Eyes to the North: a multi-element analysis of copper-alloy eye brooches in the eastern Baltic, produced during the Roman Iron Age

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Introduction

Evidence for copper-alloy working in the eastern Baltic is present from the Early Bronze Age onwards, even though the raw materials (i. e. copper, tin and zinc) have never been mined in the region[1]. The supply of new copper-alloy would therefore always have to have arrived through contact with other areas. During the Roman Iron Age, many new forms of personal copper-alloy ornaments emerged along the eastern coast of the Baltic Sea; many of which bore strong similarities to ones distributed in other parts of Europe[2]. The archaeological evidence suggests that during this period, many connections existed between these regions and that these connections facilitated the flow of cultural material and ideas across this large geographic area. Much discussion has subsequently taken place regarding how local and foreign ideas may have fused together based on these multidirectional contacts[3]. But in the taking up of foreign ideas especially, the nature of local copper-alloy production for this period – for Estonia in particular – is not well understood, mainly due to the lack of excavated settlement sites[4]. The research up to now has mainly been typologically based with some limited compositional assessment, and the artefacts mainly derive from burial contexts.

Our area of study focuses on the region of modern day Estonia and Northern Latvia, where the practice of 'typical' *tarand* cemetery burials[5] emerged at the beginning of the Roman Iron Age (for Estonia it is considered to be from AD 50–450, but for Latvia it is generally considered to be from AD 1–400). These burial places are monumental, above ground, stone cemeteries. They consist of joined, quadrangular stonewall enclosures, holding scattered fragmented bones, cremated and uncremated, together with grave goods *(fig. 1)*. Intact burial contexts within these cemeteries are very rare[6]. It has been commonly

[1] Lang 2007, 115.
[2] Ibid. 206.
[3] Bitner-Wróblewska 2008; Ekengren 2009; Hilberg 2009; Andrzejowski / Madyda-Legutko 2011, 6–24; Banytė-Rowell 2013.
[4] Lang 2007, 120.
[5] Different forms of *tarand* cemeteries are already known from the late Bronze Age and the beginning of the Pre-Roman Iron Age, but in the beginning of the Roman Iron Age they formed an uniform grave form and they are called typical or classically joined *tarand* cemeteries. – Ibid. 190–191.
[6] Ibid. 170, 192, 203, 206; Olli / Kivirüüt 2017.

accepted that many local forms of personal ornaments emerged in this region based on the influence of imported goods, mainly from the coastal area of the south-eastern part of the Baltic Sea[7]. A number of researchers have suggested that contact with the south-eastern coast of the Baltic Sea, i. e. West-Lithuania, the Sambian Peninsula, and the Masurian Lakelands, had a major cultural influence on the people using *tarand* cemeteries[8]. But beyond this little has been discussed regarding long-range contact with the Roman world[9]. In this article we take another look at the nature of the contact the region had during this period and take advantage of newly developed research into Roman period brooch compositions. In particular we will examine the eye brooch series, as they are commonly found in the research area, dating between AD 50–600. This type of brooch is of particular interest because it is the oldest brooch type found in the region[10]. Although a number of other personal bronze and iron ornaments are known from the Pre-Roman Iron Age, such as bracelets, neck rings, and decorative pins, no other brooch types are known before this one[11]. The 88 brooches included in this study come from archaeological collections housed in the Tallinn University Archaeological Research Collection, the University of Tartu Archaeological Collection and the Estonian History Museum, Tallinn.

Brooches, like many other small, personal items, are highly portable, therefore their find location, especially burial sites, cannot automatically be assumed to be their place of production. Furthermore the goods from artisan production have always been transported over long distances, and mass-produced copper-alloy objects would have very likely been moving through the large-scale exchange networks of the time[12]. Our aim subsequently is to extend the understanding of how brooch production was organised in the context of local production versus long-range exchange. A multi-element study of these copper-alloy brooch forms was included in the analysis, using handheld, portable X-ray fluorescence spectrometry (pXRF). This was to assess the type and consistency (or otherwise) of the alloy composition chosen by the craftsmen that made them. The links between alloy choice, typology, and the organisation of production will be discussed followed by a presentation of the methodology and results sections. The results will lead into our hypotheses regarding local versus non-local brooch production and the influence that may have been extended from the distant Roman world.

History of research

In Estonia, research into the typologies of Roman Iron Age brooches began around the turn of the 20th century, after the completion of Oscar Almgren's studies of the main northern European typologies and their chronology[13]. Subsequent studies have built on this early work with smaller complementary adjustments to both typology and chronol-

← Fig. 1. Pada *tarand* cemetery (after Schmiedehelm 1955, pl. X). 1 granite stone; 2 crushed limestone wall; 3 limestone wall; 4 crushed limestone; 5 artefact; 6 pottery; 7 charcoal, burnt stones, burnt bones.

7 Moora 1938; Vassar 1943; Nowakowski 1998, 107; Vaska 2013.

8 Moora 1938; Lang 2007.

9 E. g. Koovit / Kiudsoo 2015.

10 Lang 2007, 206.

11 See ibid. 181–182.

12 Wickham 2005, 699.

13 Almgren 1897; Moora 1923; Id. 1938; Schmiedehelm 1923.

ogy, but the main characteristics essentially stayed the same[14]. However, research into the compositional nature of ancient copper-alloys has only really taken off since the 1950's, due to the invention of new X-ray technologies. These technical advances gave rise to a number of laboratory-based techniques used in the study of archaeological materials including copper-alloys. One of the most well known techniques is X-Ray fluorescence spectrometry (XRF), which has contributed to the understanding of the way ancient craftsmen worked with copper-alloy[15]. From antiquity onwards, the two most well known alloys of copper are bronze and brass. To make bronze, ancient artisans deliberately added tin to the molten mixture. Conversely, to make brass, ancient artisans heated zinc ore with copper until it achieved a gaseous form and permeated the copper. Both techniques produced copper-alloys of differing properties and with differing technical limitations. Lead could also be added in varying amounts and brass and bronze could also be deliberately mixed together to make an alloy referred to as gunmetal. This alloy could also be the result of recycling scrap brass and bronze[16]. Bronze was a commonly used alloy until the 1st century BC but then the Romans introduced a new alloy, brass, on an industrial scale, through a new technological process called cementation[17]. It is thought that the Roman state initially reserved this alloy for military equipment and coinage before becoming more readily available[18]. By the end of the 1st century AD however, widespread brass use was largely replaced by gunmetals and bronzes[19]. Heeren and van der Feijst suggest the circulation date for eye brooches as being between AD 5–70[20], which would coincide with these chronological changes in alloy use. If this date is correct, it means that they were out of fashion in *Germania libera* and the Roman provinces before the decline in brass use at the end of the 1st century AD.

Research into these technical choices has revealed a lot about the complex relationship between typology and composition[21]. The technological choices for the production of different artefact types has also been given a lot of attention in differentiating between items that would require being beaten into the required shape by a hammer or by being heated in a crucible until liquid and then cast in a mould[22]. Brooches for example could be made of brass, bronze or gunmetal, with or without the addition of lead[23]. There has been some compositional research into the copper-alloys of the eastern Baltic for this period but none until now that has focused upon a combined typological and compositional approach to the study of production[24]. Research into the manufacturing techniques for brooches found within the Roman world has revealed that deliberate and consistent choices regularly took place in the production of large quantities of similarly looking objects. Many Roman period brooches have previously been analysed, mainly using quantitative methods[25]. These results, from brooches recovered from the northern frontier provinces of *Britannia* and *Germania,* provide valuable comparative data when assessing production choices. With the help of this data we can present an updated multi-element analysis of

[14] Vassar 1943; Schmiedehelm 1955; Laul 2001; Rohtla 2005.

[15] E. g. Martinón-Torres et al. 2012; Olli / Roxburgh 2018.

[16] See Baumeister 2004.

[17] Craddock 1978, 8–9; Bayley / Butcher 1995, 13; Istenič 2005, 187–188.

[18] Bayley / Butcher 1995, 118.

[19] Dungworth 1997, 903.

[20] Heeren / van der Feijst 2017, 73.

[21] Dungworth 1997, 902.

[22] E. g. Craddock 1988; Unglig 1991; Bayley 1998; Hammer 1998; Bayley / Butcher 2004.

[23] Bayley / Butcher 2004, 15.

[24] E. g. Ckernykh / Hoferte / Barceva 1969.

[25] Riederer 1993; Rehren 2002; Bayley / Butcher 2004; Droberjar / Frána 2004; Roxburgh et al. 2016; Id. 2017.

eye brooches found in the eastern Baltic and subsequently formulate new hypotheses about their cultural associations.

Material

Many copper-alloy artefacts, including brooches, are regularly found together with the bones of the deceased when excavating *tarand* cemeteries – in which most of the material is severely commingled, mainly due to the ancient depositional practices[26]. The same cemetery enclosures were in use for a long period of time and therefore the mixture of items can date over several centuries, making it difficult to date items more precisely as their find context is not sealed[27]. Many of the items are thought to have been produced locally, but because of the uncertainty of the find context it is difficult to establish the extent of their period of use before they were deposited in the cemeteries[28]. Therefore an absolute chronology is difficult to establish and more emphasis has to be put on the study of their typological development, based on the construction, decoration and other characteristic elements. Useful comparisons can be made however to other associated artefacts which are well dated and found from closed find contexts, such as wealth deposits. These comparisons can suggest an overall date for some of their technological and constructional elements, and help to establish their broad period of use.

Around 200 eye brooches have been found so far from the *tarand* cemetery areas in Estonia and north Latvia[29]. Most are found in the north-eastern part of Estonia, but also from other areas in Estonia and north Latvia, but in much lower numbers[30]. From this number, those stored in different collections around Estonia are included in the study. Those that were not included are either in Latvian collections, in smaller museums, or lost. Also the brooches whose subtypes could not been precisely determined and atypical eye brooches were excluded from the final count. Subsequently, 88 brooches were included, most of which have been found in, or around these *tarand* cemetery burials (see *fig. 2*).

