The beginning of the use of brass in Europe with particular reference to the southeastern Alpine region

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ABSTRACT Research on Roman brooches of the 1st century BC has shown that the beginning of the relatively regular use of brass in Europe should be dated to *c.* 60 BC, about 15 years before the first issue of brass coins in Europe in 46/45 BC. Brass was initially used for military equipment (which included brooches) and not for coins, as has been generally accepted until now.

Keywords: brass, brooches, PIXE, Roman, Italic, coin, Europe.

Introduction

It is generally assumed that it was the Romans who spread the use of brass (a metal that they called *aurichalcum* or *orichalcum*) through Europe (Caley 1964: 31; Craddock 1978: 8–9). It seems likely that they encountered brass in Asia Minor, where deliberate production had probably commenced at the beginning of the 1st century BC. The earliest intentionally made and reliably dated items of brass in the region comprised a coin series, issued by Mithradates VI, the king of Pontus, in the period *c.* 75–65 BC. By about 50 BC, brass was frequently used for coinage in the Roman provinces of Asia, Bithynia-with-Pontus and Cilicia (Burnett *et al.* 1982). Brass was probably produced by a direct process reacting zinc ores and copper metal together in a closed crucible (Cowell *et al.* 2000: 670, 677) and by zinc oxide reacting with molten copper (Craddock and Eckstein 2003).

An important landmark in the use of brass in Europe was the coinage reform instigated by the Roman emperor Augustus at the mint of Rome in *c.* 23 BC. As part of this reform, brass was introduced as a new base metal (Burnett 1987: 54; Burnett *et al.* 1982). From the Augustan period onwards, and especially in the 1st century AD, brass was also widely used for military equipment, brooches and medical instruments (Bayley 1990: 13–21; Bayley and Butcher 1995; 2004: 209–10; Craddock and Lambert 1985; Jackson and Craddock 1995: 89–99; Ponting 2002; Riederer 2001: 225–35; 2002a: 109–20; 2002b: 286–90).

There has been little research on the use of brass in Europe before Augustus. The existence of an issue of brass coins made in 46–45 BC by Julius Caesar's *praefectus Clovius*, probably in Cisalpine Gaul (present-day northern Italy) has already been known for a century (Bahrfeldt 1905: 42; 1909: 78–84). There is also evidence of Caesar's brass coinage in the province of Macedonia, dated to 44 BC. In Grant's opinion (1969: 13–19, 87–90), it was Caesar himself who authorised this coinage; he would probably have profited significantly from the *orichalcum* issues because brass coins were considerably overvalued. Grant's view (1969: 7–11, 13–19) that brass had its origin in these coin issues was widely accepted (Burnett *et al.* 1982: 264, n. 11; Caley 1964: 92). Caley (1964: 31, 92) stressed that initially the Romans used *orichalcum* only for coinage. This view was not challenged because numismatics aside, there was no evidence for pre-Augustan brass in Europe until recently. In 1996, a monograph appeared on the copper-alloy objects from the American excavations at the Titelberg, Luxembourg. It included three fragments of brass dated to 100–50 BC (Hamilton 1996: 59–60, fig. 48). Unlike Hamilton, who interpreted them as evidence that the Gauls were using brass earlier than the Romans, we see no reason to doubt that these objects were Roman (see discussion below). Moreover, four years after that publication, a well-preserved Roman sword scabbard with brass fittings was published. It was found in Slovenia and was dated to the beginning of the second half of the 1st century BC at the very latest (Istenič 2000a, 2000b; Šmit and Pelicon 2000). From this it was apparent that the Romans did not use brass for coinage alone, even initially, and therefore research on pre-Augustan Roman finds other than coins might add to our knowledge of the emergence of the use of brass in Europe.

