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RESEARCH OF ROMAN-PERIOD METALLURGY: REMARKS BASED ON THE CHEMICAL COMPOSITION ANALYSES OF THE EYE BROOCHES OF THE PRUSSIAN SERIES FROM THE BURIAL GROUND IN MALBORK-WIELBARK

ABSTRACT

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Analyses of the alloy composition of the 114 artefacts from 21 sites of the Wielbark and Przeworsk cultures indicate that these brooches largely correspond to the Roman categories of alloys. The most numerous group of brooches was made of an alloy type M – middle, that is the product of mixing new pure brass with scrap bronze. Such finds are most often found in the cemeteries of the Wielbark culture. Other items were made of metal type B, often found in Roman period artefacts. It is high in zinc content and created with the use of non-mixed brass. This smallest group in the analysed data set appears both in cemeteries of the Wielbark and Przeworsk cultures. Also quite prelevant were recycled alloys, obtained through melting together various raw materials (lower zinc content metal – type A). Most of such brooches are from the Mazovian sites. This may indicate the functioning of local workshops there, which worked using available, processed raw material.

Keywords: eye brooches, Prussian series, Roman period, chemical analyses, workshops
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INTRODUCTION

The eponymous burial ground Fin Malbork-Wielbark, Pomeranian Voivodeship, is one of the biggest cemeteries of the Wielbark culture and virtually the only one that provided a continuous series of finds from the whole period of this culture. In the years 1927-1936, German archaeologists conducted research in the burial ground, which, however, was never fully published, most of the materials and documents perished at the end of World War II (German excavations and the research history: Kleemann 2017, there also earlier literature; also Andrzejowski and Martens 1996). Excavation work was renewed in 2008 and finished in 2021 (Kleemann 2010; Kleemann *et al.* 2013; 2017; Kleemann and Münster 2011; Chanko *et al.* 2018; Daszkiewicz *et al.* 2019; Łuczkiewicz and Kuzioła 2019; Łuczkiewicz *et al.* 2021). In total, over 2100 burials come from this site, dating from the Younger Pre-Roman Period (phase A1 – end of the 3rd/beginning of the 2nd century BC) up until the early stage of the migration period (phase D1 – beginning of the 5th century AD). The necropolis was mostly used in the Roman period, especially in the 3rd century AD; about 90% of the graves come from that time.

Some of the most numerous finds in Malbork-Wielbark are the ornaments and parts of dress, including (so far at least) 48 eye brooches from 40 graves. Prussian series, comprising types A.57-61 (Almgren 1923, 29-32, Pl. 3: 57-61; Pfeiffer-Frohnert 1998; see also Twardo 2003; Chilińska-Früboes 2017) and being the subject of this analysis, is represented by 25 specimens from 21 graves (645/1929, 661/1929, 820/1929, 922, 924 or 925/1929 (2012), 935/1929 [x2] (2009), 962/1929 (2017), 971/1929 (2017), 1034/1929, 1694c/1932, 1694d/1932, 2008/18 [x2], 2010/19 [x2], 2012/52, 2012/66, 2019/22 [x2], 2019/34, 2019/43, 2019/59, 2021/6, 2021/25, 2021/43: Kleemann 2017, 17-200, 344, Pl. 68; Kleemann *et al.* 2013, 182, fig. 10; 2017, 240, fig. 12: 4; Kleemann and Münster 2011, 398, fig. 10; also unpublished materials from research in the years 2008-2021). The study of the chemical composition was conducted in the Bio- and Archaeometry Laboratory of the Institute of Archaeology and Ethnology of the Polish Academy of Sciences in Warsaw and involved eight brooches from five graves (Figs 1-3): 2008/18 (A.57 and A.61), 2019/22 (A.58 and A.60), 2019/34 (A.60), 2019/59 (a fragment of A.59) and 2019/43 (A.57 and a brooch of the main series A.53).