These brooches were selected for study to explore the hypothesis that a number of types were locally made and that their manufacture was influenced by imported brooches from other regions. Brooches were first introduced to the region at the beginning of the Roman Iron Age and the eye brooch series was chosen because they were the earliest type imported into Estonia[31]. That said, their exact place of origin is still uncertain. It is believed that local types of eye brooches developed from original imported ones and these local types were in use throughout the Roman Iron Age[32], therefore their development over time can be studied.

Eye brooches in Estonia are divided into three typological groups: the main series, Estonian series and Prussian series (see *fig. 3,1–4*). The eye brooches of the main series found in Estonia date from c. AD 50–150[33] and were classified according to the typologies proposed by Almgren[34]. The types Almgren 49–53 are present and are grouped within the broader main series classification. According to current thinking, they were introduced by

[26] Lang 2007, 206; Kivirüüt / Olli 2016.
[27] Ibid.
[28] Lang 2007, 206.
[29] Moora 1923, 118–120; Id. 1938, 58, 60, 64; Vassar 1943, 62; Schmiedehelm 1955; Laul 2001, 90.
[30] Schmiedehelm 1955, 200 fig. 56.
[31] Lang 2007, 206.
[32] Moora 1938, 60.
[33] Moora 1923, 116; Id. 1938, 57; Laul 2001, 90.
[34] Almgren 1897.

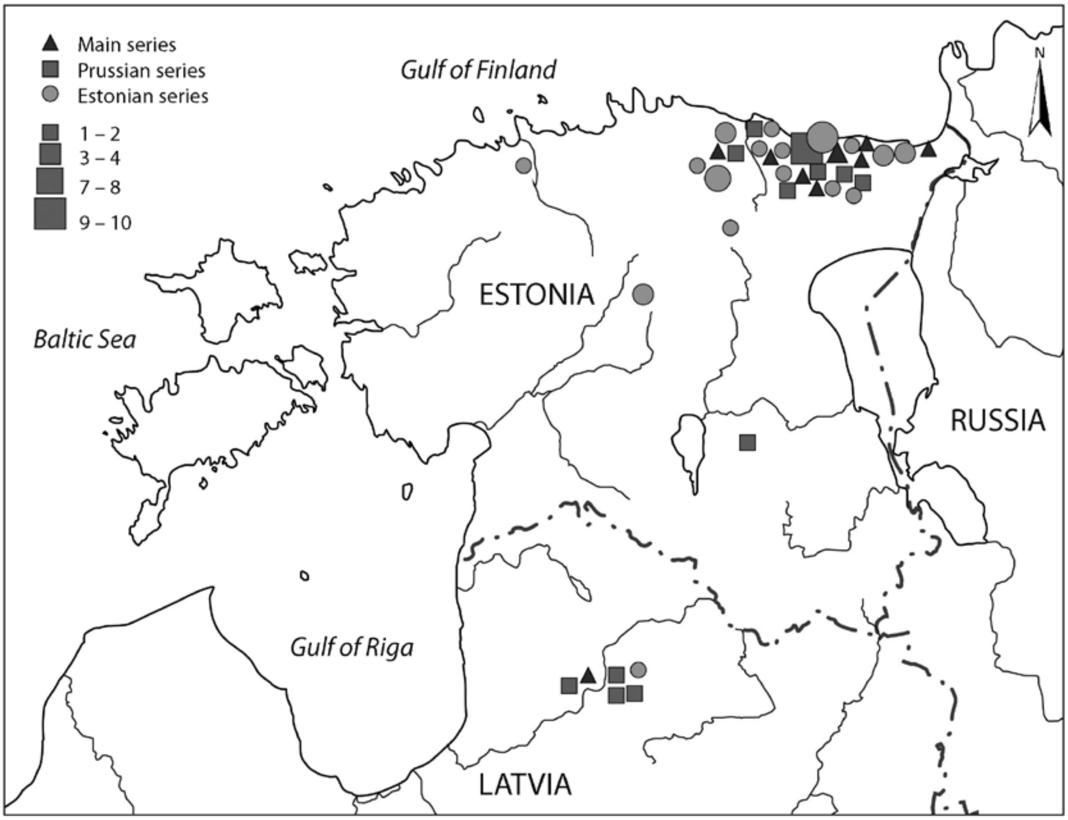


Fig. 2. Find locations of the brooches included in this study (in range 5–6 no brooches are present).

sea into north-east Estonia (in particular the region of Virumaa) from the Vistula river basin[35]. Another thought is that they were introduced by connections with Öland and Gotland[36], although this is less likely. The sea route hypothesis, rather than land or river, can also be supported by the fact that the main distribution area is north-east Estonia as shown in *figure 2*[37]. Although the Sambia Peninsula (Dollkeim-Kovrovo culture area) is thought to be a central trading area at the beginning of the Roman Iron Age[38], eye brooches of the main series are quite scarce there, the Vistula river basin is the area where most main series brooches have been found in the Baltic Sea region. Eye brooches of the main series have been dated in the Vistula river basin to c. AD 20–80 and the same in other regions or a little later[39]. In Lithuania, type Almgren 52 is the most common brooch found, which is dated there to c. AD 50–100[40].

According to Harri Moora (1900–1968), the brooches of the Estonian series, classified for Latvia and Estonia by Almgren as types 55–56, are thought to have developed from the main series from c. AD 50. He considered Almgren's type 49 (described as being from

[35] Moora 1938, 59.
[36] Chilińska-Früboes 2018, 33.
[37] Moora 1938, 58–59.
[38] Nowakowski 1998, 107.
[39] Kunow 1998b, 96 fig. 1; Schmiedehelm 2011, map IV; Nowakowski 2013, 132; Chilińska-Früboes 2018.
[40] Michelbertas 1986, 110.

the Roman Rhine provinces) to be a prototype for the Estonian series[41]. The brooches of the Estonian series have many features that differ from the main series, but it is difficult to date the different phases of development because of the commingled nature of the finds in the *tarand* cemeteries mentioned earlier. However, their area of geographical distribution primarily matches the area of *tarand* cemetery use, concentrating to the north-east part of Estonia, where presumably they were developed over time, with very few being exported to neighbouring areas, as very few have been found outside of the *tarand* cemetery area[42]. Moora suggested that the Estonian series can be divided into four groups[43]. The first group comprises the earliest specimens, which are quite similar to the main series especially in being one piece assemblies with their spring being hammered and turned out of the body of the brooch itself. They are also longer than the main series brooches, as is their spring. The hook is also widened and decorated, and the eyes are large and open, surrounded by circles. The second group has similar features, except that the brooches have multi-piece assemblies, the body being made separately to the spring. The second group evolves to the third group. Their features developed over time and the overall size increased. The main feature of the third group is that the needle is fixed around an axis, with the spring and the hook only having a decorative function. As the brooch itself is quite big, the spiral and the axis are also elongated and therefore two extra loops are added to hold the axis. Sometimes the hook is also "closed" as a sleeve. The brooches of the fourth group are hinged, having an axis inside a sleeve from which the needle pivots. The pin constructions of the third and fourth group are similar to other brooch type's pin constructions found in the research area, i. e. the north-east Baltic group of cross ribbed brooches *(Dreisprossenfibeln)* and crossbow brooches, dating from the 3rd to the 5th centuries AD[44]. These last two groups of eye brooches change in a similar fashion over time: the head grows and flattens, the eyes become smaller, the chord gets smaller and flatter and the needle holder gets longer and lower. Only a broad date of c. AD 50–200/300 can be given for groups 1 and 2, but for the larger variants of groups 3 and 4 a later date, c. AD 200/300–600, can be suggested. This is based on find contexts from wealth deposits and the above mentioned development of the pin constructions[45].

The brooches of the Prussian series found in Estonia form a very uniform group (Almgren's 57–61 types), however only types 60 and 61 were available in sufficient numbers to be included in the study. A60 and A61 brooches are distinguished from one another as A60 usually has a rectangular higher part between the bow and the foot, in some occasions the bow has a flat curved cross section and the profile of the brooch is rounder, as for A61 no higher part is present between the bow and the boot, the bow is flat *(fig. 3,4)* and the profile of the brooch is more rectangular. It has been suggested from their features that they originated from one centre, perhaps located somewhere in the territory of former East Prussia, as their concentration areas are the Sambia Peninsula, Masurian Lakeland and lower Vistula[46]. In Estonia and North-Latvia the Almgren 57–59 types have been dated to around AD 100, but the rest, including the Almgren 60 and 61 types are dated to c. AD 100–200[47]. In the Dollkeim-Kovrovo, Wielbark and Przeworsk culture areas the types A57–59 are approximately dated to the 1st century AD, which is also the

