for determination of Ag, As, Bi, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, Sb, Sn, Zn by ICP-QMS (XSeriesII ThermoScientific Bremen, Germany). For the purpose of this study, two lead isotopic ratios then were considered: $^{207}Pb/^{206}Pb$ and $^{208}Pb/^{206}Pb$. The Pb isotopic ratios have been determined by ICP-QMS in solutions diluted to 20 µg/L (Pb) following the analytical procedures given elsewhere (Ďurišová, et al., 2015, Ettler, Mihaljevič and Komárek, 2004, Mihaljevič, et al., 2006). Corrections for the mass bias were performed using SRM NIST 981. The analytical error (expressed as RSD) was 0.02 – 0.2 % for $^{207}Pb/^{206}Pb$ and $^{208}Pb/^{206}Pb$ ratios. Generally, the ICP-QMS lead isotopic data show larger divergences than that obtained by the MC-ICP-MS.

Results

The alloys and compositional characteristic of various artefact groups

Generally speaking, our findings correspond with the character of alloys at other *oppida* sites in Europe (cf. Penz, 2012, Schwab, 2011, Schwab 2014). The chemical

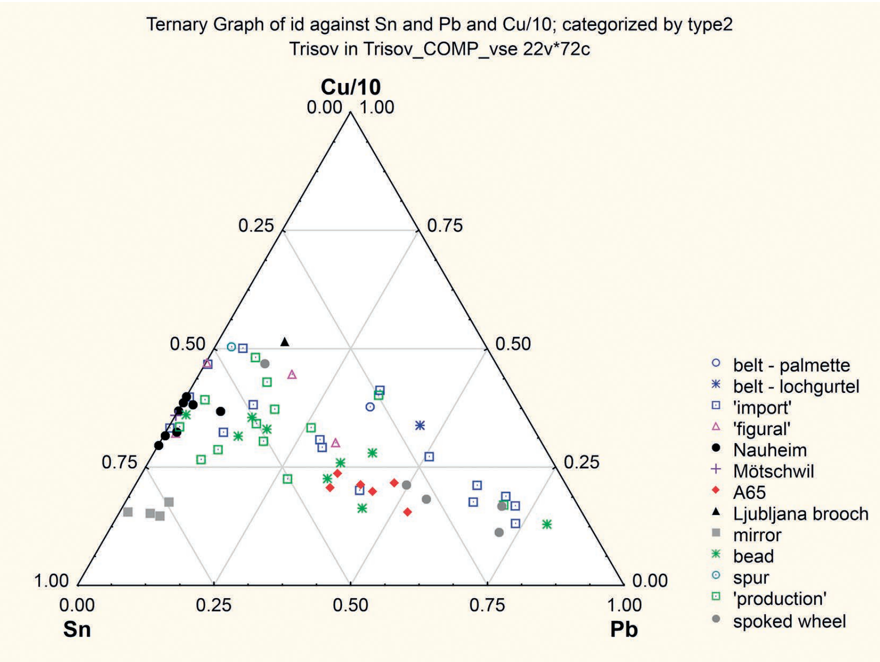


Figure 4. Ratio of Cu-Sn-Pb of selected objects from Třísov analysed by ICP-MS (Cu concentrations have been divided by 10). The main trends in the composition of each category of objects (brooches, imports, mirrors, amulets, local production etc.) are apparent. Graphics: A. Danielisová.

Table 1. Element concentrations in samples (artefacts) from the Třísov oppidum (for details on instrumentation see the text); for measurement units and detection limits see second and third row of the table respectively; < = below detection limit. The analytical data have been normalised to add up to 100%.

sample	type of object	Cu %	Zn %	Sn %	Pb %	Fe %	As %	Sb %	Cr ppm	Mn ppm	Co ppm	Ni ppm	Ag ppm	Cd ppm	Bi ppm	total %	analy. total %
		<0.05	<0.01	<0.05	<0.001	<0.10	<0.005	<0.005	<100	<50	<50	<100	<50	<10	<50		
A33038	„amulet“ - rouelle	89,3	0,02	8,07	2,07	0,21	0,096	0,059	<100	<50	310	1000	230	<10	<50	100	98,53
A33041a	„amulet“ - rouelle	52,3	<0.01	8,02	33,3	0,21	0,483	5,141	500	50	<50	650	3800	<10	100	100	94,43
A33041b	„amulet“ - rouelle	72,0	0,01	9,90	16,8	0,52	0,302	0,149	<100	<50	480	700	2300	<10	170	100	101,36
A33162	„amulet“ - rouelle	68,0	<0.01	10,1	20,4	0,59	<0.1	0,380	<100	<50	<50	890	1800	<10	<50	100	93,75
A33164	„amulet“ - rouelle	63,5	<0.01	5,32	26,3	0,13	0,228	3,732	<100	<50	<50	320	7000	<10	<50	100	94,45
A32659	„bead“	81,6	<0.01	14,2	3,53	0,17	0,188	0,104	<100	<50	110	690	740	<10	130	100	91,01
A32688	„bead“	78,8	<0.01	9,01	11,2	<0.1	0,161	0,398	<100	<50	<50	1700	2200	<10	430	100	91,36
A32724	„bead“	84,7	<0.01	14,6	0,44	0,15	0,035	0,031	<100	<50	<50	580	450	<10	60	100	91,11
A32777	„bead“	76,6	<0.01	11,5	10,4	0,03	0,193	0,998	<100	<50	80	980	1000	<10	150	100	92,68
A32949	„bead“	65,7	<0.01	16,0	17,7	0,03	0,227	0,143	<100	<50	280	560	780	<10	320	100	96,35
A33104	„bead“	59,3	0,06	3,52	36,4	0,39	0,066	0,168	<100	<50	10	520	130	<10	<50	100	100,97
A33391	„bead“	83,9	<0.01	11,9	3,35	0,10	0,093	0,364	<100	<50	40	640	2500	<10	65	100	92,42
A33479	„bead“	82,9	<0.01	12,3	4,55	0,02	0,117	0,031	<100	<50	60	990	210	<10	<50	100	92,94
A33920	„bead“	74,1	<0.01	14,1	11,3	<0.1	0,285	0,079	<100	<50	270	620	420	<10	160	100	94,83
A32834	„belt“_ Lochgurtel	83,3	0,08	5,04	11,3	0,30	0,003	0,041	<100	<50	<50	<100	120	<10	<50	100	98,67
A32946	„belt“_ Palmette	85,0	0,33	6,21	7,80	0,44	0,070	0,100	<100	<50	60	650	200	10	65	100	100,52
A32475	„brooch“_ A65	71,8	<0.01	12,7	13,9	0,01	0,273	0,188	<100	<50	200	570	10200	<10	530	100	101,66
A32827	„brooch“_ A65	70,6	0,01	12,9	15,7	0,20	0,207	0,087	<100	<50	120	420	2300	<10	190	100	98,59
A33178	„brooch“_ A65	72,5	<0.01	10,4	15,8	0,04	0,318	0,391	<100	<50	180	1800	2800	<10	650	100	101,66
A33191	„brooch“_ A65	71,9	<0.01	15,1	12,5	<0.1	0,150	0,097	<100	<50	230	390	600	<10	590	100	90,67
A33199	„brooch“_ A65	75,4	<0.01	12,9	11,4	<0.1	0,096	0,044	<100	55	340	390	200	<10	<50	100	101,99
A33201	„brooch“_ A65	64,3	0,01	13,2	21,9	0,02	0,202	0,060	<100	<50	310	320	1400	<10	550	100	97,63
A33194	„brooch“_ Ljubljana type	88,9	0,21	6,27	2,10	1,69	0,581	0,120	<100	60	150	840	350	<10	<50	100	94,91
A33190	„brooch“_ Mötschwil	84,2	<0.01	15,0	0,02	0,58	0,127	0,055	<100	<50	190	65	70	<10	<50	100	101,31
A32748	„brooch“_ Nauheim	83,5	0,99	12,6	1,76	0,75	0,057	0,155	<100	70	<50	290	390	1600	<50	100	63,11
A32758	„brooch“_ Nauheim	85,5	<0.01	13,6	0,02	<0.1	0,034	0,020	<100	<50	<50	930	7200	<10	<50	100	101,17
A32924	„brooch“_ Nauheim	84,5	<0.01	14,5	0,02	<0.1	0,047	0,037	<100	<50	<50	820	8100	<10	<50	100	100,80
A32947	„brooch“_ Nauheim	80,3	<0.01	19,1	0,03	<0.1	0,028	0,027	<100	<50	<50	840	4300	<10	<50	100	101,19
A33160	„brooch“_ Nauheim	81,7	<0.01	17,6	0,07	0,02	0,096	0,160	<100	<50	<50	590	3500	<10	150	100	100,30
A33179	„brooch“_ Nauheim	85,7	0,11	13,4	0,47	<0.1	0,046	0,095	<100	<50	<50	740	520	<10	<50	100	101,74