The territory of the southeastern Alpine region (present-day Slovenia) seemed to be an appropriate geographical framework for this research. Being an immediate neighbour of Italy to the northeast, it was the zone traversed by all the land routes from Italy to the Balkans and the Danube region and it had contacts with the Romans from the 2nd century BC onwards. In the period under discussion, i.e. the middle of the 1st century BC, the western part of this territory was already under Roman control, and Roman influence was gradually spreading eastwards and southwards (Istenič 2000b). There

is also evidence for the presence of the Roman army in this period (Istenič 2005a; forthcoming). This is important, as the army was a major user of brass in the Augustan period – and also presumably before that as the Ljubljanica sword scabbard and perhaps also the sword scabbard fitting from Titelberg (see below) suggest.

Research strategy

We anticipated that in addition to the sword scabbard from the river Ljubljanica there would be other Roman pre-Augustan objects made of brass. In particular, brass might reasonably be expected in items of Roman military equipment. Among pre-Augustan weapons, which are rare finds generally, items made of iron predominate significantly. There is a class of artefact worn by soldiers as well as by civilians, however, which was not usually made of iron: brooches. Because they are numerous in the southeastern Alps, these objects seemed to be an appropriate subject for our research.

For the purposes of comparison we included in our research not only Roman brooches but also contemporary brooches characteristic of the indigenous peoples of the southeastern Alps and also of northern Italy. We did not expect that they would include brass items. In fact, it seemed unlikely that the non-Roman population of this wider region would have already mastered the production of brass in pre-Roman times. They might have reused imported Roman brass objects by melting them down, however, either on their own or mixed with bronze. In either of these instances, the alloy from such processes would inevitably be reflected in the percentage of zinc in the alloy.

Selection of objects for analysis

A total of 77 brooches (all found in Slovenia) belonging to seven different groups was included in this research. On archaeological grounds, a division between the presumed Roman and the non-Roman brooches could be made for most of the groups. The Italic and Roman brooches belonged to three groups: Almgren 65, Alesia and Jezerine I.

Almgren 65 group brooches (Fig. 1) were manufactured in Italy. They were produced in large quantities and widely distributed through trade, especially to Celtic *oppida* in central Europe. It is assumed that their production began between 90 and 70 BC. The latest examples, which already exhibited some of the characteristics of the *Flügelfibeln*, were probably post-Caesarean (Demetz 1999: 27–38). Thirteen brooches in this group were analysed.[1]

The brooches of the Alesia group take their name from the site of Alesia, the Gaulish stronghold besieged and captured by Caesar in 52 BC. This was an explicitly Roman class of brooch, the earliest type to have had a new mechanism: a hinge instead

Figure 1 Brooches of the Almgren 65 group. The largest brooch (at the bottom) is made of brass. (Source: Archive of the National Museum of Slovenia, photograph by Tomaž Lauko.)

Figure 2 Brooches of the Alesia group. All the brooches were made of brass except the upper three brooches (upper left corner), which were made of bronze, and the brooch fragment in the middle of the second row at the bottom. (Source: Archive of the National Museum of Slovenia, photograph by Tomaž Lauko.)

Figure 3 Brooches of the Jezerine I group, both made of brass. (Source: Archive of the National Museum of Slovenia, photograph by Tomaž Lauko.)

Figure 4 A selection of brooches of the Jezerine II group made of brass (on the right), bronze (on the left) and gunmetal (top and bottom). (Source: Archive of the National Museum of Slovenia, photograph by Tomaž Lauko.)

of the spring which had characterised all previous brooches (Demetz 1999: 156–64). They were worn mostly by Roman soldiers, who are thought to have been the most important factor in their wide geographic distribution. The Alesia group brooches date roughly from the period of Caesar's Gallic wars (58/51 BC) to the period of the civil war following his death in 44 BC. Their production most probably ceased in the early years of the Augustan period (beginning in 27 BC) at the latest (Brouquier-Reddé and Deyber 2001: 295, 298, pl. 91/48; Istenič 2005a, 2005b; Ocharan Larrondo and Unzueta Portilla 2002: fig. 2/10). Eighteen brooches of this group were included in the research (Fig. 2).[2]

Jezerine I is a small group (20 brooches) distributed mainly in northern Italy and southern Gaul. Their production probably began in Italy around 50/40BC and perhaps continued into the Augustan period (Demetz 1999: 99–105, maps 29–31). Two brooches from this group[3] were submitted for analysis (Fig. 3).