Brooches of the Prussian series constitute one of the elements of a stylistic community, comprising the areas of the Wielbark and Przeworsk cultures in the early Roman period; they are also abundant in the Balt cultures area. In recent years, more and more brooches of this type are being noted in the Lublin region (Niezabitowska 2005), which until recently had almost been a terra incognita on the map of heir distribution. Brooches of the Prussian series can also be found, though in lower numbers, in Scandinavia, Finland and Estonia (*cf.* Roxburgh and Olli 2019) to the north, to the west from the Oder river as well as in the Czech Basin and Slovakia (Pfeiffer-Frohnert 1998, 127-132, fig. 1-5; Zeman 2017b, 185); in the south, they occasionally occur in the Roman areas up to the Balkans

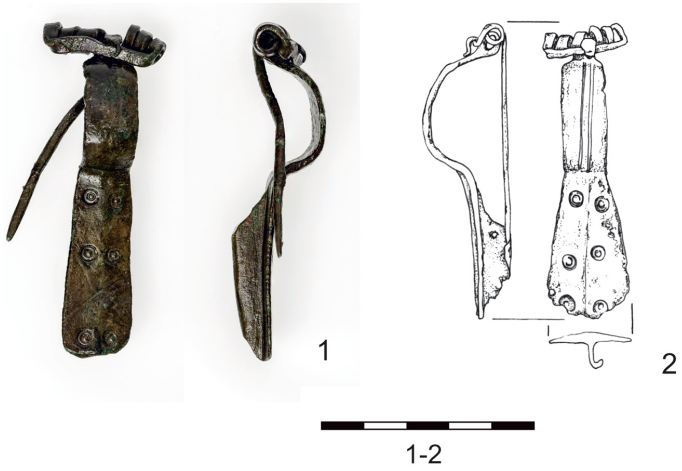

Fig. 1. Malbork-Wielbark, grave 2008/18 (1 – photograph by P. Maciuk; 2 – drawing by A. Kuzioła)

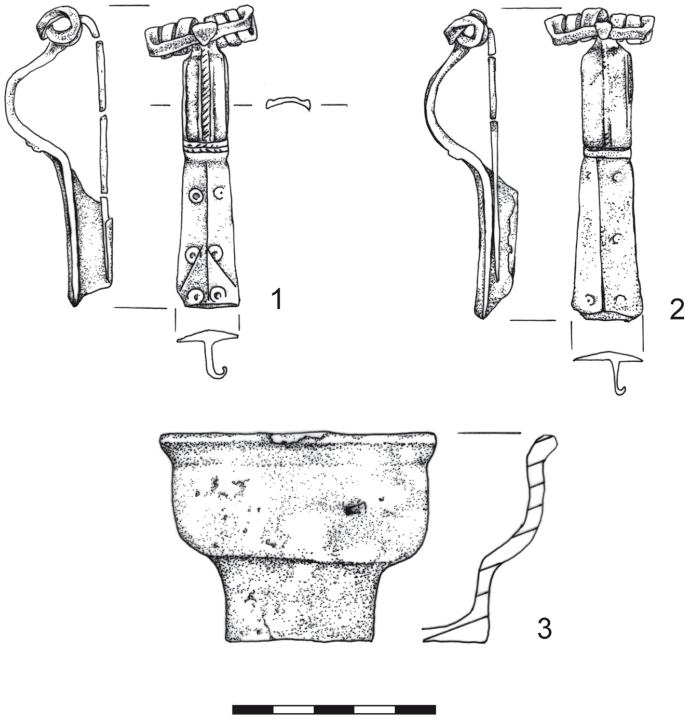

Fig. 2. Malbork-Wielbark, grave 2019/22 (Drawing by A. Kuzioła)