sample	type of object	Cu %	Zn %	Sn %	Pb %	Fe %	As %	Sb %	Cr ppm	Mn ppm	Co ppm	Ni ppm	Ag ppm	Cd ppm	Bi ppm	total %	analy. total %
		<0.05	<0.01	<0.05	<0.001	<0.10	<0.005	<0.005	<100	<50	<50	<100	<50	<10	<50		
A33188	„brooch“_ Nauheim	83,4	1,18	12,6	<0.001	2,42	0,071	0,132	<100	210	<50	1100	490	<10	<50	100	94,81
A34019	„brooch“_ Nauheim	81,3	1,18	16,5	0,50	0,35	0,008	0,095	<100	120	<50	550	680	<10	<50	100	95,86
A33209	„figural“- duck head	89,4	<0.01	10,1	0,04	0,11	0,161	0,022	<100	<50	<50	800	380	<10	<50	100	98,85
A326838	„figural“- fitting	82,0	<0.01	16,8	0,49	0,33	0,025	0,082	<100	<50	<50	540	2000	<10	<50	100	95,50
A32878	„figural“- fitting	88,3	<0.01	7,61	3,35	0,31	0,101	0,208	<100	<50	50	850	280	<10	<50	100	100,62
A33177	„figural“- human leg	80,9	<0.01	10,1	8,62	0,02	0,099	0,097	<100	<50	<50	1100	750	<10	120	100	94,03
A32480	„import“- vessel	86,3	<0.01	12,9	0,11	0,15	0,053	0,269	<100	<50	<50	600	1500	<10	<50	100	94,26
A32483	„import“- vessel	69,7	<0.01	4,53	25,5	<0.1	0,111	0,110	<100	<50	90	330	460	<10	<50	100	97,76
A32725	„import“- vessel	90,8	<0.01	8,10	0,94	0,05	0,030	0,027	<100	<50	<50	250	190	<10	<50	100	95,77
A32754	„import“- vessel	78,5	<0.01	6,35	14,6	<0.1	0,194	0,169	<100	<50	50	570	750	<10	180	100	99,12
A32882	„import“- vessel	85,7	<0.01	10,9	2,92	<0.1	0,232	0,086	<100	<50	60	360	210	<10	130	100	100,63
A33069	„import“- vessel	59,7	<0.01	6,09	33,5	0,07	0,281	0,139	<100	<50	340	430	490	<10	300	100	101,33
A33080	„import“- vessel	81,4	<0.01	10,6	7,63	0,23	0,020	0,053	<100	<50	<50	470	260	<10	<50	100	101,37
A33184	„import“- vessel	82,8	0,23	16,5	0,06	0,03	0,091	0,133	<100	<50	<50	560	540	<10	100	100	92,15
A33185	„import“- vessel	81,2	0,27	14,3	2,62	1,40	0,081	0,084	<100	90	60	200	480	<10	<50	100	101,12
A33186	„import“- vessel	89,7	<0.01	10,1	0,09	<0.1	0,008	0,006	<100	<50	<50	<100	75	<10	80	100	93,20
A33204	„import“- vessel	60,2	<0.01	4,12	25,6	2,42	7,218	0,146	<100	70	<50	1400	880	<10	90	100	100,89
A33206	„import“- vessel	70,8	0,01	13,5	14,6	0,79	0,127	0,071	<100	<50	280	510	490	<10	380	100	98,57
A33211	„import“- vessel	67,6	0,01	7,19	24,3	0,02	0,111	0,015	<100	<50	<50	80	1300	<10	5800	100	96,60
A33218	„import“- vessel	80,3	<0.01	11,2	8,30	0,01	0,028	0,038	<100	<50	<50	640	510	<10	50	100	99,50
A33219	„import“- vessel	86,9	0,48	5,07	7,30	0,11	0,024	0,056	<100	10	<50	120	340	130	<50	100	98,70
A33602a	„import“- vessel	72,2	<0.01	5,56	21,3	<0.1	0,346	0,030	<100	<50	<50	280	1600	<10	3700	100	96,33
A32199	„import“- mirror	64,6	<0.01	34,4	0,60	0,13	0,137	0,042	<100	<50	90	470	240	<10	230	100	98,70
A32339	„import“- mirror	63,0	<0.01	33,2	3,31	0,05	0,119	0,141	<100	<50	<50	390	500	<10	190	100	94,88
A33208	„import“- mirror	63,9	<0.01	33,1	2,38	<0.1	0,099	0,352	<100	<50	<50	1600	600	<10	<50	100	93,44
A33892	„import“- mirror	67,8	<0.01	28,6	3,05	0,01	0,173	0,121	<100	<50	110	860	860	<10	230	100	96,91
A32141	„production“- semi-product	89,9	<0.01	8,09	1,58	0,02	0,104	0,153	<100	<50	50	630	590	<10	60	100	98,93
A32282	„production“- semi-product	73,4	<0.01	16,4	8,86	0,17	0,265	0,527	<100	<50	130	1200	1700	<10	220	100	94,43
A32409	„production“- semi-product	83,5	<0.01	12,2	3,82	0,03	0,098	0,141	<100	<50	120	920	590	<10	60	100	93,07
A32478	„production“- semi-product	82,1	<0.01	10,0	6,42	0,04	0,238	0,886	<100	<50	180	1000	1400	<10	160	100	95,50