41 Moora 1923, 116.

42 Moora 1938, 61.

43 Moora 1923, 111–115.

44 Moora 1938, 87–88; Laul 2001, 105–106; Rohtla 2005, 134.

45 Based on Moora 1923; Id. 1938; Vassar 1943; Schmiedehelm 1955, 64.

46 Moora 1938, 65; Pfeiffer-Frohnert 1998; Mączyńska 2004, 214.

47 Moora 1938, 62–63.

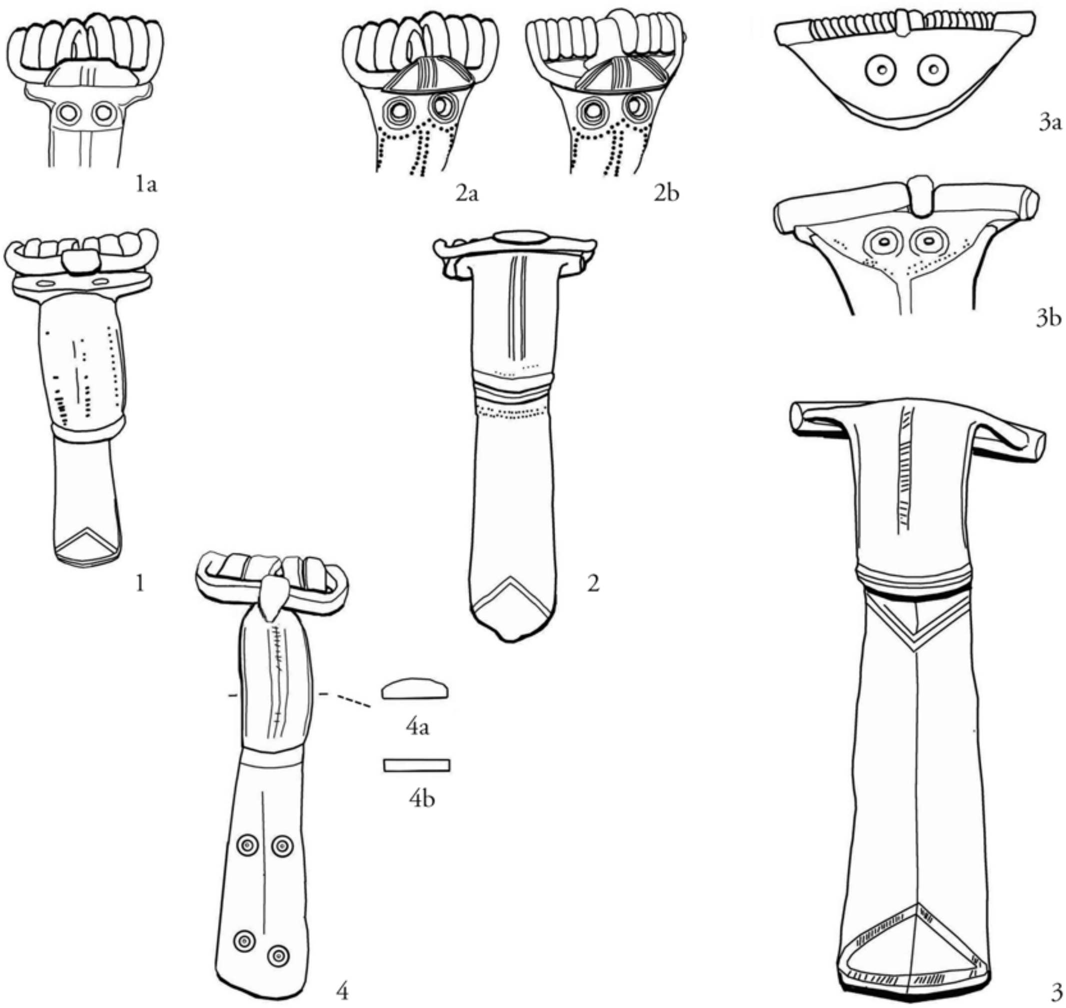


Fig. 3. Eye brooches from Estonia. 1 Main Series; 2 Estonian Series, a 1st group, b 2nd group; 3 Estonian Series 3rd group, a spring, b hinge; 4 Prussian Series, a A60, b A61.

period when the A60 brooches mostly occur and the A61 start to appear; brooches A60 and A61 are in circulation together during the first half of the second century[48]. In West-Lithuania the Prussian series are dated to c. AD 100–150. In the rest of Lithuania, the Prussian series has been dated c. AD 75–200, with Almgren types 60 and 61 c. AD 100–200[49]. Therefore the dating of the eye brooches of the Prussian series is broadly consistent over this larger region, covering the first two centuries AD.

To sum up, the timespan for the use of Main Series brooches is c. AD 50–150, the Estonian Series, c. AD 50–600, and the Prussian Series c. AD 100–200.

48 Dąbrowska 1997, 115; Mączyńska 2004, 213; Id. 2014; Chilińska-Früboes 2017, 54.

49 Michelbertas 1986, 110; Nowakowski 2013, 134–135.

Sample	Cu (av.)	Sn (av.)	Zn (av.)	Pb (av.)
Niton Analyser				
bronze	79.0	15.0	0.0	5.5
brass	84.0	0.0	12.0	4.5
gunmetal (+Sn)	80.5	10.0	4.5	5.5
gunmetal (+Zn)	79.5	6.0	8.0	6.5
Bruker Analyser				
bronze	76.0	16.5	0.0	7.5
brass	82.5	0.5	12.0	5.5
gunmetal (+Sn)	79.0	10.0	4.5	6.5
gunmetal (+Zn)	79.5	5.5	8.0	7.0

Tab. 1. Comparison of measurements of two machines.

Method

The device used to gather the compositional data was a handheld, portable, X-ray fluorescence spectrometer, which has the advantage of being easily transported to museums and other temporary sites of use. These devices can also be operated on a portable test bench, which can conveniently be set up to provide a more stable working environment[50]. A Bruker tracer IIIsd device was used for this study and it was fitted with the yellow filter (position 1) – dry air atmosphere – as recommended for the high mass elements found in copper-alloys and set to 40 kev – 10 µm. After trial testing at differing time intervals, the signal was found to be stable at 60 seconds. These settings were subsequently maintained throughout the data-gathering phase. Also, the analyser was mounted to its portable test bench to achieve a consistent operating environment. The output was saved in PDZ file format, which allowed the spectra to be individually checked for inconsistencies with the manufacturers dedicated S1PXRF software. To convert the data into quantitative chemical weights (in %), a manufacturer supplied copper-alloy calibration (Cu1) was used. The elements measured through this calibration were Mn, Fe, Co, Ni, Cu, Zn, As, Pb, Bi, Zr, Nb, Ag, Sn, Sb.

One measurement per brooch was undertaken, on the centre of the bow when possible, or otherwise a relatively flat surface on the front of the head or foot. An external normalisation of the completed dataset was then undertaken in Microsoft Excel™ to correct for contamination from soil and other light element residues. The alloying elements Cu, Sn, Zn, Pb were then normalised on a light element free basis. To aid comparison and measurement repeatability on other machines the calibration of the Bruker analyser was compared against a Niton XL 3t GOLDD XRF analyser, using a shared set of copper-alloy samples. The Niton analyser (belonging to the Cultural Heritage Agency of the Netherlands) had previously been checked against the CHARM heritage alloys reference set, the details of which are published elsewhere[51]. The measurements from both machines are presented in *Table 1*. It can be seen that there is a small variation between the two machine

[50] For more details see Potts / West 2008; Shackley 2011; Shugar / Mass 2012.

[51] See Heginbotham et al. 2015; Roxburgh et al. 2016, 411.

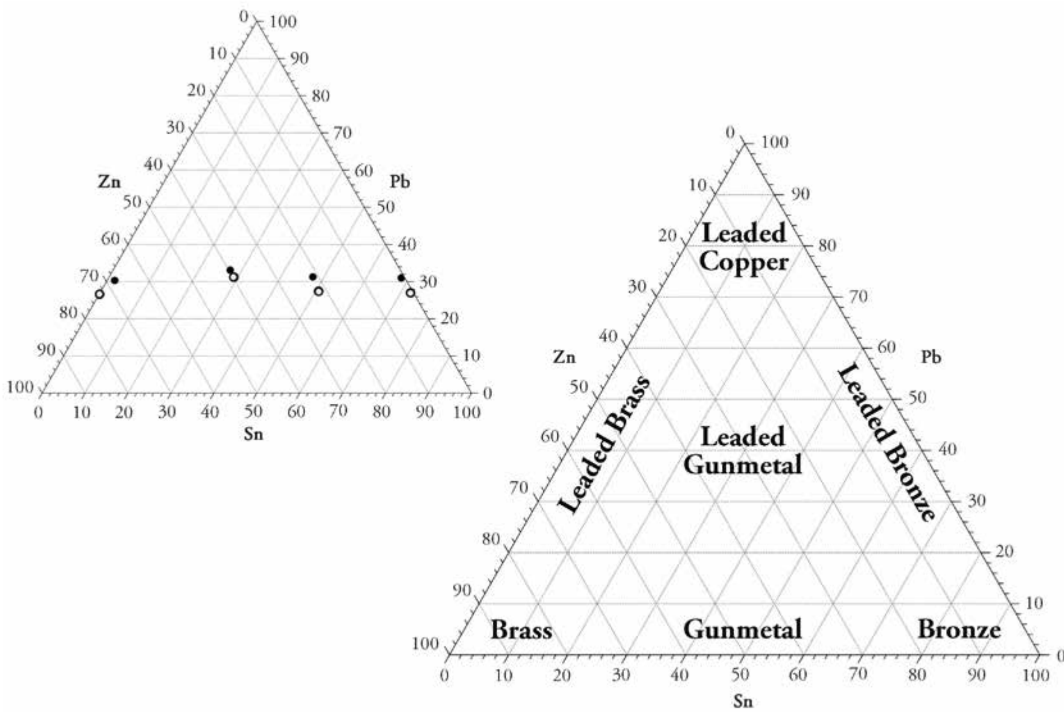


Fig. 4. Above – the classification scheme (after Bayley / Butcher 2004, fig. 7). Below left – eye brooch results from Nijmegen, below right eye brooch results from Kempten-Cambodunum, visualised in ternary diagrams.

measurements. This small variation however does not impede the approach employed in this paper.

The measurements were taken on the uncleaned surfaces in line with earlier studies[52]. This non-destructive approach is effective for the basic identification of alloy types[53], as once interesting alloy groups are identified, the data is interpreted in a qualitative manner (e. g. if it is brass or bronze), following the method by Roxburgh et al.[54]. This method was adopted rather than applying the destructive sampling regime needed to gain quantitative data (e. g. to establish an exact numerical value for the ingredients present in each brooch). This would have required damaging a large number of artefacts; a method that would be unacceptable to most museum curators and artefact owners. The method accepts that there are systematic compositional differences in measuring corroded outer surfaces versus the inner core, but argues that the magnitude of these differences are only relevant to the type of research question you are asking. Identifying basic trends in alloy choice, visible when measuring large datasets, has been shown to be a relevant application of this technology, as the compositional ratios remain within a satisfactory tolerance. Our measurements where subsequently classified in line with the scheme espoused by Bayley and

[52] Tate 1986; Lutz / Pernicka 1995; Bayley / Butcher 2004; Roxburgh et al. 2016; Roxburgh et al. 2018.

[53] Tate 1986, 23.

[54] Roxburgh et al. 2018; also see Rehren 2002, 146.