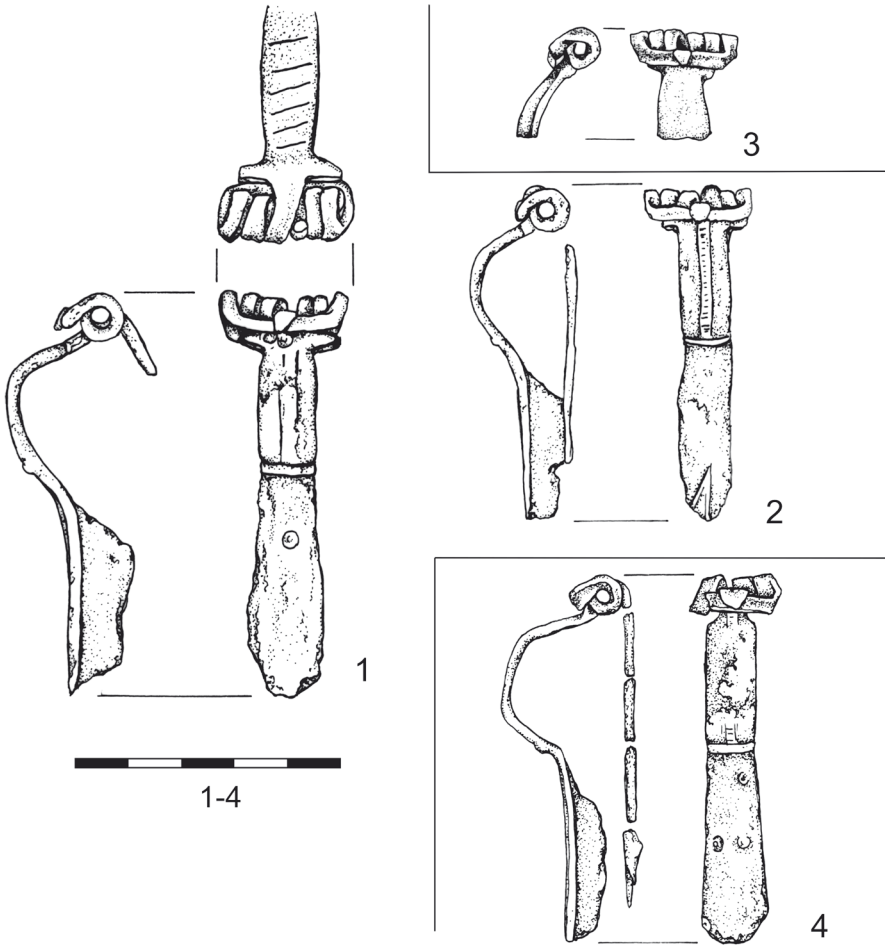

Fig. 3. Malbork-Wielbark. 1-2 – grave 2019/43; 3 – grave 2019/59; 4 – grave 2019/34 (Drawing by A. Kuzioła)

and in the east, up to Belarus and Ukraine (Haralambieva 2002; Beliavets 2014, 161-172, map 1, fig. 2).

Particular attention should be devoted to a very numerous group of the Prussian series eye brooches from Augsburg (*Augusta Vindelicorum*), the capital of the province of *Raetia* (Bakker 1993, 106; 2002, 263, 264, fig. 3; Voss 2008, 343-345, fig. 1). Altogether, 258 such brooches were found there, including particularly numerous semi-finished items. The spectrum of the types comprises forms ranging from A.57 to 61; apart from these, there are also earlier types, ranging from A.45 to A.53, indicating a long tradition of local manufacturing of those items.

The discussed brooches are one of the indicators of phase B2, especially its early stage (B2a), though in both the Wielbark culture and the east area of the Przeworsk culture, typologically younger forms (A.60 and 61) often appear together with artefacts typical of stage B2b (Pfeiffer-Frohnert 1998, 130-133; Andrzejowski 1998, 107; Cieśliński 2010, 55; Mączyńska 2011, 25; Chilińska-Früboes 2017, 57-59). The earliest type (A.57) appears already at the end of phase B1 (Pfeiffer-Frohnert 1998, 133; Cieśliński 2010, 55).