sample	type of object	Cu %	Zn %	Sn %	Pb %	Fe %	As %	Sb %	Cr ppm	Mn ppm	Co ppm	Ni ppm	Ag ppm	Cd ppm	Bi ppm	total %	analy. total %
		<0.05	<0.01	<0.05	<0.001	<0.10	<0.005	<0.005	<100	<50	<50	<100	<50	<10	<50		
A32619	„production“-semi-product	78,7	0,01	16,4	3,10	0,95	0,407	0,199	<100	160	100	810	900	<10	200	100	96,09
A32710	„production“-semi-product	83,2	<0.01	16,0	0,48	0,08	0,030	0,054	<100	<50	<50	900	520	<10	<50	100	92,34
A32837	„production“-semi-product	85,3	<0.01	10,4	4,00	0,08	0,048	0,067	<100	<50	<50	460	470	<10	<50	100	89,95
A33604a	„production“-semi-product	86,2	<0.01	12,5	0,81	0,02	0,067	0,153	<100	<50	<50	880	800	<10	50	100	90,42
A33604c	„production“-semi-product	87,6	<0.01	8,93	2,68	0,01	0,173	0,389	<100	<50	<50	1000	1100	<10	130	100	87,67
A32179	„production“-technological object	85,7	<0.01	11,1	2,49	0,02	0,102	0,319	<100	<50	<50	760	2000	<10	90	100	92,11
A32467	„production“-technological object	81,1	<0.01	13,5	4,99	0,03	0,073	0,132	<100	<50	<50	890	450	<10	60	100	94,85
A33495	„production“-technological object	85,9	<0.01	5,30	7,47	0,02	0,227	0,832	<100	<50	80	1000	900	<10	100	100	92,21
A33841	„production“-technological object	66,3	<0.01	5,27	27,0	0,01	0,250	0,875	<100	<50	140	1300	1200	<10	60	100	95,35
A33846	„production“-technological object	78,0	<0.01	18,8	2,73	0,04	0,113	0,135	<100	<50	110	930	570	<10	70	100	96,03
A33227	„spur“	90,7	<0.01	8,38	0,53	<0.1	0,135	0,130	<100	<50	250	820	460	<10	<50	100	100,96

composition of copper-alloys objects from Třísov (Table 1) can be characterised by a combination of three major elements, copper-tin-lead (Cu-Sn-Pb), with an admixture of several trace elements such as antimony (Sb), arsenic (As), cobalt (Co), nickel (Ni), silver (Ag), or iron (Fe), (Fig. 4, 6). The results confirm previously (Danielisová, et al., 2017, pp.90-92) detected uniformity in composition of individual typological groups of artefacts such as brooches or mirrors (Figure 4, 6:3,4), and variability within the ‘imports’ group, especially what concerns the bronze vessels and their functional parts (handles, bases etc.), that are usually heavily leaded (Figure 6:2), or within the ‘production’ category (Figure 4, 6:1). In fact, most of the bronze objects from Třísov revealed quite significant amounts of lead, comparable to tin (10-15%), (Figure 4, 5:1,2). There is also quite a substantial group of items with very little or no amount of lead at all; this comprises certain groups of artefacts such as Nauheim, Mötschwil or other types of brooches (Figure 4, 6:3). Some artefacts, most often from the category of presumed ‘imports’, also have very small amounts of lead and/or tin in their compositions (Figure 6:2). Considering bulk elements patterns, ‘imports’ also show partially similar values with the possibly locally manufactured bronze objects which generally overlap with other items possibly produced by casting (Figure 4).

Trace elements, beside technological aspects (such as smelting conditions), can be symptomatic in the question of provenance (cf. Pernicka, 1999, Pernicka, 2014, Villa, 2016) such is, for instance, the case for elevated content of antimony. The leaded antimony bronzes, where antimony content could be as high as 10% or more, were reported among the copper alloys from the *oppidum* of Manching (cf. Schwab, 2014, pp.177-179) and were attributed to the general shortage of metal, when the required silvery appearance of the casted objects was achieved by adding antimony instead of (increasingly scarce) tin. At Třísov, we were able to detect the heavily leaded alloys with increased content of antimony (up to 5%) (Figure 5:3) only in the case of specific amulets - the eight-beamed spoked wheels (Figure 6:6). The specific character of the alloy required for production of these amulets could have a cultural background, which could not necessarily reflect a purely practical or technological purpose. The trace element pattern can point to the origin of the used copper (but not lead, see below) in

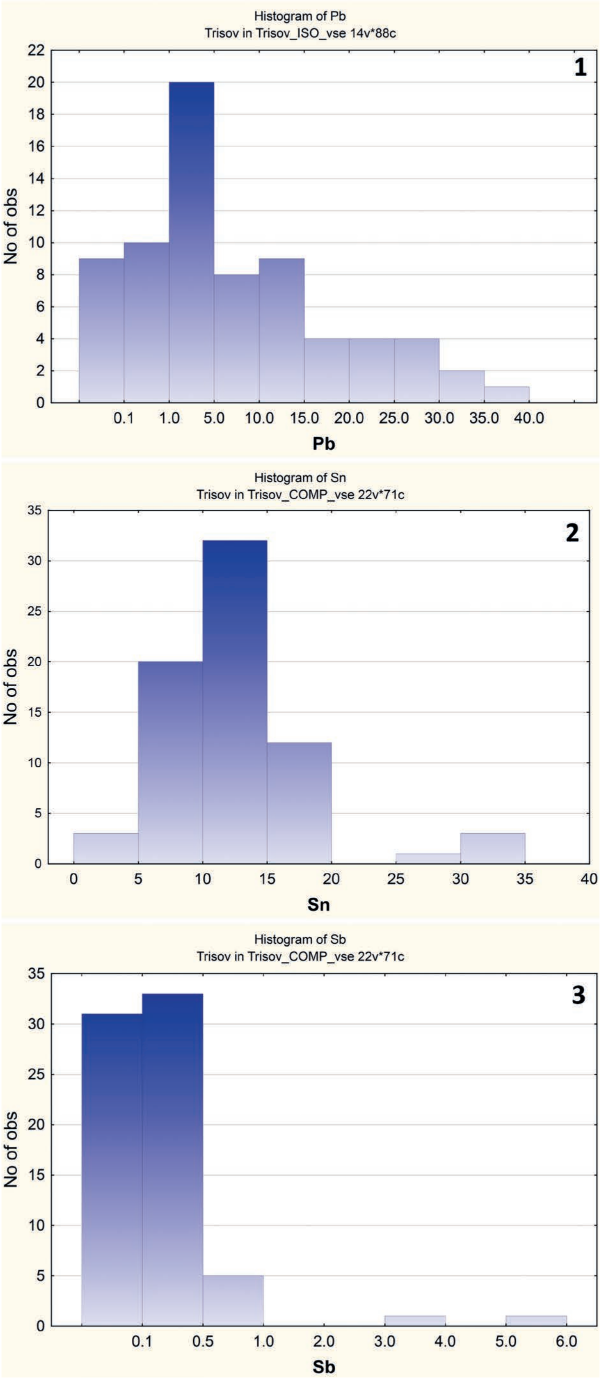


Figure 5. Lead (1), tin (2) and antimony (3) contents of bronze objects from Třísov. Graphics: A. Danielisová.

the Alpine or the low mountains area, specifically the fahlores from the Inn valley in Austria (Höppner, et al., 2005, Krismer, et al., 2011, Pernicka, Lutz and Stöllner, 2016, p.29, Schwab, 2014, p.183). However, unlike the Třísov samples, the Inn valley copper minerals contain also 0.1% Bi (Pernicka, et al., 2016, p.39). Tetrahedrite minerals with increased contents of antimony and silver were also reported from the Příbram area in Bohemia that was likely exploited since the Early Bronze Age (Frána, Chvojka and Fikrle 2009). Fahlores also occur in the Slovakian Ore Mountains (Pernicka, et al., 2016, p.41) so the origin of copper used for fabrication of these objects so far remains unclear.