Butcher[55], and as part of their methodology they effectively used ternary diagrams to visualise the three alloying elements, lead, tin and zinc, to display how clusters of measurements relate to each other (*fig. 4* above). This visualisation method is also adopted here. The results presented in the following section comprise of measurements taken on corroded outer surfaces. Previous research has suggested that the main surface changes are decuprification, the leeching of copper from the outer surface of the brooch and similarly – but also to a lesser extent – dezincification, the leeching of zinc[56]. The results therefore, for interpretation purposes, must consider a bias towards higher original copper and zinc levels, when discussing the original brooch compositions. This can be seen when comparing measurements from eye brooches recovered from Nijmegen, the Netherlands and Kempten-Cambodunum, Germany (*fig. 4* below left and right)[57]. The former shows an XRF analysis of a corroded outer surface, with a dispersed result due to zinc loss from corrosion. The latter shows a tight cluster of measurements taken from the clean inner core of the brooches. Both results indicate that brass was consistently chosen for the production of these items. Previous studies have shown that many Roman brooches were made in brass – possibly for a time production was reserved to the *fabricae* of legionary fortresses such as at Xanten, Germany[58] – but equally quite a number of other brooch types were also made in gunmetal or bronze[59]. It is this choice that we are interested in visualising.

Results

The measurements presented in this section are visualised using ternary diagrams to enable better comparison with previous results as well as enabling better interpretation of trends within the alloying metals *(fig. 5)*. The ternary diagrams visualise the ratios of the alloying components, tin, zinc, and lead, whereby each black dot in the diagram represents the measurement taken from one brooch. The chronology of the three series runs parallel for some years but the results begin with specimens from the main series as they are potentially the earliest – and then progress through the Estonian and Prussian series. A set of numerical results including copper is provided in the *Appendix*.

Discussion

As mentioned earlier, although personal copper-alloy ornaments existed before the Roman period, the main series are the first brooch types found in the region. The most important feature we have identified is that they were made in a brass technological tradition, not a gunmetal or a bronze tradition. This would very likely make them the earliest mass produced brass objects found in the region. The ternary diagram *(fig. 5a)* visualises these results and as mentioned earlier, dezincification from the corrosion process will have reduced the amount of zinc measured on their surfaces, but it is still evident that they were consistently made using a brass alloy. This choice of alloy is consistent with that chosen for a large number of early Roman brooch types in North Western Europe, including the earliest Roman military types, especially for the eye series found along the frontier

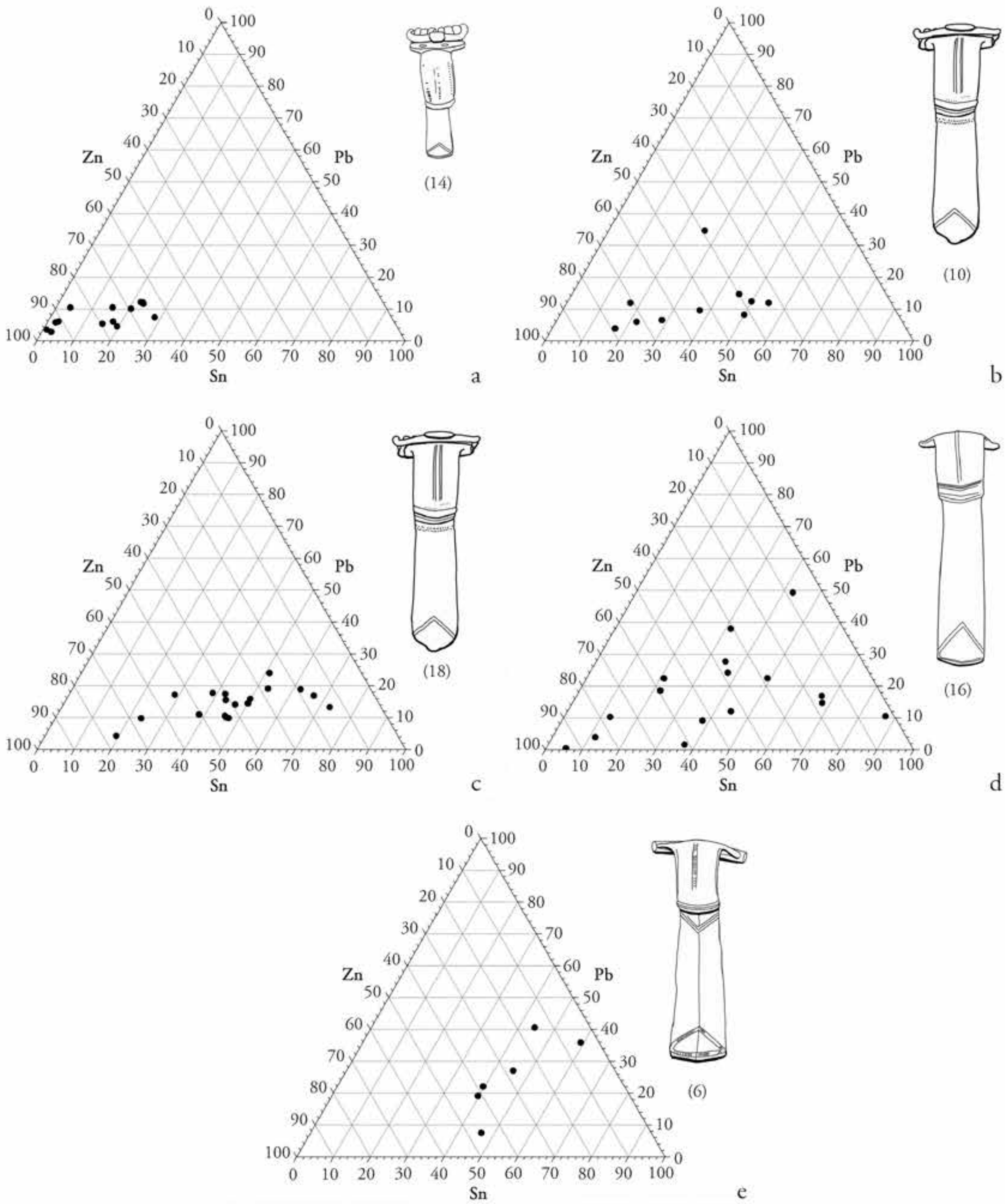
[55] Bayley / Butcher 2004, 24.

[56] Robbiola et al. 1998, 2108; Chiavari et al. 2007; also see Roxburgh et al. 2016, fig.1c for expected deviation due to corrosion.

[57] See Roxburgh et al. 2018, fig. 2 and Riederer 1993, 47 tab. 1.

[58] Rehren 1999.

[59] For numerous examples see Roxburgh et al. 2017, 185 fig. 5,3.9–16.



region of *Germania Inferior*[60]. The results are also comparable to the examples from Nijmegen and Kempten shown in *figure 4* and also with Xanten[61]. Brass can be considered a typical alloy used in early Roman production and the main series found in Estonia, also being in brass, can be compared to parallels found much closer to the Roman frontier[62]. It is has been suggested by Hans-Ulrich Voss that Germanic craftsmen north of the frontier imported material for their non-ferrous metalworking which, if this is the case, would likely have included brass in the form of ingots or scrap for recycling. Furthermore, Ger-

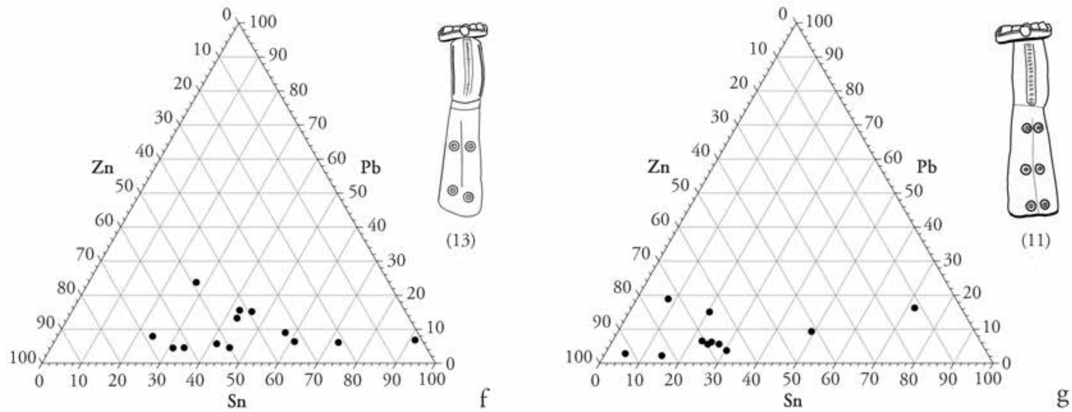


Fig. 5. Ternary diagrams visualising the results as ratios of alloying elements. a Main series; b Estonian Series 1st group; c Estonian Series 2nd group; d Estonian Series 3rd group; e Estonian Series 4th group; f Prussian Series, A60; g Prussian Series, A61.

manic craftsmen from the 1st century AD onwards are thought to have been highly skilled, implying that eye brooch production would have been well within their capability[63]. But Voss goes on to suggest that the high quality goods found in Germanic graves could also have been made in the Roman provinces for rich Germanic customers[64]. Droberjar and Frána suggest for Bohemia that Roman and Germanic brass was fairly indistinguishable, but was frequently being made with a high zinc content. They also propose that there was a strong trade in brass into the Barbaricum during the early Roman period[65].

The standard use of brass in the production of main series brooches may therefore indicate closer contact with the Roman world than previously thought, as at first local copies could easily have been made in bronze, the commonly available alloy before the Roman period. This copying in an established bronze technological tradition could have continued as long as fresh supplies of copper and tin were available, however brass must have quickly become the preferred new alternative in local production, either entering the region as brass ingots (although none have yet been found), or as brass objects became available as scrap. It would have been needed, for example, to produce objects in gunmetal. The simplest scenario therefore is that the main series brooches arrived in the region, possibly alongside other 'foreign' brass objects, in such quantities that brass became the dominant alloy. It has already been proposed that these brooches arrived by a sea route rather than by land or river, from the Vistula river delta[66], but as their alloy resembles that from the Roman world, it is also possible that brooches from Roman or Germanic production centres reached northern Estonia. The date given for the eye brooches found along the Rhine is c. AD 15–70, which is a slightly earlier start than suggested by Moora for the main series. But considering the problems of dating mentioned earlier and a possible delay of goods moving between trading centres, there is a reasonable time overlap. It is

[60] Roxburgh et al. 2017, 258.
[61] See ibid. fig. 3, and Rehren 2002, 149–151.
[62] See fig. 4.39, type 20d, and also fig. 4.40 for parallels in Heeren / Van Der Feijst 2017, 72–75.
[63] Voss 2016, 139.
[64] Ibid. 155.
[65] Droberjar / Frána 2004, 462.
[66] Moora 1938, 58–59.