The production of the large and widespread Jezerine II group of brooches probably started in northern Italy in about 40 BC, and continued in the Augustan period when they were presumably also produced in other regions such as the southeastern Alps and the Balkans. In fact, the brooches in this group were clearly concentrated in northern Italy and also on the eastern side of the Adriatic (Demetz 1999: 99–105). Twenty-five brooches of the Jezerine II group were analysed (Fig. 4).[4]

Three groups of non-Roman brooches of the 1st century BC were chosen for analysis: the southeastern Alpine group of so-called *Palmettenfibeln* (Fig. 5),[5] which were probably made locally in the southeastern Alps, the so-called *Schüsselfibeln* (Fig. 6),[6] probably by the non-Romanised population of northern Italy (Demetz 1999: 76–7, 64–72), and the Nauheim-type group of brooches (Fig. 7),[7] which were of Celtic origin. Of the

Figure 5 *Palmettenfibeln*, all made of bronze. (Source: Archive of the National Museum of Slovenia, photograph by Tomaž Lauko.)

Figure 6 *Schüsselfibeln*, all made of bronze. (Source: Archive of the National Museum of Slovenia, photograph by Tomaž Lauko.)

Nauheim-type brooches analysed,[8] all except one belonged to a subgroup, Nauheim II. Brooches of this subgroup were found mostly in northeastern Italy and Slovenia, and were most probably produced in northeastern Italy during approximately the same period as the Almgren 65 brooches (Božič 1993: 141–3, 150–51; Salzani 1996: 51, pl. 26, C 8a).[9]

Analytical methods

Two techniques were used to investigate the material from which the brooches were made: energy-dispersive X-ray fluorescence spectroscopy (XRF) and proton-induced X-ray emission spectrometry (PIXE). The other analytical methods at our disposal (e.g. inductively coupled plasma–atomic emission spectroscopy (ICP–AES)) were not appropriate, as most of the investigated objects were extremely thin, and for some of them hardly any metal core had survived. We expected, however, that the results obtained by the PIXE method would be accurate enough for the purposes of our research. In addition, PIXE spectrometry was also suitable for the analysis of the surface coatings (not discussed here).[10]

The presence or absence of zinc in the brooch alloys was determined by the application of XRF analysis to the unprepared surface of the objects.[11] The measurements involved a circular area, 11 mm in diameter. Thus the unprepared surface, i.e. the corrosion layer on the surface of the brooches, was investigated. For this reason, the results provide only an estimate of the approximate composition of the alloy. As our main interest was to detect brass or gunmetal brooches, the presence or absence of zinc was of primary importance.

Due to de-zincification we expected that the proportion of zinc in the corrosion layer on objects made of brass or gunmetal could be very small, therefore the unprepared surfaces of the brooches were also analysed by PIXE. The detection limit for zinc with PIXE was relatively high at < 0.5%, mainly due to interference of zinc K-alpha line with a strong, asymmetric K-beta line of copper.

The brooches for which the XRF or PIXE analyses showed the presence of zinc on the unprepared surface were submitted for further PIXE analyses.[12] The technique was applied to prepared areas of 2–3 mm^2, one or more on each brooch, from which the corrosion layer had been removed as thoroughly as possible, down to the metal core. It was obvious that all the corrosion products could not be removed from the selected area on the very poorly preserved brooch, RM Novo mesto inv. no. 1256. Observation of the prepared areas under a binocular

Figure 7 Nauheim group brooches, all made of bronze. (Source: Archive of the National Museum of Slovenia, photograph by Tomaž Lauko.)

microscope showed that, even with relatively well-preserved brooches, the complete removal of corrosion products from the surface area was a rather difficult task. This is also the main reason for the variation of concentrations obtained in different areas of the same brooch. The results of the measurements therefore provide approximate information on the composition of the brooches.