Provenance of the Třísov copper alloys

As the results show (Figure 7, Table 2), despite their low precision, the values of ^{207}Pb/^{206}Pb and ^{208}Pb/^{206}Pb are quite homogenous and vary as follows: ^{207}Pb/^{206}Pb = 0.834-0.845 ± 0.002, ^{208}Pb/^{206}Pb = 2.068-2.098 ± 0.002, and ^{206}Pb/^{204}Pb = 18.20-18.85 ± 0.03. This is surprising considering the presumed typological variability of different artefact groups as to their expected places of origin – chiefly 'local' or 'Mediterranean'. More importantly, the production-related objects seem to have similar isotopic signatures as the category of 'imports' as well as other artefacts. Only few outliers have been detected and mostly represented specific kinds of artefacts (Figure 7:1). The results also showed similar isotopic ratios independent of the lead content of the samples (Figure 7:2) that may have been caused by a common source of the lead used or by contamination of the low-leaded or non-leaded alloys for example by using the same crucibles to melt highly leaded alloys.

Overlaying the Pb isotopic values of Třísov bronzes with the signatures of Central European and Mediterranean area ores (Figure 8:1,2) shows a (partial) overlap with the latter (Figure 8:2). Quadrupole based data are sensitive enough to exclude the use of Central European sources (Bohemia, Erzgebirge area and South-Eastern Alps). Beside the Mediterranean, however, other deposits with similar isotopic signatures to Třísov need also to be considered:

- **Slovakia**
  Tertiary mineralisation of the Central Slovakian neovolcanites (cf. Černyšev, Cambel and Koděra, 1984, Schreiner, 2007, Abb.3.11) has similar isotopic ratios to Třísov (Fig 8:3). Exploitation of the local ores has been confirmed for the Bronze Age (e.g. Pernicka, Lutz and Stöllner, 2016, p.39), but for the Iron Age mining, much less the transport of (any form of) material to Bohemia, there is no evidence yet.

- **South-Eastern Europe and Balkan Peninsula**
  The corresponding isotopic ratios (Fig 8:4) from the areas of Bulgaria or Serbia (cf. Kuleff, et al., 1995, Simic, 2001, Stos-Gale, et al., 1998) are associated mostly with Pb/Zn or Pb/Ag sources that would require transport either of the pure lead or it being part of the silver trade. The evidence of lead objects from the *oppida* in Bohemia is practically unknown.

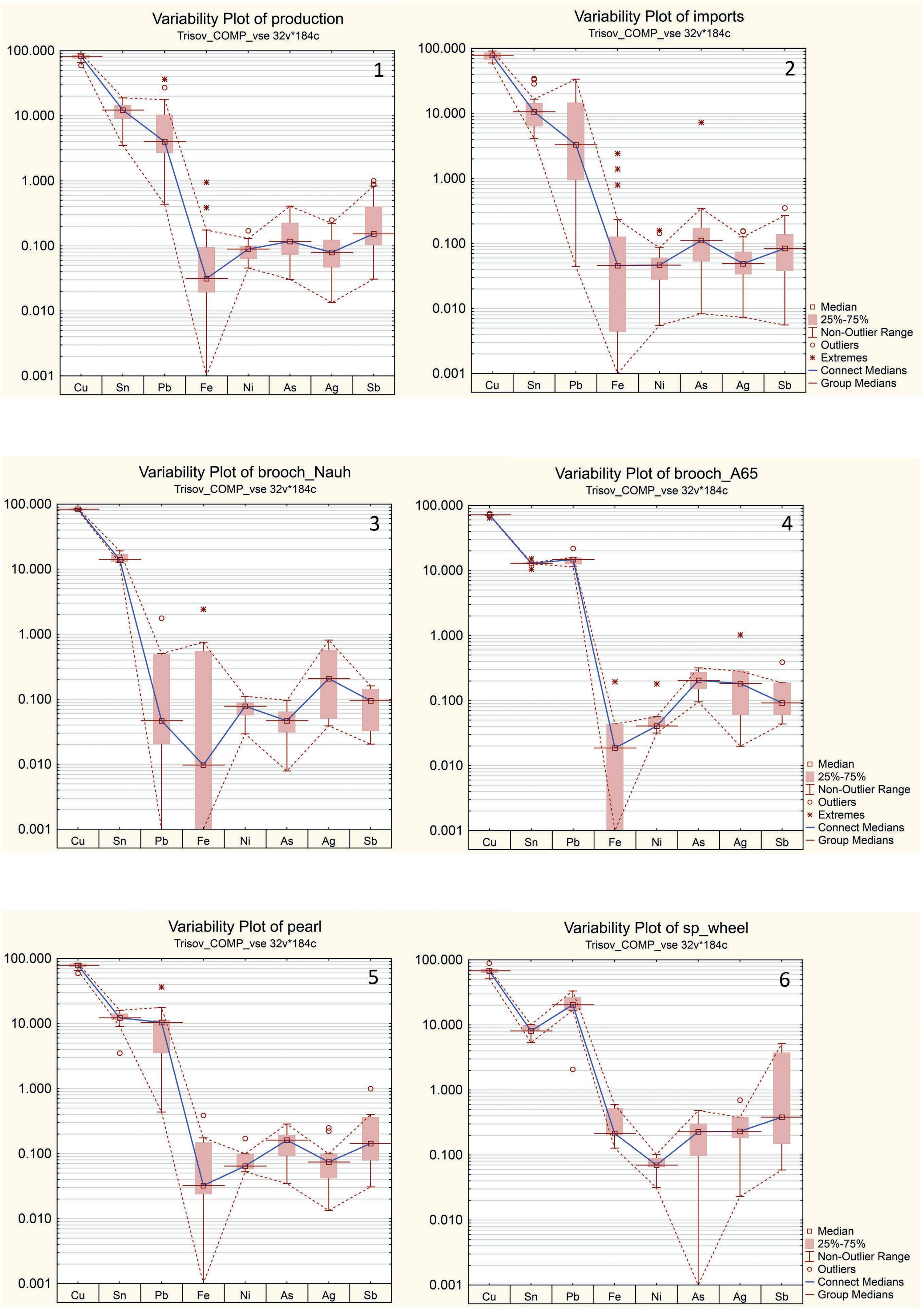


Figure 6. Bulk and trace element patterns of the main artefact groups (1 - objects related to production: casting refuse, semi-products, technological objects etc.; 2 - possible imports: Roman republican vessels, mirror parts etc.; 3 - Nauheim brooches; 4 - Almgren 65 brooches; 5 - beads possibly produced in the local workshop(s); 6 - amulets - spoked wheels; values are normalised to 100%). Graphics: A. Danielisová.