Region	Find ID	Description	Date c.	Cu	Zn	Pb	Sn
Latvia	AI1378:2	Main series	AD 50–150	79	14	2.5	4.5
Estonia	AI2617:201	Main series	AD 50–150	63	34	2	1
Estonia	AI2617:95	Main series	AD 50–150	89.5	8.5	0.5	1.5
Estonia	A83:1	Main series	AD 50–150	81	6.4	0.5	1.5
Estonia	AI2496:72	Main series	AD 50–150	88	7	1.5	3.5
Estonia	AI2736:1	Main series	AD 50–150	92	7.5	0	0
Estonia	AI2617:208	Main series	AD 50–150	87	8.5	1.5	3
Estonia	AI2834:8	Main series	AD 50–150	86.5	10.5	0.5	2.5
Estonia	AI7170:10	Main series	AD 50–150	88	8	0.5	0
Estonia	A110:3	Main series	AD 50–150	84	5.5	0.5	2.5
Estonia	A110:4	Main series	AD 50–150	88.5	7	0.5	0
Estonia	A111:2	Main series	AD 50–150	84.5	6.5	1	1.5
Estonia	A297:2	Main series	AD 50–150	73.5	7	1.5	2.5
Estonia	A297:3	Main series	AD 50–150	84	6.5	1	2
Estonia	AI2470:2	Main series	AD 50–150	90	4.5	0.5	0
Estonia	AI2485:11	Estonian series, Group 1	AD 50–200/300	85	8	0.5	2.5
Estonia	AI2488:43	Estonian series, Group 1	AD 50–200/300	74	9.5	1.5	2.5
Estonia	A297:31	Estonian series, Group 1	AD 50–200/300	82	11	0.5	2.5
Estonia	AI2485:13	Estonian series, Group 1	AD 50–200/300	89	2.5	1	2.5
Estonia	A83:2	Estonian series, Group 1	AD 50–200/300	87	5	1	1
Estonia	A83:3	Estonian series, Group 1	AD 50–200/300	75.5	7	1.5	0.5
Estonia	AI3737:2	Estonian series, Group 1	AD 50–200/300	85	2.5	2	1.5
Estonia	AI3737:5	Estonian series, Group 1	AD 50–200/300	66	9	3	12
Estonia	AI3990:21	Estonian series, Group 1	AD 50–200/300	78	4.5	1.5	7.5
Estonia	AI3172:921	Estonian series, Group 1	AD 50–200/300	87.5	5.5	0.5	2.5
Estonia	AI2617:147	Estonian series, Group 2	AD 50–200/300	61	7	1.5	7.5
Estonia	AI2655:4	Estonian series, Group 2	AD 50–200/300	77	8	2	8
Estonia	AI2486:95	Estonian series, Group 2	AD 50–200/300	62.5	7.5	7	15
Estonia	AI2655:471	Estonian series, Group 2	AD 50–200/300	74	5.5	4	10.5
Estonia	AI2834:1	Estonian series, Group 2	AD 50–200/300	75.5	8	1	2.5
Estonia	AI3735:2	Estonian series, Group 2	AD 50–200/300	58	7	3	7
Estonia	AI2486:84a	Estonian series, Group 2	AD 50–200/300	80	4.5	2	6.5
Estonia	AI2511:1	Estonian series, Group 2	AD 50–200/300	76.5	4.5	2	6.5
Estonia	AI3358:251	Estonian series, Group 2	AD 50–200/300	84.5	9.5	0.5	2.5
Estonia	A110:5	Estonian series, Group 2	AD 50–200/300	81	4.5	1.5	5
Estonia	A85:1	Estonian series, Group 2	AD 50–200/300	67	10	4	8.5
Estonia	A110:7	Estonian series, Group 2	AD 50–200/300	72	3	3.5	13
Estonia	A110:8	Estonian series, Group 2	AD 50–200/300	73	6.5	2.5	7
Estonia	AI3323:210	Estonian series, Group 2	AD 50–200/300	61.5	3.5	3.5	19

Appendix. Numerical results of the components copper, tin, lead, and zinc of the measurements of 89 copper-alloy fibulae.

Region	Find ID	Description	Date c.	Cu	Zn	Pb	Sn
Estonia	AI2432:1	Estonian series, Group 2	AD 50 – 200 / 300	61	5	5	17
Estonia	AI3737:3	Estonian series, Group 2	AD 50 – 200 / 300	78	6.5	1.5	7
Estonia	AI3737:1	Estonian series, Group 2	AD 50 – 200 / 300	79	7.5	1.5	5.5
Estonia	AI3905:19	Estonian series, Group 2	AD 50 – 200 / 300	74.5	8.5	2.5	4.5
Estonia	AI2012I:2	Estonian series, Group 3	AD 200 / 300 – 500	77.5	5.5	7	5.5
Estonia	AI2485:12	Estonian series, Group 3	AD 200 / 300 – 500	82.5	5	1.5	5
Estonia	AI2643:364	Estonian series, Group 3	AD 200 / 300 – 500	90	4.5	1.5	1.5
Estonia	AI2719:3	Estonian series, Group 3	AD 200 / 300 – 500	80.5	4.5	2.5	4
Estonia	AI2012I:4	Estonian series, Group 3	AD 200 / 300 – 500	79	16.5	0	1
Estonia	AI2604:472	Estonian series, Group 3	AD 200 / 300 – 500	77	10.5	0.5	6.5
Latvia	AI1243:1	Estonian series, Group 3	AD 200 / 300 – 500	72	3	3.5	13
Estonia	AI3735:1	Estonian series, Group 3	AD 200 / 300 – 500	83.5	1	5.5	5
Estonia	AI3358:293	Estonian series, Group 3	AD 200 / 300 – 500	81.5	3.5	2.5	6
Latvia	AI1237:8	Estonian series, Group 3	AD 200 / 300 – 500	64	4.5	4	17.5
Estonia	A9:1	Estonian series, Group 3	AD 200 / 300 – 500	78.5	13	1.5	2
Estonia	AI2485:16	Estonian series, Group 3	AD 200 / 300 – 500	84.5	6	1	4.5
Estonia	AI2485:17	Estonian series, Group 3	AD 200 / 300 – 500	84	6	2.5	2
Estonia	AI2488:5	Estonian series, Group 3	AD 200 / 300 – 500	80.5	6	4.5	5.5
Estonia	A110:9	Estonian series, Group 3	AD 200 / 300 – 500	52	1	4	33
Estonia	AI2604:11	Estonian series, Group 3	AD 200 / 300 – 500	78.5	14.5	0.5	2
Estonia	AI2485:15	Estonian series, Group 4	AD 200 / 300 – 500	72	2.5	7.5	8
Estonia	AI2834:2	Estonian series, Group 4	AD 200 / 300 – 500	80	0.5	4.5	7.5
Estonia	AI2012I:3	Estonian series, Group 4	AD 200 / 300 – 500	90.5	2.5	1	2.5
Estonia	AI1091:2	Estonian series, Group 4	AD 200 / 300 – 500	69.5	8	4.5	8.5
Estonia	AI2488:26	Estonian series, Group 4	AD 200 / 300 – 500	80	6	1	6
Estonia	AI2643:137	Estonian series, Group 4	AD 200 / 300 – 500	78	4.5	4.5	7
Estonia	A111:15	Prussian series A60	AD 100 – 200	73.5	7.5	3	7.5
Estonia	A297:4	Prussian series A60	AD 100 – 200	78	8.5	1	8
Estonia	A297:5	Prussian series A60	AD 100 – 200	72	0.5	1.5	19.5
Latvia	AI1250:3	Prussian series A60	AD 100 – 200	69	7	2	12
Latvia	AI1251:1	Prussian series A60	AD 100 – 200	72	4.5	1	14.5
Latvia	AI1378:1	Prussian series A60	AD 100 – 200	83	4	1.5	4.5
Estonia	AI2571:2	Prussian series A60	AD 100 – 200	81	7	1	2.5
Estonia	AI2617:111	Prussian series A60	AD 100 – 200	69.5	11	3.5	11
Estonia	AI2834:6	Prussian series A60	AD 100 – 200	76	12.5	1	6
Estonia	AI3737:6	Prussian series A60	AD 100 – 200	71	7	1.5	13
Estonia	AI3905:20	Prussian series A60	AD 100 – 200	77	9.5	1	7.5
Estonia	AI7170:7	Prussian series A60	AD 100 – 200	79	8.5	0.5	4.5
Estonia	TÜ2886:1	Prussian series A60	AD 100 – 200	86	3	1.5	1.5
Estonia	A83:5	Prussian series A61	AD 100 – 200	83	5	1	1.5
Latvia	AI1250:1	Prussian series A61	AD 100 – 200	60.5	3	4	18

Appendix (continued).

Region	Find ID	Description	Date c.	Cu	Zn	Pb	Sn
Latvia	AI2549:1	Prussian series A61	AD 100–200	76.5	5.5	1.5	6.5
Estonia	AI2617:98	Prussian series A61	AD 100–200	82	9	0.5	4
Estonia	AI2834:4	Prussian series A61	AD 100–200	87.5	6	0.5	2.5
Estonia	AI2834:5	Prussian series A61	AD 100–200	80	9	1	3
Estonia	AI3172:917	Prussian series A61	AD 100–200	78.5	10	1	3.5
Estonia	AI3172:934	Prussian series A61	AD 100–200	82	13	0.5	0.5
Estonia	AI3172:98	Prussian series A61	AD 100–200	72	10.5	1	3.5
Estonia	AI3358:264	Prussian series A61	AD 100–200	85.5	9.5	0.5	1.5
Estonia	AI3990:48	Prussian series A61	AD 100–200	83.5	3	1	0.5

Appendix (continued).

thought, however, that in the Roman world at least brass was withdrawn from widespread circulation towards the end of the 1st century, being replaced by production in gunmetal, possibly as a technical preference rather than a loss of brass making *per se*[67]. Dungworth argued that whilst this loss of brass production has been seen by some as evidence of a technological or economic problem affecting the Roman world, the amount of brass being produced across Europe could well have been absorbed into an increasingly larger demand for gunmetal[68]. Either way, this puts the later 2nd century date for the main series under scrutiny because this would mean that their production in brass – in the Baltic region – continued long after the Roman world's transition to gunmetal. It is more likely therefore that the main series have a 1st century origin but could have been in circulation, perhaps for cultural reasons a little later in Estonia. Otherwise we may expect later specimens to have been locally copied in gunmetal, which is not the case.