Very small areas were measured with a narrow beam (0.3 mm) in addition to measurements made with a beam of 2 mm diameter (as used normally). Unless otherwise stated, the values given in Table 1 were obtained with a 2 mm beam. In the calculation of concentrations given in Table 1, the sum of all metal constituents was normalised.

Results

Among the brooches of groups that are regarded as non-Roman (the eight brooches of southeastern Alpine *Palmettenfibeln*, three *Schüsselfibeln* and eight Nauheim-type brooches), not a single example was found to have been made of a zinc-containing alloy. They were all made of bronze or leaded bronze, alloys with a long prehistoric ancestry (cf. Giumlia-Mair 1998; Jerin 2001; Trampuž Orel 1999: 415–17).

Zinc alloys – brass and gunmetal (Table 1) – appeared in the three groups of brooches that were regarded as Italic or Roman, that is the Almgren 65, Alesia and Jezerine I groups. They also appeared among the brooches of the Jezerine II

Table 1 Elemental concentrations (in wt%) measured by PIXE on small areas from which the corrosion layer was removed as thoroughly as possible. Only brooches with zinc are included. Abbreviations: for NMS, IPCHS NG and RMNG see notes 1 and 3; RM = Regional Museum, n.b. = narrow beam. Asterisk (*) indicates area where considerable traces of corrosion products remained.

Brooch	Group	Meas.	Cu	Zn	Sn	Pb	Fe	Ag	Ni	As	Bi	Notes
NMS, inv. no. R18485	Almgren 65	area 1	76.9	21.1	0.9	0.26	0.8					
NMS, inv. no. R17393	Alesia	area 1	78.2	19.9	0.4	0.36	1.2					
“		area 2	78.4	19.8	0.4	0.31	1.1	0.07				
NMS, inv. no. P19282	“	area 1	76.4	21.3	0.6	0.49	1.0		0.15			
“		area 2	76.0	21.0	0.8	0.53	1.7		0.08			
RMNG, inv. no. 7	“	area 1	90.0	3.1	5.4	1.06	0.3			0.09		
NMS, inv. no. R17281	“	area 1	80.7	16.8	1.2	0.26	1.1					
“		area 2	81.4	15.9	1.2	0.30	1.2					
NMS, inv. no. R18974	“	area 1	77.9	20.1	0.6	0.98	0.5					
“		“	80.8	18.1		0.92	0.26					n.b.
RMNG, inv. no. 10	“	area 1	79.2	15.4	2.8	0.86	1.6	0.12				
NMS, inv. no. R17319	“	area 1	79.2	19.9	0.5	0.28	<0.5		0.10	0.01		
“		area 2	79.0	18.8	0.5	0.26	1.3		0.06		0.09	
NMS, ident. no. Zn198/49	“	area 3	79.6	19.1	0.6	0.16	0.6					
“		area 5	77.1	20.6	0.7	0.33	1.4					
“		area 6	76.9	21.2	0.6	0.42	0.7	0.09	0.10			
NMS, inv. no. R19078	“	area 3	78.1	20.4	0.6	0.39	0.6					
NMS, inv. no. P19946	“	area 1	81.5	17.9	0.3	0.34	<0.5					
IPCHS NG, ident. no. K1874	“	area 1	79.9	18.1	0.5	0.21	1.2	0.06				
“		“	78.1	21.7			0.17					n.b.
NMS, inv. no. P12982	“	area 1	81.2	17.0	0.7	0.26	0.7			0.07		
RMNG, inv. no. 8	“	area 1	77.7	20.0	0.5	0.81	0.9					
RM Novo mesto, inv. no. 1256	“	area 1	78.7	16.1	0.8	0.67	3.6	0.1				*
NMS, inv. no. 24045	“	area 3	78.2	19.5	0.9	0.36	1.1					
MNG, inv. no. 24	Jezerine I	area 1	80.2	16.7	0.7	0.87	1.5					
NMS, inv. no. R19077	“	area 1	80.1	18.2	0.5	0.22	1.0	0.07				
“		area 2	78.4	19.3	0.5	0.20	1.5	0.07				
NMS, inv. no. R18758	Jezerine II	area 1	78.7	19.9	0.7	0.26	0.5			0.05		
NMS, inv. no. P19838	“	area 1	80.4	17.9	0.8	0.75	<0.5		0.20			
NMS, inv. no. R18756	“	area 1	78.1	21.2	0.5	0.23	<0.5					
IPCHS NG, ident. no. K1873	“	area 2	80.0	16.5	1.0	1.35	1.0	0.07		0.11		
NMS, inv. no. P19462	“	area 1	77.7	21.1	0.7	0.23	<0.5		0.13	0.03		
NMS, inv. no. P19281	“	area 1	74.4	21.7	0.6	1.45	1.7	0.09		0.05		
NMS, inv. no. 1918	“	area 1	77.9	19.5	0.6	0.48	1.5	0.08				
NMS, ident. no. Zn210/10	“	area 1	84.3	3.2	12.3	0.22	<0.5			0.07		
“		area 2	86.1	3.2	10.5	0.18	<0.5			0.07		
NMS, ident. no. Zn210/9	“	area 3	83.1	5.3	9.8	0.50	1.1			0.17		
“		area 4	83.2	5.0	9.9	0.54	1.3			0.11		