METALLURGICAL ANALYSES – GENERAL COMMENTS

Material research, taking the form of technological (Strobin 1995, 51-55; 2000, 231-252; 2018, 138-156; Natuniewicz-Sekuła 2017, 185-233), isotopic (Stos-Gale 1993; Voss *et al.* 1998, 164-176; Roxburgh and Olli 2019) or chemical analyses (Andrzejowski 1998, 125-130; Gan 2015; Gan and Hensel 2017), have been an integral part of the studies on the artefacts and manufacture from the Roman period for many years now. The published lists of analyses often comprise series amounting up to several hundred results. They serve as a basis for formulating both general and detailed conclusions on the manufacturing methods and techniques in the various areas of European *Barbaricum*, its organisation, genesis, external influences or raw material base (Niewęgłowski 1986, 322, 323; Hammer *et al.* 1997; Hammer and Voss 1998; Voss 2008; 2016; Voss *et al.* 1998; Droberjar and Frána 2004; Bayley and Butcher 2004; Fagner *et al.* 2015; Natuniewicz-Sekuła 2017, 217-220; Roxburgh and Olli 2019).

In the literature on the subject, a prevailing view is that the addition of zinc played a key role in the metallurgy of non-ferrous metals in the Roman Empire, as well as in the Wielbark and Przeworsk cultures (Niewęgłowski 1986, 319-323; Rehren and Martinón-Torres 2009, 170). In modern metallurgy, this alloy is referred to as brass; however, in antiquity it was called *aurichalcum* (Craddock 1978, 5-9; see also Voss *et al.* 1998, 276-286). In technological terms, it was an alloy of copper and zinc, which was absorbed into the metal in a specialist metallurgical process called cementation (Szmoniewski 2009, 118). The essence of this process was to heat a mixture of metallic copper and crushed zinc ore to the boiling point of zinc, that is 918°C in a closed crucible. The ore was added in the form of zinc oxide, sphalerite, or the so-called furnace calamine, *i.e.* zinc oxides obtained in the furnaces while smelting other metal ores. Modern experiments (Werner 1970; Haedecke 1973; *cf.* Voss *et al.* 1998, 118, 119) demonstrated that the cementation process takes place in a precise temperature range from 900°C to 1000°C; in the lower temperatures, zinc ore would not evaporate, while in the higher temperatures, the copper would begin to melt, thus reducing the absorption surface. The brass obtained in the Roman workshops could have contained from 22% to 28% of zinc (Hammer and Voss 2009, 202).

The upper limit of zinc content is a subject of discussion. The experiments conducted by Werner and Haedecke determined the limit of zinc content obtained through the cemen-

tation process as up to 28-32%. Nevertheless, it should be mentioned that there is a small number of chemical analyses of artefacts in which higher levels of zinc were found.

If another metal was used as a matrix, *e.g.* copper mixed with tin or with lead, hence obtained from scrap bronze, the absorption of zinc in the cementation process was reduced due to the lower melting point of copper. Therefore, the final content of zinc depended to a large degree on the temperature reached, the length of the process, the quality of the crucible, and even the thickness of the charcoal layer (Rehren 1999, 252).

Another significant characteristic of brass is related to oxidation, and its gradual reduction in the alloy by about 10% during further smelting. The zinc content in the ancient alloys is usually considered in three ranges (Craddock 1978, 11, 12). The first group comprises objects containing below 4% Zn, indicating the use of scrap brass or even its unintentional admixture related to the smelting of zinc oxide ore. The second group comprises objects with zinc content between 4% to 22%. This group varies the most in terms of its chemical composition, with significant admixtures of tin or lead; it is also the most frequently found. In the third group, there is brass with over 22% zinc content, which is directly related to the cementation process; apart from the copper contamination, there should not be other alloying additives.

Initially, brass was used in Rome for mostly military purposes and minting; only later was it also used for manufacturing ornaments and objects of everyday use. In the light of the description by Pliny the Elder (*Hist. Nat. XXXIV: 4*), the *aurichalcum* alloy was for Romans one of many different types of copper and was characterised by its outstanding technological properties, as well as its beautiful golden gloss. Its price was also relatively high. *Aurichalcum* production depended to a high degree on access to the ore, which was unfortunately limited; Pliny names a few already exploited deposits in Cyprus and Campania and mentions active mines providing similar 'copper' in Spain, Gaul and Germania. Pliny characterises different alloys used by Roman manufacturers: *campana* – for manufacturing vessels and items of everyday use; *tenerrima*– for making casting forms; *temperatura statuaria*– for casting statues; *ollaria*– for manufacturing vessels. For the purpose of future discussion, it is crucial to emphasise that, while doing so, Pliny names – apart from copper – three main ingredients of the alloys: *plumbum argentarium, plumbum nigrum* and *aes collectaneum*. While the latter two are unambiguously interpreted as lead and scrap bronze, the identification of *plumbum argentarium* is more tentative; it is understood as tin, an alloy of tin and lead, or lead being a by-product of silver metallurgy (Healy 1999, 325). Given all of the above, the variance in the chemical composition of the alloys used by Roman manufacturers must have been significant.