Group 1 of the Estonian series shows a relatively even split between production in brass and gunmetal *(fig. 5b)*. This group is believed to have been a local development, copying imported main series brooches. The brass brooches may have been produced from melting imported brass objects, possibly through the recycling of old, unserviceable, main series brooches. The gunmetal brooches were created by mixing brass with some bronze, either deliberately, or in the melting of mixed scrap. This may have happened to make up volume if there was a shortfall of brass for production, or equally may reflect a change in preference for production in gunmetal, possibly making them later in date than those made in brass.

Group 2 of the Estonian series is also thought to be a local development whose main feature is that the body of the brooch is made separate from the spring. The results are comparable to those for group 1 but with the majority of the brooches being produced in gunmetal *(fig. 5c)*. Production in gunmetal may also be associated with recycling of scrap brass and bronze items, perhaps where it was easier than sorting old scrap items back into brass and bronze groups[69]. A benefit of casting the body separate would have been that alloy choice would have been more flexible, better suited to using recycled alloy with an

[67] Dungworth 1996, 228–234; Ibid. 1997, 907; Rehren 2002, 150.

[68] Dungworth 1997, 903.

[69] Ibid. 909.

uncertain proportion of lead. Following on from the idea that the earliest group 1 brooches may have been in brass, the relative lack of brass in group 2 may indicate a slightly later starting date for this group, but still broadly contemporary to group 1. This is because they share many stylistic similarities between the two groups, but the technological developments in the construction (multi-piece assemblies) make them later in date, typologically speaking.

The brooches of group 3 are later in date and were also multi-piece assemblies as per group 2. But in contrast to the groups mentioned earlier a much wider number of alloy choices seem to have been employed *(fig. 5d)*. This is especially true of lead content, which is higher and more variable than in previous groups. As the brooch is a multi-piece assembly, the body could have been cast in any of the alloy ratios seen here. As mentioned earlier, the size of brooches increases considerably during this period, therefore the higher lead content may well have been a deliberate choice, to improve the casting and cold working properties of these larger brooches[70]. That said, the dispersed nature of the measurements is unusual comparing the previous results and previously mentioned literature. It has been suggested that changes in artefact production can be an important indicator when studying the complexity of a regional economy[71]. It is thought that there was considerable economic change in the region at this time due to the disruption of trade along the amber road and with that the influences from the Dollkeim-Kovrovo culture area[72]. In this scenario an irregular and inconsistent supply of metal from the south may have resulted in local craftsmen being more opportunistic in their choice of alloy, perhaps witnessed by the wider range of alloys seen in these results.

Group 4 has a contemporary date to group 3, but with a hinge construction rather than a spring. The results are comparable to group 3 in that the lead content varies significantly, but production – in leaded gunmetal – is more consistent *(fig. 5e)*. This suggests a different organisation of production to group 3 even though they are contemporary. Another workshop or group of craftsmen can be suggested, who might have been familiar with making different kinds of pin construction systems but still stayed within the stylistic form of past eye brooches. The large size, the skilful execution, and the attention to detail of the group 3 and 4 brooches are remarkable – which shows the high level of craftsmanship present in the region at this time.

As mentioned earlier, production in brass is typical in the Roman world during the 1st century AD, with a transition to production in gunmetal around the beginning of the 2nd century. The results for Prussian type A60 suggest a preference for production in gunmetal, whereas the preference for Prussian type A61 is brass (see *figs 5f* and *5g*). This would suggest that A61 is the earlier of the two, more suited to a 1st century context, with A60 more likely to have been in circulation during the 2nd century. There are also some strong similarities to the Prussian types found in the Rhine area, which date to around AD 50–100, which were also produced in brass[73]. Therefore it is likely that the Prussian A61 group is contemporary to these examples from the Rhine area. It was suggested by Moora that the Prussian series might have come from a central source, perhaps somewhere in East Prussia, as attested by the many examples found in cemeteries there[74]. But as men-

70 Bayley / Butcher 2004, 15–16.

71 Wickham 2005, 700.

72 Nowakowski 1998, 107.

73 See type 20f in Heeren / Van Der Feijst 2017, 71–76; and also type 20, fig. 5.3.6 in Roxburgh et al. 2017, 251.

74 E. g. Dąbrowska 1997; Pfeiffer-Frohnert 1998; Jaskanis 2005.

tioned earlier, these items are highly portable and found from such a large area that their find locations should not automatically infer local production, rather than just being easily available, cheap and fashionable clothes fasteners at that time. The high numbers have also lead to the thought that they were mass produced, particularly because of their relatively poor workmanship[75]. The distribution area of Prussian eye brooches in ancient times included a large stretch of Baltic Sea coastline and also local access to the southern hinterlands via the Vistula river delta and was the start of the amber trade route to Rome and the south. The archaeological evidence for Prussian brooch production takes us much further south. A large production centre for the Prussian type has been discovered at Augsburg, in Bavaria (Southern Germany), which in Roman times was part of the province of *Raetia*[76]. This production centre is quite some distance from the main distribution area for eye brooches, which have previously been referred to as a Germanic type because they are typically found along the continental North Sea coastline, southern Scandinavia and the Baltic States[77]. This has led to hypotheses that these brooches were either an export product destined for the Germanic market, or produced for Germanic soldiers serving in the Roman army, who took them back to their homelands once their service period was completed[78].

It is clear that large-scale brass production took place in the Roman world during the 1st century AD. But the evidence also suggests that brass had spread to the barbarian regions of northern Europe during this time as well, either as traded raw material such as ingots and scrap metal, or as semi- or finished products. If it was still a typical Roman alloy by this time then the Prussian A61 group could well have been an export item to the Germanic North, perhaps from somewhere in the Northern Roman provinces such as *Raetia*. Following these hypotheses the Prussian A60 group – made in gunmetal – if existing at the same time, could possibly have come from a different production centre. These brooches could have been made from recycled objects, perhaps in a more northerly area where production in brass was not very well established.

The alternative hypothesis is that the gunmetal Prussian A60 group replaces the A61 brass group, still being produced consecutively in Roman centres or East Prussia or even closer to their Northern find locations. Finally if we consider the hypothesis of soldiers returning from Roman service, then again the brass series may fit with Roman military items returning home with retiring soldiers. The gunmetal series could then be related to a growing local demand for Prussian style brooches, perhaps copying these military items and perhaps a precursor to the development of the local Estonian series in terms of their alloy composition.

If we accept the hypothesis that the earliest main series and Prussian series were imports, evidenced by their typological and alloy similarities to eye brooches found in *Germania* and the Roman provinces, then the people in north-eastern Estonia considered them to be important enough to want to copy them in both the stylistical and technological manner of the main series brooches. Perhaps as their aesthetical and original symbolic meaning was suitable for this and accepted by the local culture. When local production of the first Estonian brooches began (the Estonian series), they started to develop them by bringing in adaptations in the alloy composition and stylistic features of the brooches, in accordance to the local preferences and the development of technological capabilities. The for-

[75] Chilińska-Früboes 2017, 50.

[76] Voss 2008.

[77] See fig. 8.11 in Heeren / Van Der Feijst 2017, 380 for European distribution map of Prussian series.

[78] Ibid. 75–76.

eign visual element, perhaps with handed down knowledge of their non-local origin, suited the local cultural system and gained acceptance by the people for several centuries, long after eye brooches fell out of use in the Roman and Germanic areas. Although the eye brooches of the Prussian series were used by the locals in the *tarand* cemetery area in the 2nd century AD, unlike the main series brooches they were not developed further to suit local tastes. Perhaps they were considered to be too "ordinary" a commodity or too foreign, to reproduce them.

Conclusions

In this article we took a new look at the nature of contact this region had with other parts of the Barbaricum and the Roman world beyond. This was done by an innovative use of pXRF to perform a compositional study of a number of important brooch forms to assess the consistency or otherwise of alloy choice and to compare the results with published data from the northern Roman frontiers. Small, personal items such as eye brooches were highly portable, therefore their find locations, especially at burial sites, could be a considerable distance from their place of production, especially when they are found distributed over a large area, like the brooches of the Main and Prussian series. Our aim was to extend the understanding of how production was organised in the context of local production versus long-range exchange.

The alloy results showed that the brooches of the Main Series were very similar to those found much nearer to the Northern Roman frontier. This supports the notion that the brooches were either imports, possibly from as far south as the Roman provinces themselves, or at least made from raw material traded into the Barbaricum out of the Roman provinces. The alloy results for the Prussian Series also suggest that they were imported from the south, perhaps originally from the production centre in *Raetia* or other similar centres in the Roman provinces, but with possible later production in the north, perhaps somewhere in East Prussia. The earliest of the Estonian Series – groups 1 and 2 – were made in a similar alloy to the Prussian A60 group. Estonian Series groups 1 and 2 are considered to be the first local copies of imported eye brooches, with groups 3 and 4 subsequently being refined local developments from groups 1 and 2.

In conclusion this study contributes to our understanding of brooch production within the study area and provides a useful comparison for similar research on production in Germania and the Northern Roman provinces. Future excavations of settlement sites will hopefully produce more production related evidence, but in the meantime our paper opens up wider discussions regarding long distance connections between the eastern Baltic and the Roman world, through fresh thoughts on the nature of imported brooches and the long-term traditions that continue in local production.