group, which were most probably produced in the Roman (Romanised) communities in Italy as well as in the non-Roman (not yet Romanised) communities in the southeastern Alps and the Balkans.

- In the Almgren 65 group, which was the oldest, 12 brooches were made of bronze and one of brass. The brass brooch belonged typologically to the latest subgroup (Demetz 1999: 27–38).
- Fourteen brooches of the Alesia group (which generally date to approximately the period of Caesar's Gallic wars, 58/51 BC, and the following two decades) were made of brass, one was made of gunmetal and three were made of bronze (Fig. 2). These three bronze brooches all belonged to the same subgroup.[13]
- Of the Jezerine I brooches (an explicitly Roman type, probably produced from *c.* 40 BC onwards), both those analysed proved to be made of brass.
- Among the 25 brooches belonging to the large and widespread Jezerine II brooch group, 16 were made of bronze, seven of brass and two of gunmetal.

For the brass brooches, the analyses showed that the zinc content fluctuated between at least 15% and almost 22%, with most of the zinc values above 18%.

Discussion

The Alesia group brooches constituted the oldest group of brooches for which the new alloy, brass, was widely used. The three bronze brooches all belonged to the same subgroup (Alesia Ic), and were most probably copies of the regular Alesia-type brooches made in small local workshops. We may, therefore, conclude that, except for the presumed copies, brass was used for the Alesia-type brooches. Concomitant with this type of brooch (produced most probably from about 60 BC onwards), the Romans had also introduced a new type of brooch mechanism, a hinge instead of a spring. Brooches of the earlier, Italic type, i.e. the Almgren 65 type, were made of bronze. The only example in brass can be explained as a product belonging relatively late in the series for which the use of a new metal was influenced by the more recent, but chronologically partially overlapping Alesia-type brooches.

The analyses of the two Jezerine I brooches indicate that, for this very small group, brass was also widely or exclusively used. The production of this Roman type of brooch had probably begun a decade or two later than that of the Alesia brooch group.

The use of pure brass, gunmetal and bronze for the Jezerine II group brooches both complements and supplements our archaeological knowledge of these brooches. It can be assumed that the brass brooches had originated in Italy, where they most probably came into production later than Alesia-type brooches, from *c.* 40 BC onwards. The high proportion of bronze brooches in the Jezerine II group supports the assumption that they were also produced in the southeastern Alps and the Balkans, where they were very numerous. In these regions, Jezerine II brooches were copied by non-Roman communities in the period immediately preceding the Roman conquest. These peoples were able to imitate the brooch form but could not obtain brass. The few examples made of gunmetal may indicate that they were able to use the metal of the imported Roman brass brooches for their own brooch production. Future research will concentrate on the correlations between subgroups of the Jezerine II brooches and the material used for their manufacture.