On the basis of the modern technical terminology, archeometry developed its own classifications of historical alloys, which use correlations between main alloying elements, *i.e.* tin, zinc and lead (Bayley 1991, 17, 18; Riederer 1998, 201, 202; Hammer *et al.* 1997, 102-114; Voss *et al.* 1998, 158-178, 276-286; Fagner *et al.* 2015, 337, fig. 2-4). Using the triangular graphs, the frequencies of occurrence of respective ingredients are distinguished

rather clearly, while their position between the vertices of a triangle indicates the character and homogeneity of the alloy, specifying whether it is bronze, brass or gunmetal. This division can be subject to further classifications depending on the studied material or the results of chemical composition analysis, the studied series of products or chronology (Dungworth 1997, 906; Gan 2015, 179). Determining the chemical composition may also indicate the performance properties of the alloy as well as the way in which the finished products were manufactured. Tin bronze alloys are more resistant to stress and have higher durability than copper; they are also easier in casting, especially with the addition of lead. On the other hand, brass alloys were easier to forge than bronze. Due to their high fluidity and malleability, they could also be cast and, most significantly, they had a colour reminiscent of gold. The addition of lead lowered the melting point, thus increasing the casting properties, allowed better reproduction of the form, filled defects in the alloy and acted as a replacement for the less accessible tin. Simultaneously, due to the insolubility of copper, it decreased the plasticity of the alloy, making it more difficult to forge.

METALLURGICAL ANALYSES OF THE EYE BROOCHES FROM THE EASTERN PART OF *BARBARICUM* AND MANUFACTURING ISSUES

The eye brooches of the Prussian series from the cemetery in Malbork-Wielbark were incorporated into a database comprising the analyses of artefacts from burial grounds of the Wielbark and Przeworsk culture (in total, 114 brooches from 21 sites; Fig. 4; Tab. 1). Comparative material included the published analyses of analogous brooches from Moravia (Zeman 2017a, 306, tab. 1; 2017b, 185), from the eastern Baltic area (Estonia and northern Latvia: Roxburgh and Olli 2019, 21, -216, fig. 3, 221-226: 24 specimens), as well as parts of the materials (101 items) from the enormous group of Prussian series eye brooches from Augsburg (Riederer 2001, 233-235; 2002, 118-120; Hammer and Voss 2009, 202, footnote 1177; *cf.* Voss *et al.*1998, 176).

The analyses of the material from Malbork-Wielbark were conducted in the Bio- and Archaeometry Laboratory of the Institute of Archaeology and Ethnology PAN. The methods of X-ray spectroscopy were applied using the scanning electron microscope SEM-ECS with the following parameters: vacuum, time measurement 100 s, accelerating voltage 20 keV, spot size 250 mm^2. An Artax Brucker X-ray fluorescence spectrometer was also used with the accelerating voltage of 50 keV and time measurement of 100 s. Each measurement was taken on surfaces cleaned mechanically of corrosion products.