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Bibliography

Almgren 1897
O. Almgren, Studien über nordeuropäische Fibelformen der ersten nachchristlichen Jahrhunderte mit Berücksichtigung der provinzialrömischen und südrussischen Formen (Stockholm 1897).

Andrzejowski / Madyda-legutko 2011
J. Andrzejowski / R. Madyda-legutko, Bronze belt buckles with doubled tongue between Scandinavia and the Black Sea. In search of local and inter-regional connections during the Roman Period. In: I. Khrapunov / F.-A. Stylegar (eds), Inter Ambo Maria: Contacts Between Scandinavia and the Crimea in the Roman Period. Kulturhist. Rapporter 10 (Kristiansand 2011) 6–25.

Banyté-Rowell 2013
R. Banyté-Rowell, Baitai Cemetery Grave 37 – an inspiration to return to the question of contacts between Western Balt Areas in Late Roman Period (Baitų kapinyno kapas 37 – inspiracija grįžti prie vakarų baltų arealų ryšių vėlyvuoju romėniškuoju laikotarpiu klausimo). Arch. Lituana 14, 2013, 157–180.

Baumeister 2004
M. Baumeister, Metallrecycling in der Frühgeschichte. Untersuchungen zur technischen, wirtschaftlichen und gesellschaftlichen Rolle sekundärer Metallverwertung im 1. Jahrtausend n. Chr. Würzburger Arbeiten Prähist. Arch. 3 (Rahden / Westf. 2004).

Bayley 1998
J. Bayley, The Production of brass in antiquity with particular reference to Roman Britain. In: P. Craddock (ed.), 2000 Years of Zinc and Brass. British Mus. Occasional Paper 50 (London 1998) 7–27.

Bayley / Butcher 1995
J. Bayley / S. Butcher, The composition of Roman brooches found in Britain. In: S. T. A. M. Mols / A. M. Gerhartl-Witteveen / H. Kars / A. Koster / W. J. Th. Peters / W. J. H. Willems (eds), Acta of the 12th Congress on Ancient Bronzes. Nederland archeologische rapporten 18 (Nijmegen 1995) 113–119.

Bayley / Butcher 2004
J. Bayley / S. Butcher, Roman Brooches in Britain: A Technological and Typological Study based on the Richborough collection. Reports Research Committee Soc. Ant. London 68 (London 2004).

Bitner-Wróblewska 2008
A. Bitner-Wróblewska, Observers or participants? The Balts during turbulent epoch. In: B. Niezabitowska-Wiśniewska / M. Juściński / P. Łuczkiewicz / S. Sadowski (eds), The Turbulent Epoch. New Materials from the Late Roman Period and the Migration Period 1. Mon. Stud. Gothica 5 (Lublin 2008) 97–112.

Chiavari et al. 2007
C. Chiavari / K. Rahmouni / H. Takenouti / S. Joiret / P. Vermaut / L. Robbiola, Composition and electrochemical properties of natural patinas of outdoor bronze monuments. Electrochimica Acta 52, 2007, 7760–7769.

Chilińska-Früboes 2017
A. Chilińska-Früboes, Zapinki oczkowate serii pruskiej z terenu kultury Dollkeim-Kovrovo. In: J. Andrzejowski / W. Brzeziński / G. Orlińska / R. Prochowicz / B. Sałacińska / A. J. Tomaszewski / K. Watemborska-Rakowska (eds), Wiadomości Archeologiczne LXVIII (Warsaw 2017) 45–106.

Chilińska-Früboes 2018
A. Chilińska-Früboes, Zapinki oczkowate serii głównej jako głos w dyskusji nad początkami kultury Dollkeim-Kovrovo. In: S. Wadyla / M. Karczewskiego / M. Hoffmanna (eds), Materiały do Archeologii Warmii i Mazur II (Warsaw, Białystok, Olsztyn 2018) 15–41.

Ckernykh / Hoferte / Barceva 1969
E. H. Ckernykh / D. B. Hoferte / T. B. Barceva = Е. Н. Черных / Д. Б. Хоферте / Б. Барцева, Металлургические группы цветного металла і тысячелетия н.э. из прибалтики. Академия Наук СССР. Краткие сообщения о докладах и полевых исследованиях института археологии 119, 1969, 109–120.

Craddock 1978
P. T. Craddock (ed.), 2000 Years of Zinc and Brass[2]. British Mus. Occasional Paper 50 (London 1978).
Craddock 1988
P. T. Craddock, Copper alloys of the Hellenistic and Roman world: new analyses and old authors. In: J. E. Jones (ed.), Aspects of Ancient Mining and Metallurgy. British School Athens Conference 1986 (Bangor 1988) 55–65.
Dąbrowska 1997
T. Dąbrowska, Kamieńczyk. Ein Gräberfeld der Przeworsk-Kultur in Ostmasowien. Mon. Arch. Barbarica 3 (Kraków 1997).
Droberjar / Frána 2004
E. Droberjar / J. Frána, Antiká Mosaz (Aurichalcum) v českých nálezech časné doby Římské. Archeologie ve středních Čechách 8, 2004, 441–462.
Dungworth 1996
D. Dungworth, Caley's 'Zinc Decline' reconsidered. Num. Chronicle 156, 1996, 228–234.
Dungworth 1997
D. Dungworth, Roman copper alloys: analysis of artefacts from northern Britain. Journal Arch. Scien. 24, 10, 1997, 901–910. https://doi.org/10.1006/jasc.1996.0169.
Ekengren 2009
F. Ekengren, Ritualization – Hybridization – Fragmentation. The Mutanility of Roman Vessels in Germania Magna AD 1–400. Acta Arch Lundensia 4°, 28 (Lund 2009).
Jaskanis 2005
J. Jaskanis, Krupice. Ein Gräberfeld der Przeworsk- und Wielbark-Kultur in Ostpolen. Mon. Arch. Barbarica 10 (Warszawa 2005).
Hammer 1998
P. Hammer, Verfahrenstechnische Untersuchungen. In: H.-U. Voss / P. Hammer / J. Lutz (eds), Römische und germanische Bunt- und Edelmetallfunde im Vergleich. Archäometallurgische Untersuchungen ausgehend von elbgermanischen Körpergräbern. Ber. RGK 79, 1998, 179–199.
Heeren / van der Feijst 2017
S. Heeren / L. van der Feijst (eds), Prehistorische, Romeinse en middeleeuwse fibulae uit de Lage Landen. Beschrijving, analyse en interpretatie van een archeologische vondstcategorie (Amersfoort 2017).
Heginbotham et al. 2015
A. Heginbotham / J. Bassett / D. Bourgarit / C. Eveleigh / L. Glinsman / D. Hook / D. Smith / R. J. Speakman / A. Shugar / R. van Langh, The copper CHARM set: a new set of certified reference materials for the standardization of quantitative X-Ray fluorescence analysis of heritage copper alloys. Archaeometry 57, 5, 2015, 856–868. https://doi.org/10.1111/arcm.12117.
Hilberg 2009
V. Hilberg, Masurische Bügelfibeln. Studien zu den Fernbeziehungen der völkerwanderungszeitlichen Brandgräberfelder von Daumen und Kellaren. Daumen und Kellaren – Tumiany i Kielary 2. = Schr. Arch. Landesmus. 9 (Neumünster 2009).
Istenič 2005
J. Istenič, Brooches of the Alesia group in Slovenia. Arh. Vestnik 56, 2005, 187–212.
Kivirüüt / Olli 2016
A. Kivirüüt / M. Olli, Archaeological research on Aakre Kivivare tarand-grave. Arch. Fieldwork Estonia 2015, 2016, 59–70.
Koovit / Kiudsoo 2015
R. P. Koovit / M. Kiudsoo, Roman Age deposit from Varudi-Vanaküla. Arch. Fieldwork Estonia 2015, 2016, 71–80.
Kunow 1998a
J. Kunow (ed.), 100 Jahre Fibelformen nach Oscar Almgren. Internationale Arbeitstagung 25.–28. 05. 1997, Kleinmachnow, Land Brandenburg. Forsch. Arch. Land Brandenburg (Wünsdorf 1998).
Kunow 1998b
J. Kunow, Die Hauptserie der Augenfibeln: Gruppe III, Fig. 45–54. In: Kunow 1998a, 93–118.
Lang 2007
V. Lang, The Bronze and Early Iron Ages in Estonia. Estonian Arch. 3 (Tartu 2007).
Laul 2001
S. Laul, Rauaaja kultuuri kujunemine Eesti kaguosas (500 e.Kr. – 500 p.Kr.). Muinasaja

teadus 9 = Õpetatud Eesti Seltsi kirjad 7 (Tallinn 2001).

Lutz / Pernicka 1995
J. Lutz / E. Pernicka, Energy dispersive X-Ray fuorescence analysis of ancient copper alloys: empirical values for precision and accuracy. Archaeometry 38, 2, 1995, 313–323.

Martinón-Torres et al. 2012
M. Martinón-Torres / X. J. Li / A. Bevan / Y. Xia / K. Zhao / T. Rehren, Forty thousand arms for a single emperor: from chemical data to the labor organization behind the bronze arrows of the terracotta army. Journal Arch. Method and Theory 21, 2012, 534–562.

Mączyńska 2004
M. Mączyńska, Bemerkungen über einige Typen der Augenfibeln im Barbaricum. In: H. Friesinger / A. Stuppner (eds), Zentrum und Peripherie – Gesellschaftliche Phänomene in der Frühgeschichte. Materialien des 13. Internationalen Symposiums Grundprobleme der frühgeschichtlichen Entwicklung im mittleren Donauraum Zwettl, 4.–8. Dezember 2000. Mitt. Prähist. Komm. 57 (Wien 2004) 211–240.

Michelbertas 1986
M. Michelbertas, Senasis geležies amžius Lietuvoje. I–IV amžius (Vilnius 1986).

Moora 1923
H. Moora, Über die Augenfibel in Est- und Lettland. Sitzber. Gelehrte Estn. Ges. 1922, 1923, 109–123.

Moora 1938
H. Moora, Die Eisenzeit in Lettland bis etwa 500 n Chr. II. Teil: Analyse. Õpetatud Eesti Seltsi toimetised 25 (Tartu 1938).