From our research, it is evident that brass was not used for non-Roman brooches. This is not surprising. The only hint of any Celtic, pre-Roman use of brass derives from Elisabeth Hamilton's publication of the metal finds from the site of the Titelberg in Luxembourg (Hamilton 1996), which is briefly discussed here.

During the American excavations at Titelberg, three items were found which were made of pure brass with 18.2–21.9% zinc, and dated to before Caesar's invasion. These brass items were taken as proof that the Gauls (Celts) were using brass earlier than the Romans. Hamilton (1996: 59, 60, 79, fig. 48) speculated that the Gauls in Europe had come into the possession of brass through contacts with Gaulish tribes in Galatia in Asia Minor, or even that the knowledge of the cementation process had spread from Galatia to Gaul.

There are serious objections to this view. First, the brass object that was identified as 'stylistically German' (Hamilton 1996: fig. 48c) is, without doubt, a transverse fitment of a Roman sword scabbard (cf. Unz and Deschler-Erb 1997: pls 6–7, nos. 78–110). The other two fragments of brass objects cannot be culturally assigned so there is no reason to believe they were not Roman as well. The reliability of the dating of these three objects (to *c.* 100–50 BC) can also be questioned, as no detailed evidence of their stratigraphic context was given in the publication. In conclusion, we can claim that the three brass items from Titelberg do not provide evidence for the use of brass by the Gauls in the pre-Roman period.

It is unfortunate that very few of the brooches included in the present research derive from excavations or provide other means of precise dating (Istenič 2005a, 2005b). For this reason, most of them can be dated on typological criteria alone, which are relatively broad. For example, we cannot prove that any of the Alesia group brooches that were analysed belong to the early production period. But, in our opinion, it is highly probable that brass was used for this group of brooches from the beginning of their production, as they also represent something entirely new in brooch construction. Nevertheless, to be completely sure that this group of brooches was made of brass from its inception, a brooch found in a stratified context from the siege of 51 BC at Alesia should be analysed.

Unexpectedly, supporting evidence for our argument (that brass was used for brooches of the Alesia group from the beginning of their production), emerged recently, and quite fortuitously, from the investigation of objects which are not Roman but Celtic. Research on the coins of the Arverni (a Celtic tribe in central-southern Gaul) has shown that six examples, all found at Alesia, were made of brass which contained 10–15% zinc. They were of the same type as the contemporary gold staters (which they copied), and two of them bore the name of Vercingetorix, the leader of the Gallic revolt of 53/52. Most probably they were struck at Alesia during the Roman siege of 52 BC, and brass was used because of a

shortage of gold. The source of the brass used for these coins was recycled Roman brass objects which comprised brooches (Nieto 2004). Thus, the coins of Arverni provide firm supporting evidence for the Roman use of brass during the period of Caesar's wars in Gaul.

Conclusions

The results of this research on the pre-Augustan brooches, together with the research on the coins of the Arverni, have several wider implications. They confirm that it was the Romans who introduced the use of brass to Europe and indicate that the beginning of the relatively regular use of brass in Roman Europe should be dated to about 60 BC. Brass was initially used for military equipment, which included brooches. Slightly later, in 46/45 BC, brass was also used for a coin issue. It seems, however, that Caesar's death in 44 BC halted the initial use of brass for coins. It was not until over a quarter of a century later, in the first decade of the reign of the Emperor Augustus, that brass began to be used for coins in the mint of Rome and on a large scale.

Acknowledgements

J. Istenič would like to thank Dr Dragan Božič for his specialist advice on the classification and dating of the brooches as well as for discussions concerning late La Tène and late Republican periods. She is also indebted to Dr Vivien Swan who edited the English.