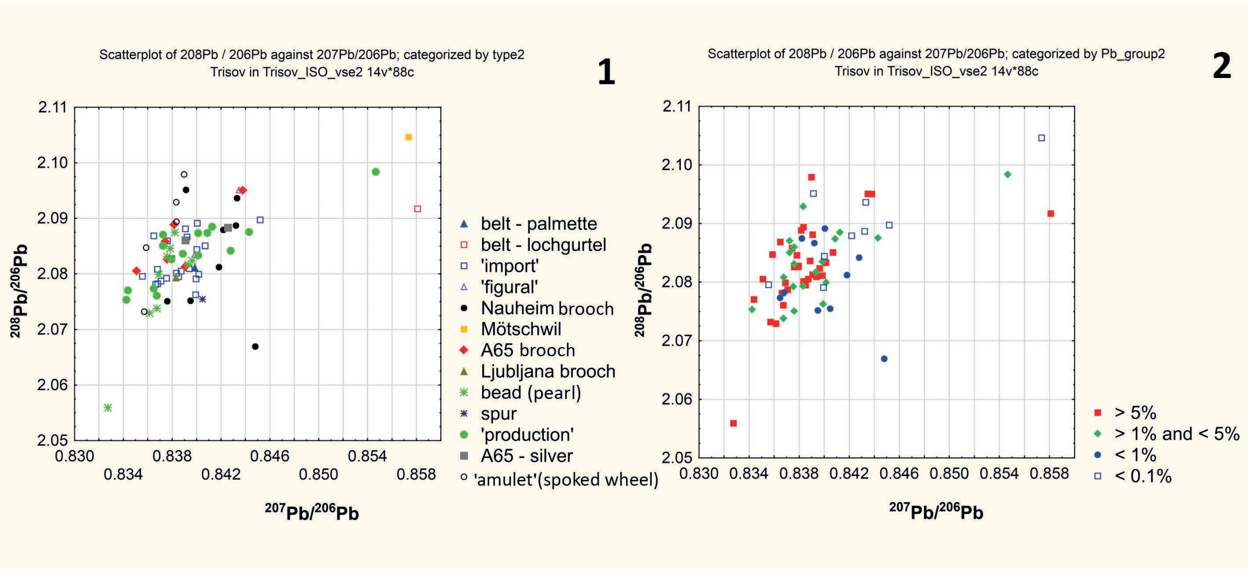


Figure 7: Isotopic ratios of the Třísov bronzes according to their typological groups (1) and Pb content (2). Graphics: A. Danielisová.

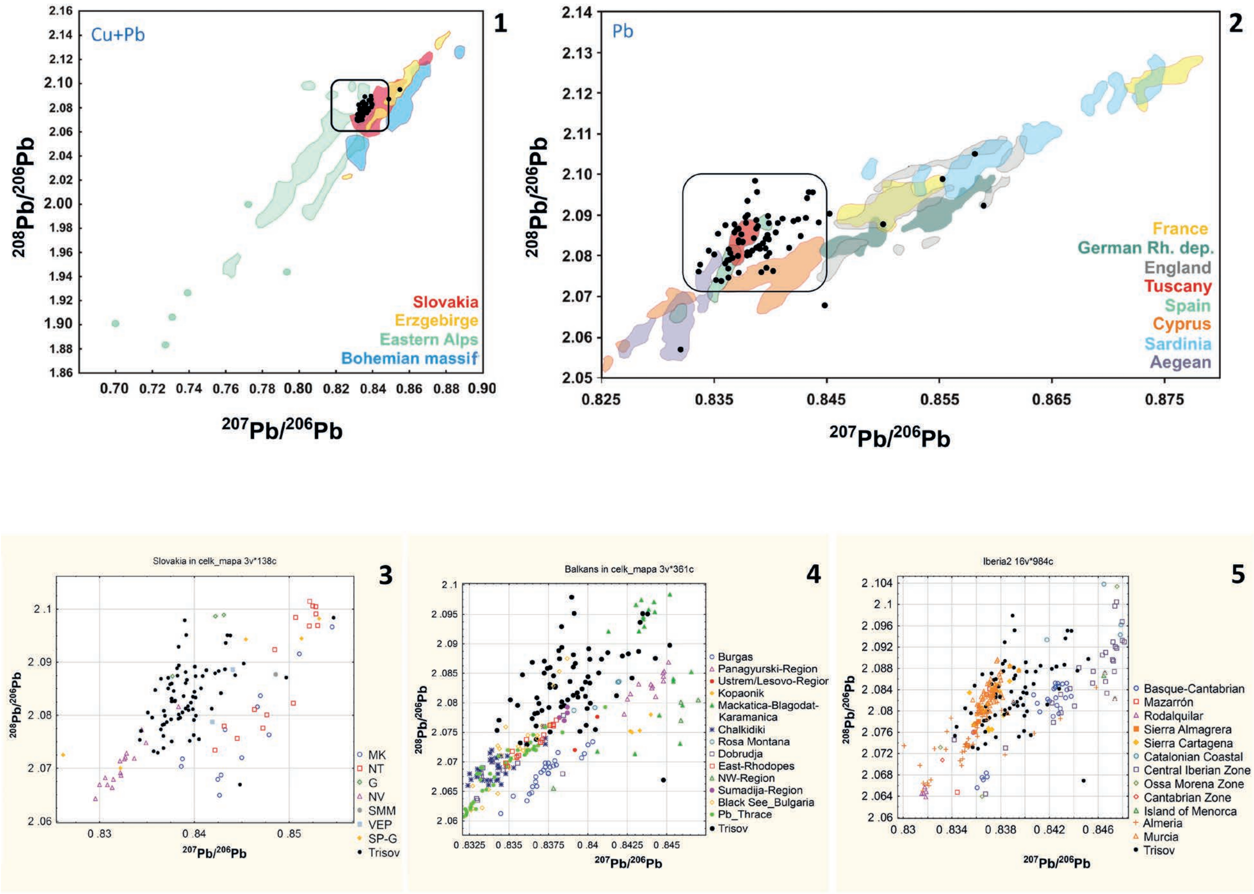


Figure 8. ^{207}Pb/^{206}Pb vs. ^{208}Pb/^{206}Pb isotope plot showing the trend of Třísov bronzes in relation to various European and Mediterranean ore deposits: 1 - Central Europe, 2 - Mediterranean and Western Europe, 3 - Slovakia, 4 - Balkan area, 5 - Spain. (data plots based on OXALID, Arribas and Tosdal, 1994, Baron, et al., 2011, Černyšev, Cambel and Koděra, 1984, Durali-Müller, 2005, Höppner, et al., 2005, Klein, et al., 2004, Kuleff, et al., 1995, Kuleff et al., 2006, Legierski and Vaněček, 1967, Niederschlag, et al., 2003, Pernicka, Lutz and Stöllner, 2016, Sayre, et al., 2001, Schreiner, 2007, Simic, 2001, Stos-Gale, et al., 1995, Stos-Gale, et al., 1998, Trincherini, et al., 2001, Trincherini, et al., 2009, Velasco, et. al., 1996, Vlad, et al. 2011, own data). Graphics: A. Danielisová.