Nowakowski 1998
W. Nowakowski, Die Funde der römischen Kaiserzeit und der Völkerwanderungszeit aus Masuren. Mus. Vor- u. Frühgesch. (Berlin, Germany). Bestandskat. 6 (Berlin 1998).

Nowakowski 2013
W. Nowakowski, Masuren in der Römischen Kaiserzeit. Auswertung der Archivalien aus dem Nachlass von Herbert Jankuhn. Stud. Siedlungsgesch. u. Arch. Ostseegebiete 12 (Neumünster 2013).

Olli / Kivirüüt 2017
M. Olli / A. Kivirüüt, Individual and collective based on the Viimsi tarand-graves, North Estonia. In: A. Kannike / E. H. Västrik / M. Tasa (eds), Body, Personhood and Privacy: Perspectives on Cultural Other and Human Experience. Approaches to Culture Theory 7 (Tartu 2017).

Olli / Roxburgh 2018
M. Olli / M. Roxburgh, Disc brooches of the Roman Iron Age, from the tarand cemeteries of Estonia and North Latvia. Lietuvos Arch. 44, 2018, 39–70.

Pfeiffer-Frohnert 1998
U. Pfeiffer-Frohnert, "Mit Augen am Fuß und mit Wulst statt Scheibe", Verbreitung und Zeitstellung der preußischen Nebenserie A 57–61 und ihrer Varianten. In: Kunow 1998a, 125–134.

Potts / West 2008
P. J. Potts / M. West (eds), Portable X-ray Fluorescence Spectrometry: Capabilities for In Situ Analysis (Cambridge 2008).

Rehren 1999
T. Rehren, Small size, large scale: roman brass production in Germania Inferior. Journal Arch. Scien. 26, 8, 1999, 1083–1087. https://doi.org/10.1006/jasc.1999.0402.

Rehren 2002
T. Rehren, Metallanalysen an römischen Fibeln aus der CUT. In: U. Boelicke, Die Fibeln aus dem Areal der Colonia Ulpia Traiana. Xantener Ber. 10 (Mainz 2002) 146–147.

Riederer 1993
J. Riederer, Metallanalysen römischer Fibeln aus Kempten. In: M. Schleiermacher / C. Flügel (eds), Fibeln und Bronzegefäße von Kempten-Cambodonum. Cambodunumforsch. 5 = Materialh. Bayer. Vorgesch. A 63 (Kallmünz 1993) 45–52.

Robbiola et al. 1998
L. Robbiola / J. M. Blengino / C. Fiaud, Morphology and mechanisms of formation of natural patinas on archaeological Cu–Sn alloys. Corrosion Scien. 40, 12, 1998, 2083–2111. https://doi.org/10.1016/S0010-938X(98)00096-1.

Rohtla 2005
M.-L. Rohtla, Crossbow fibulae as a reflection of social status and relations. In: V. Lang

(ed.), Culture and material culture: Papers from the first theoretical seminar of the Baltic archaeologists (BASE) held at the University of Tartu, Estonia, October 17th–19th, 2003. Interarch. 1 (Tartu, Riga, Vilnius 2005) 121–145.

Roxburgh et al. 2016
M. Roxburgh / S. Heeren / H. Huisman / B. van Os, Early Roman copper-alloy brooch production: a compositional analysis of 400 brooches from Germaina Inferior. Journal Roman Arch. 29, 2016, 411–421.

Roxburgh et al. 2017
M. Roxburgh / S. Heeren / H. Huisman / B. van Os, De koperlegeringen van Romeinse fibulae en hun betekenis. In: Heeren / van der Feijst 2017, 243–258.

Roxburgh et al. 2018
M. Roxburgh / S. Heeren / H. Huisman / B. van Os, Non-destructive survey of early Roman copper-alloy brooches using portable X-ray fluorescent spectrometry. Archaeometry https://doi.org/10.1111/arcm.12414.

Schmiedehelm 1923
M. Schmiedehelm, Beiträge zu der sogenannten gotischen Frage im Baltikum. Sitzber. Gelehrte. Estn. Ges. 1922 (Dorpat 1923) 76–108.

Schmiedehelm 1955
M. Schmiedehelm, Археологические памятники периода раз- ложения родового строя на северо-востоке Эстонии (V в. до н. э. – V в. н. э.) (Таллин 1955).

Schmiedehelm 2011
M. Schmiedehelm, Das Gräberfeld am Jaskowska-See in Masuren. Studien zur westmasurischen Kultur der römischen Eisenzeit (Warszawa 2011).

Shackley 2011
M. S. Shackley (ed.), X-Ray Fluorescence Spectrometry (XRF). Geoarch. (London 2011).

Shugar / Mass 2012
A. N. Shugar / J. L. Mass (eds), Handheld XRF for Art and Archaeology. Studies Arch. Scien. 3 (Leuven 2012).

Tate 1986
J. Tate, Some problems in analysing museum material by non-destructive surface sensitive techniques. Nuclear Instruments and Methods in Physics Research B 14 (Amsterdam 1986) 20–23. https://doi.org/10.1016/0168-583X(86)90417-9.

Unglig 1991
H. Unglig, Structure, composition and technology of late Roman copper alloy artifacts from the Canadian excavations at Carthage. Archaeomat. 5, 1, 1991, 91–110.

van Thienen / lycke 2017
V. van Thienen / S. Lycke, From commodity to singularity: the production of crossbow brooches and the rise of the late roman military elite. Journal Arch. Scien. 82, 2017, 50–61. https://doi.org/10.1016/j.jas.2017.04.005.

Vaska 2013
B. Vaska, Ornamentation on Roman Iron Age jewellery in Latvia made in openwork technique. Arch. Lituana 14, 2013, 88–110.

Vassar 1943
A. Vassar, Nurmsi kivikalme Eestis ja tarandkalmete areng. PhD thesis (Tartu 1943).

Voss 2008
H.-U. Voss, Fremd, nützlich, machbar. Römische Einflüsse im germanischen Feinschmiedehandwerk In: S. Brather (ed.), Zwischen Spätantike und Frühmittelalter. Archäologie des 4. bis 7. Jahrhunderts im Westen. Ergbd. RGA 57 (Berlin, New York 2008) 343–365.

Voss 2016
H.-U. Voss, Material und Herstellungstechnik – Überlegungen zum germanischen Feinschmiedehandwerk in der Römischen Kaiserzeit. In: B. Armbruster / H. Eilbracht / O. Hahn / O. Heinrich-Tamáska (eds), Verborgenes Wissen: Innovation und Transformation feinschmiedetechnischer Entwicklungen im diachronen Vergleich. Berlin Stud. Ancient World 35 (Berlin 2016) 139–161.

Wickham 2005
C. Wickham, Framing the Middle Ages: Europe and the Mediterranean 400–800 (Oxford 2005).

Abstract: Eyes to the North: a multi-element analysis of copper-alloy brooches in the eastern Baltic, produced during the Roman Iron Age

Eye brooches are the earliest form of brooch to enter the Eastern Baltic region during the Roman Iron Age. Their forms bear strong similarities to those found much further south in *Germania* and the northern Roman provinces, leading to the conclusion that they originally arrived in the region as imports, perhaps by sea from an as yet undiscovered production centre in an area of former East Prussia. In contrast, the eye brooches found within the Germanic areas, north of the Roman frontier, are thought to have originated as export goods produced within the Roman provinces, some distance from the areas in which they are found. We re-examine therefore the debate surrounding local production versus foreign imports, through an innovative use of pXRF. The study compares compositional data of both imported and locally produced brooches against the current typological framework with the aim to better understand how, where and when they were made.

Zusammenfassung: Augen nach Norden. Eine Multielementbestimmung von Fibeln der römischen Eisenzeit aus Kupferlegierungen im östlichen Baltikum

Augenfibeln sind die ältesten Fibeltypen, die während der römischen Eisenzeit das östliche Baltikum erreichten. Ihre Formen zeigen deutliche Ähnlichkeiten mit jenen, die viel weiter südlich in der *Germania* und in den nördlichen römischen Provinzen gefunden wurden, was zu dem Schluss führt, dass sie zunächst als Importe in die Region kamen, möglicherweise über das Meer von einem noch unentdeckten Produktionszentrum im ehemaligen Ostpreußen. Im Gegensatz hierzu wird von den Augenfibeln aus den germanischen Gebieten nördlich der römischen Grenze angenommen, sie stammten als Exportgüter aus den römischen Provinzen aus einiger Entfernung von ihren Fundregionen. Vor dem Hintergrund der Diskussion um lokale Produktion versus Fremdimporte untersuchen wir die Fibeln erneut mit einer innovativen Nutzung von pXRF. Diese Studie vergleicht die Zusammensetzung von importierten und lokal produzierten Fibeln auf Grundlage der akzeptierten Typologie mit dem Ziel, ein besseres Verständnis zu erreichen für die Art, den Ort und die Zeit der Herstellung.

Résumé: Des yeux vers le nord : une analyse multi-éléments des fibules en alliage de cuivre de la Baltique orientale, fabriquées durant l'âge du Fer romain

Les fibules oculées représentent le premier type de fibule à pénétrer dans la région balte orientale au cours de l'âge du Fer romain. Leurs formes ressemblent beaucoup à celles que l'on a trouvées bien plus au sud, en Germanie et dans les provinces septentrionales de l'Empire romain, laissant conclure qu'elles avaient été importées, peut-être par voie de mer, d'un centre de production situé en Prusse orientale, mais qui reste encore à découvrir. Par contre, les fibules oculées découvertes en Germanie, au nord de la frontière romaine, passent pour être des produits d'exportation fabriqués dans les provinces romaines, à une certaine distance des territoires où elles furent trouvées. La problématique « production locale ou importations » est réexaminée à l'aide d'une nouvelle utilisation du pXRF. Cette étude compare la composition des fibules importées et des exemplaires produits sur place, puis confronte ces résultats à la typologie actuelle pour mieux comprendre comment, quand et où elles furent fabriquées.

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References of figures:
Fig. 1: K. Ruppel, RGK, after Schmiedehelm 1955, pl. X. – Figs 2–5: authors. – Tab. 1 and Appendix: authors, graphics K. Ruppel, RGK.