Notes

1. National Museum of Slovenia (NMS), inv. nos. R3419, R16720, R18464, R18485, R18555, R18565, R18687, P19286, P19704, P19962, P19465, R24088; Institute for the Protection of the Cultural Heritage of Slovenia, Nova Gorica district unit (IPCHS NG), ident. no. K 238. All the brooches except IPCHS NG, ident. no. K 238 can be seen in Figure 1.
2. In addition to the brooches listed in Table 1, the following brooches of the Alesia group were analysed: NMS inv. nos. R1464, R19080 and P19283. All the brooches except IPCHS NG, ident. no. K1874 are illustrated in Figure 2.
3. NMS inv. nos. R19077 and Regional Museum Nova Gorica (RMNG), inv. no. 24. Both brooches are illustrated in Figure 3.
4. NMS inv. nos. R1918, R11005, R16728, R18627, R18756, R18758, R19074, R19075, R19091, R24085, P19276, P19277, P19279, P19280, P19281, P19462, P19838, P19944, P19945, Zn 201/9, 10; IPCHS NG, inv. nos. K237, K1873, K2520, K2523. Brooches NMS inv. nos. R19091, Zn201/9, 10 and R1918 are illustrated in Figure 4.
5. Eight brooches of this group were submitted for analysis: NMS inv. nos. R17674, R18624, R18625, R18626, R18766, P19284, P19285 and P19955; all can be seen in Figure 5.
6. Three brooches of this group were included in the research: NMS inv. nos. R17668, P19587 and P19705; all are included in Figure 6.
7. Eight brooches of this group were included in the research: NMS inv. nos. R3760, R17675, R18595, R18755, R18827, R24086, P15234 and P19940; all are illustrated in Figure 7.
8. NMS inv. no. R18595.
9. The chronology and the precise dating of the brooches within the 1st century BC are still the subject of debate. The majority of the *Palmettenfibeln*, the *Schüsselfibeln* and the Nauheim-type brooches should, in general, be dated to approximately the first half of the 1st century BC (Dragan Božič, pers. comm.).
10. Tinning and also thin silver foil soldered to the substrate occur on the brooches of the Alesia group (Šmit *et al*. 2005a, 2005b: 32–3, fig. 5). Tinning appears also on few brooches of the Jezerine II group (not yet published).
11. The analyses were carried out at the NMS using a Model PEDUZO 01/Am/Sip-250 X-ray analyser manufactured at the Jožef Stefan Institute. The radiation source was Am-241 with an activity of 25 mCi. The X-ray detector was a Peltier-cooled Si PIN diode with a resolution of 150 eV at 5.9 keV. The diode window was made of beryllium 25 μm thick. The spectrometer energy region (preset during manufacture) extended between 3 and 30 keV.
12. The PIXE measurements, using a proton beam in the air, were made at the Tandetron Accelerator of the Jožef Stefan Institute. The protons were accelerated up to energy of 2.5 MeV, but their impact energy at the target was reduced to about 2.2 MeV. The proton beam hit the target at an angle of 22.5 degrees with respect to the surface. The X-ray detector was positioned at the same angle. The detection of induced X-rays was performed by a Si(Li) detector with an energy resolution of 160 eV at 5.9 keV. During the measurements, the detector was equipped with an aluminium absorber of 0.3 mm thickness. With such a thick absorber we improved the relative sensitivity for hard X-rays around tin, so the minimum detection limit in this region was 0.1%. Such a thick absorber also improved discrimination between the K X-ray lines of arsenic and the L X-ray lines of lead, as the filter increased the relative intensity of arsenic K_{β} lines and lead L_{β} lines in the spectra. The minimum detection limit for arsenic was 0.03%. A drawback of the absorber was the partial overlap of the iron K X-ray lines with the escape peaks of copper. The elemental concentrations were determined with a precision better than 5% for major elements and better than 10% for minor and trace elements. The uncertainties were greater for silver and tin due to low counting statistics (up to 20%), and for iron due to the subtraction of the copper escape peak; the resulting absolute uncertainty in iron concentration was 0.5–1%.
13. A detailed report on brooches of the Alesia group from Slovenia is given in Istenič 2005b.

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