Table 2. Lead isotope ratios in the samples (artefacts) from the Třísov oppidum (for details on instrumentation see the text); the precision of measurement is ± 0.1 % for ratios with ^{206}Pb in the denominator and up to ± 0.2 % for ^{206}Pb/^{204}Pb (due to larger error the ^{206}Pb/^{204}Pb was not used in graphs and in the discussion).

sample	type of object	^{207}Pb/^{206}Pb	^{208}Pb/^{206}Pb	^{206}Pb/^{204}Pb
A33038	„amulet“-rouelle	0,838	2,093	18,73
A33041a	„amulet“-rouelle	0,836	2,073	18,72
A33041b	„amulet“-rouelle	0,836	2,085	18,83
A33162	„amulet“-rouelle	0,838	2,089	18,74
A33164	„amulet“-rouelle	0,839	2,098	18,69
A32659	„bead“	0,837	2,074	18,71
A32688	„bead“	0,840	2,082	18,70
A32724	„bead“	0,838	2,088	18,74
A32777	„bead“	0,838	2,085	18,74
A32949	„bead“	0,836	2,073	18,75
A33104	„bead“	0,833	2,056	18,76
A33391	„bead“	0,838	2,083	18,71
A33479	„bead“	0,839	2,082	18,65
A33920	„bead“	0,837	2,080	18,74
A32834	„belt“_Lochgurtel	0,858	2,092	18,20
A32946	„belt“_Palmette	0,840	2,081	18,66
A32475	„brooch“_A65	0,839	2,081	18,79
A33191	„brooch“_A65	0,838	2,089	18,74
A33199	„brooch“_A65	0,838	2,083	18,69
A33180	„brooch“_A65Ag	0,839	2,086	18,69
A33369	„brooch“_A65Ag	0,843	2,088	18,64
A33178	„brooch“_A66	0,835	2,081	18,72
A32827	„brooch“_A67	0,837	2,086	18,67
A33201	„brooch“_A68	0,844	2,095	18,53
A33194	„brooch“_ Ljubljana type	0,838	2,079	18,71
A33190	„brooch“_Mötschwil	0,857	2,105	18,18
A32748	„brooch“_Nauheim	0,838	2,075	18,70
A32758	„brooch“_Nauheim	0,843	2,094	18,43
A32924	„brooch“_Nauheim	0,843	2,089	18,46
A32947	„brooch“_Nauheim	0,839	2,095	18,63
A33160	„brooch“_Nauheim	0,842	2,088	18,53
A33179	„brooch“_Nauheim	0,842	2,081	18,56
A33188	„brooch“_Nauheim	0,845	2,067	18,38
A34019	„brooch“_Nauheim	0,840	2,075	18,62
A33209	„figural“- duck head	0,845	2,090	18,61
A326838	„figural“-fitting	0,840	2,089	18,65
A32878	„figural“-fitting	0,840	2,084	18,64
A33177	„figural“-human leg	0,844	2,095	18,57
A32480	„import“-vessel	0,840	2,084	18,69
A32483	„import“-vessel	0,839	2,080	18,68
A32725	„import“-vessel	0,839	2,087	18,73
A32754	„import“-vessel	0,837	2,087	18,71
A32882	„import“-vessel	0,838	2,086	18,73
A33069	„import“-vessel	0,837	2,079	18,77
A33080	„import“-vessel	0,839	2,081	18,70
A33184	„import“-vessel	0,840	2,079	18,66
A33185	„import“-vessel	0,838	2,079	18,66
A33186	„import“-vessel	0,836	2,080	18,80
A33204	„import“-vessel	0,839	2,081	18,73
A33206	„import“-vessel	0,837	2,078	18,72
A33211	„import“-vessel	0,839	2,088	18,65
A33218	„import“- vessel	0,838	2,080	18,79
A33219	„import“- vessel	0,841	2,085	18,64
A33602a	„import“- vessel	0,838	2,083	18,79
A32199	„import“-mirror	0,837	2,078	18,67
A32339	„import“-mirror	0,837	2,081	18,85
A33208	„import“-mirror	0,840	2,076	18,61
A33892	„import“-mirror	0,840	2,080	18,72
A32141	„production“-semi-product	0,841	2,087	18,79
A32282	„production“-semi-product	0,837	2,076	18,74
A32409	„production“-semi-product	0,844	2,088	18,54
A32478	„production“-semi-product	0,840	2,083	18,60
A32619	„production“-semi-product	0,855	2,098	18,37
A32710	„production“-semi-product	0,837	2,077	18,77
A32837	„production“-semi-product	0,837	2,085	18,67
A33604a	„production“-semi-product	0,843	2,084	18,58
A33604b	„production“-semi-product	0,840	2,087	18,61
A33604c	„production“-semi-product	0,841	2,089	18,59
A32179	„production“-technological obj.	0,834	2,075	18,69
A32467	„production“-technological obj.	0,839	2,084	18,70
A33495	„production“-technological obj.	0,838	2,083	18,73
A33841	„production“-technological obj.	0,834	2,077	18,78
A33846	„production“-technological obj.	0,837	2,087	18,64
A33227	„spur“	0,841	2,076	18,62

- **Western Mediterranean**
  Within the Western Mediterranean area the Pb isotopic values are consistent with several possible lead deposits including Italy (Tuscany), Aegean (Cyclades) and South-Eastern Spain (Murcia, Almeria and Cartagena Mazzarón regions), (Fig 8:5). According to historic sources (Trincherini, et al., 2009, Hirt, 2010) the only lead mining activities in these areas contemporary with the occupation of the *oppida* are those from Spain, which excludes the Tuscany and Cyclades from the interpretation. We may assume that lead exploited there was transported to North Italy (Trincherini, et al., 2009, Fig. 5) and from there it was transported to transalpine areas already in the form of finished (leaded) alloys (as the evidence of lead objects from the *oppida* is scarce, cf. above).

Discussion and conclusion

When dealing with the complex production environments we may assume that the Pb isotopic signatures do not represent one single source, but are the result of mixing of several sources. In the case of copper-alloys, it is most often due to recycling which was possibly on a regular scale towards the Late La Tène period especially at the *oppida* (cf. Leicht, Sievers, 1998, pp.60–62, Schwab, 2014). However, because of our results we now have reason to rethink the general acceptance of the local provenance of material used for the bronze production. We may be observing hints that it was perhaps more effective actually to import readily alloyed material even from considerable distances than to source it locally, except for components that tend to get lost during the recycling process, such as tin. We may suggest that regular recycling of (not only) Mediterranean imports probably formed at least some part of the source material used for the fabrication of local bronzes. The Pb isotopic composition of Třísov samples points probably to the area of Western Mediterranean, specifically to its Spanish Pb/Zn deposits in Murcia and Almeria regions. Widespread reuse and common recycling of scrap metal during the period in question allows for a hypothesis that the producers at the *oppida* mostly used the ready copper alloys imported from the Northern Italy in the form of bronze ware for which the lead ingots from Spanish mines were used. Their mixing with lead from areas closer by, however, cannot be excluded. In this case, data that are more precise (currently under way) may help to clarify this issue.

Despite the lower precision of our Pb isotope data caused by the instrumentation used they correspond with the results from the *oppidum* of Manching (Schwab, 2014, pp.182-183) so we can assume a uniform patterns of metal supply from the Mediterranean to Central Europe. In this case the system of sourcing the bronze alloys can be related to the possible system of sourcing silver where its Mediterranean origin is also often suggested (Bendall, et al., 2009, p.614), though has not yet been sufficiently backed up by data. However, there are still too many unknowns in this theory. The case remains open also for other possible source areas, such as Slovakian Ore Mountains or Balkan area, where the transport of pure lead in connection with the silver trade comes into consideration, but cannot be proven yet by any other evidence. It is true that the idea of Mediterranean imports as the only external source of bronze metal needs further verification especially from the point of view of data from the presumed areas of origin and (so far unknown) potential local sources. In addition, there is no evidence of possibly standardised form in which the source material may have been transported; at this moment, we are really dealing only with the scrap metal. We also as yet do not know whether this was the situation exclusively for the *oppida* or whether it was characteristic for other settlements as well. In any case, in order to obtain comparative data more analyses from different environments are needed. This issue, therefore, deserves further serious investigation and contextualisation together with data from other regions, socio-economic milieus — such as *oppida* contrasting with open settlements — as well as evidence from other periods.

Acknowledgements

The authors would like to thank Michael Bode and Katrin Westner (Deutsches Bergbau-Museum, Bochum) for sharing their bibliography and lead isotope data. We are also grateful to Ernst Pernicka for helpful consultation on the interpretation of the results. Comments from anonymous reviewers have helped us improve the paper; any remaining shortcomings are our own. Support of the project from the Czech Science Foundation no. 18-20096S ‘Mobility of materials and life cycles of artefacts: archaeometry of metals and glass of the La Tène and Early Roman period’ is gratefully acknowledged.

References

Arribas, A., and Tosdal, R. M., 1994. Isotopic composition of Pb in ore deposits of the Betic Cordillera, Spain; origin and relationship to other European deposits. *Economic Geology*, 89(5), pp.1074–1093.

Baron, S., Tamas, C., Cauuet, B. and Munoz, M., 2011. Lead isotope analyses of gold-silver ores from Roşia Montanâ (Romania): A first step of a metal provenance study of Roman mining activity in Alburnus Maior (Roman Dacia). *Journal of Archaeological Science*, 38(5), pp.1090-1100.

Bendall, C., Wigg-Wolf, D., Lahaye, Y., von Kaenel, H.-M. and Brey, G.P., 2009. Detecting changes of Celtic gold sources through the application of trace element and Pb isotope laser ablation analysis of Celtic gold coins. *Archaeometry*, 51, pp.598–625.

Černyšev, I., Cambel, B. and Koděra, M., 1984. Lead isotopes in galenas of the West Carpathians. *Geologický Zborník - Geologica Carpathica*, 353, pp.307-327.

Danielisová, A., Kysela, J., Mihaljevič, M. and Militký, J., 2017. Metalworking at the *Oppidum* of Třísov - a review. In: J. Kysela, A. Danielisová and J. Militký, eds. 2017. Stories that made the Iron Age. Studies in Iron Age dedicated to Natalie Venclová. Prague: Institute of Archaeology of the CAS, Prague and Faculty of Arts, Charles University. pp.83-99.

Durali-Müller, S., 2005. Roman lead and copper mining in Germany their origin and development through time, deduced from lead and copper isotope provenance studies. Ph.D. Dissertation, Johann Wolfgang Goethe-Universität, Frankfurt am Main.

Ďurišová, J., Ackerman, L., Strnad, L., Chrastný V. and Borovička, J., 2015. Lead Isotopic Composition in Biogenic Certified Reference Materials Determined by Different ICP-based Mass Spectrometric Techniques. *Geostandards and Geoanalytical Research*, 39, pp.209-220.

Ettler, V., Mihaljevič, M. and Komárek, M. 2004. ICP-MS measurements of lead isotopes in soils heavily contaminated by lead smelting: tracing the sources of pollution. *Analytical and Bioanalytical Chemistry*, 378, pp.311–317.

Ettler, V., Červinka, R. and Johan, Z., 2009. Mineralogy of medieval slags from lead and silver smelting (Bohutín, Příbram district, Czech Republic): towards estimation of historical smelting conditions. *Archaeometry*, 51, pp.987–1007.

Frána, J., Chvojka, O. and Fikrle, M., 2009. Analýzy obsahu chemických prvků nových depotů surové mědi z jižních Čech. Příspěvek k metalurgii starší doby bronzové. [Chemical composition analyses of new raw copper hoards from South Bohemia. A contribution to the metallurgy of the Early Bronze Age]. *Památky archeologické*, 100, pp.91-118.

Hirt, A., M., 2010. *Imperial Mines and Quarries in the Roman World: Organizational Aspects 27 BC - AD 235*. Oxford: Oxford University Press.

Höppner, B., Bartelheim, M., Huijsmans, M., Krauss, R., Martinek, K.-P., Pernicka, E. and Schwab, R. 2005. Prehistoric copper production in the Inn valley (Austria), and the earliest copper in Central Europe. *Archaeometry*, 47, pp.293-315.

Klein, S., Lahaye, Y., and Brey, G.P., 2004. The Early Roman imperial Aes coinage II: Tracing the copper sources by analysis of lead and copper isotopes – copper coins of Augustus and Tiberius. *Archaeometry*, 46, pp.469–480.

Krismer, M., Vavtar, F., Tropper, P., Kaindl, R. and Sartory, B., 2011. The chemical composition of tetrahedrite-tennantite ores from the prehistoric and historic Schwaz and Brixlegg mining areas (North Tyrol, Austria). *European Journal of Mineralogy*, 23, pp.925-936.

Kuleff, I., Djingova, R., Alexandrova, A. and Amov, B., 1995. INAA, AAS, and lead isotope analysis of ancient lead anchors from the Black Sea. *Journal of Radioanalytical and Nuclear Chemistry*, 196(1), pp.65-76.

Kuleff, I., Iliev, I., Pernicka, E. and Gergova, D., 2006: Chemical and lead isotope compositions of lead artefacts from ancient Thracia (Bulgaria). *Journal of Cultural Heritage*, 7(4), pp.244-256.

Kysela, J., 2016. Sitos – chrémata? chalkos – eikona? K řeckým mincím ve střední Evropě mladší doby železné [Sitos – khrémata? Khalkos – eikona? On Greek coins in central Europe in the Late Iron Age Period]. Numismatický sborník, 30/2, pp.193-227.

Kysela, J., Danielisová, A. and Militký, J., 2014. Středomořské importy z *oppida* Třísov. Nálezy z povrchové prospekce s detektory kovů z let 2007–2013. [Mediterranean imports at the Třísov *oppidum*. Finds from surface surveys with metal detectors, conducted in 2007-2013]. *Archeologické rozhledy*, 66, pp.567–608.

Legierski, J. and Vaněček, M., 1967. Lead isotopic composition of some galenas from the Bohemian massif. Acta Universitatis Caroliane - Geologica, 2, pp.153-172.

Leicht, M. and Sievers, S., 1998. Recycling im Oppidum von Manching? *Archäologisches Jahr in Bayern*, 1998, pp.60–62.

Mihaljevič M., Zuna M., Ettler V., Šebek O., Strnad L. and Goliáš V., 2006. Lead fluxes, isotopic and concentration profiles in a peat deposit near a lead smelter (Příbram, Czech Republic). *Science of the Total Environment*, 372, pp.334-344.

Niederschlag, E., Pernicka, E., Seifert, T. and Bartelheim, M., 2003. The determination of lead isotope ratios by multiple collector ICP-MS: a case study of Early Bronze Age artefacts and their possible relation with ore deposits of the Erzgebirge. *Archaeometry*, 45, pp.61-100.

OXALID. Oxford Archaeological Lead Isotope Database from the Isotrace Laboratory. http://oxalid.arch.ox.ac.uk/. (accessed Mai 22nd 2018).

Penz, D., 2012. Die chemische Analyse der Produktionsreste von Altenburg. *Fundberichte aus Baden-Württemberg*, 32/1, pp.805–838.

Pernicka, E., 1999. Trace Element Fingerprinting of Ancient Copper: A Guide to Technology or Provenance? In: S. M. M. Young, A. M. Pollard, P. Budd and R. A. Ixer, eds. 1999. *Metals in Antiquity*. BAR International Series, 792. Oxford: BAR Publishing. pp.163–171.

Pernicka, E., 2014. Provenance Determination of Archaeological Metal Objects. In: B. W. Roberts and C. P. Thornton, eds. 2014. *Archaeometallurgy in Global Perspective*. New York: Springer Science + Business Media. pp.239-268.

Pernicka, E., Lutz, J. and Stöllner, T. 2016. Bronze Age Copper Produced at Mitterberg, Austria, and its Distribution. *Archaeologica Austriaca*, 100/2016, pp.19-55.

Roymans, N., Huisman, H., van der Laan, J. and van Os, B., 2014. La Tène Glass Armrings in Europe. *Archäologisches Korrespondenzblatt*, 44/2, pp.215-228.

Sayre, E. V., Joel, E. C., Blackman, M. J., Yener, K. A., and Özbal, H., 2001. Stable lead isotope studies of Black Sea Anatolian ore sources and related Bronze Age and Phrygian artefacts from nearby archaeological sites. *Archaeometry*, 43, pp.77–115.

Schreiner, M. 2007. Erzlagerstätten im Hrontal, Slowakei: Genese und prähistorische Nutzung. *Forschungen zur Archäometrie und Altertumswissenschaft*, 3, Rahden/Westf.

Schwab, R., 2011. Kupferlegierungen und Kupferverarbeitung im Oppidum auf dem Martberg. *Berichte zur Archäologie an Mittelrhein und Mosel*, 17, pp.267-285.

Schwab, R., 2014. Resources and Recycling. Copper Alloys and Non-ferrous Metalworking in the *Oppidum* of Manching (Germany). In: E. Pernicka and R. Schwab, eds. 2014. *Under the Volcano. Proceedings of the International Symposium on the Metallurgy of the European Iron Age (SMEIA) held in Mannheim, Germany, 20-22 April 2010*. Forschungen zur Archäometrie und Altertumswissenschaft, Band 5. Rahden: Verlag Marie Leidorf GmbH. pp.175–188.

Simić, M, 2001. Metalogenija zone Mačkatica-Blagodat-Karamanica. *Posebna izdanja Geoinstituta*, 58, pp.1-335.

Stos-Gale, Z. A., Gale, N. H., Houghton, J. and Speakman, R., 1995. Lead isotopic data from the Isotrace laboratory, Oxford: Archaeometry data base 1, ores from the Western Mediterranean. *Archaeometry*, 37/2, pp.407-415.

Stos-Gale, Z. A., Gale, N. H., Houghton, J. and Speakman, R., 1998. Lead isotope data from the Isotrace Laboratory, Oxford: Archaeometry Data Base 5, ores from Bulgaria. *Archaeometry*, 40(1), pp.217-226.

Trincherini, P. R., Barbero, P., Quarati, P., Domergue, C., and Long, L., 2001. Where do the lead ingots of the Saintes-Maries-de-la-Mer wreck come from? Archaeology compared with physics. *Archaeometry*, 43(3), pp.393–406.

Trincherini, P., R., Domergue, C., Manteca, I., Nesta, A. and Quarati, P., 2009. The identification of lead ingots from the Roman mines of Cartagena (Murcia, Spain): the role of lead isotope analysis. *Journal of Roman Archaeology*, 22, pp.123–145.

Vavelidis, M et al, 1985. Geologie und Erzvorkommen der Insel Sifnos. In Wagner, G. A, Weisgerber, G (eds), Blei, Silber und Gold auf Sifnos. *Prähistorische und antike Metallproduktion. Der Anschnitt*, Beiheft 3, pp.59-80.

Velasco, F., Pesquera, A., and Herrero, J. M., 1996. Lead isotope study of Zn-Pb ore deposits associated with the Basque-Cantabrian basin and Paleozoic basement, Northern Spain. *Mineralium Deposita*, 31(1–2), pp.84–92.

Vlad, A. M., Niculescu, G., Villa, I., Kasper, H.U., Chiriac, C. and Sârghie, I., 2011. The origins of lead archaeological artifacts using mass spectrometry analysis. *Archaeology, Ethnology and Anthropology of Eurasia*, 39(1), pp.50-55.

Venclová, N., 2016. *Němčice and Staré Hradisko. Iron Age glass and glass-working in Central Europe*. Praha: Institute of Archaeology CAS, Prague, v.v.i.

Villa, I., M., 2016. Provenancing Bronze: Exclusion, Inclusion, Uniqueness, and Occam's Razor. In: G. Grupe and G. C. McGlynn, eds. 2016. *Isotopic Landscapes in Bioarchaeology. Proceedings of the International Workshop 'A Critical Look at the Concept of Isotopic Landscapes and its Application in Future Bioarchaeological Research', München, October 13–15, 2014*. Berlin – Heidelberg: Springer. pp.141–155.

Authors

Alžběta Danielisová (Corresponding Author)
Archeologický ústav av čr, Praha, v. v. i.
Letenská 4, 118 01 Praha 1, Czech Republic
danielisova@arup.cas.cz

Ladislav Strnad
Faculty of Science, Charles University
Albertov 6
128 43 Praha 2, Czech Republic
ladislav.strnad@natur.cuni.cz

Martin Mihaljevič
Faculty of Science, Charles University
Albertov 6
128 43 Praha 2, Czech Republic
martin.mihaljevic@natur.cuni.cz