The chemical analyses (Tab. 2) indicated that the brooches from Wielbark were made from alloys of copper (Cu –79.05-86.48%) with zinc (Zn – 7.90-16.63%) and tin (Sn – 2.12-4.62%). The lower level of zinc in the analysis CL20802 (grave 2019/59) may be related to the significant corrosion of the preserved piece of the brooch. It may be assumed

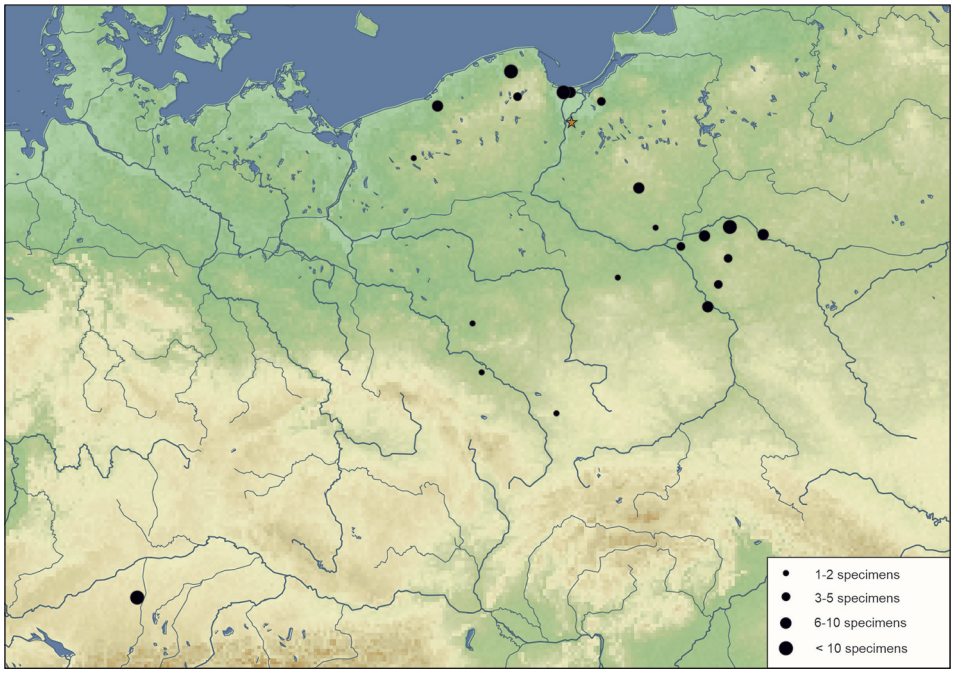

Fig. 4. Eye brooches of the Prussian series from the area of Wielbark and Przeworsk cultures subjected to metallographic study and included in Table 1 (also therein Augsburg). Asterisk: Malbork-Wielbark (graphics by A. Kuzioła)

that all brooches were manufactured with a similar brass alloy. In the analysis of the database, we applied statistical methods based on the principal component analysis (PCA) and the minimum spanning tree (MST) to rank spanning trees with the least distance – analysis with most similar factors. In Kaiser's methodology, the first two factors derived from the analysis are the most significant to determine the similarity of the analysed set, while the others are related to the level of internal differentiation. In the analyses was used free software *Past* (Hammer *et al.* 2001).

In the case of the analysed eye brooches, we used the results obtained for nine elements: Cu, Fe, Ni, Zn, As, Ag, Sn, Sb, Pb, reflecting the applied metallurgical technology and the profile of the deposit (Pernicka 2014, 253). All the data were normalised to reduce the weight of the main alloy ingredients. None of the factors stood out in particular; two factors with the highest correlation degree are responsible for 46% of all obtained variations. This result shows that most of the analyses point toward similar values, which are probably related to the way/technology of production that took place in large manufacturing centres. This suggests a significant centralisation of manufacturing. On the other hand, the analyses testify to a different raw material base and metallurgical technology, hence

Table 1. List of analysed metals from the Przeworsk and Wielbark cultures sites

Cl no.	Site	Contex	Type	Comments	Other	Literature
8313	Bieńkowice	stray find	A.60	Jamka 1964, 95: type A. 58 or 57.	MAW/III/124	Jamka 1964, 95 (earlier literature there)
7855	Brzeźce	grave 5	A.58/59		lack	Balke 1976, 41-42 fig. 10.
18591	Czarnówko	object R288	A.60		10/88 [36]	Gan 2015, 187-214.
18638	Czarnówko	object 402/09	A.60		863/09 [87]	
18642	Czarnówko	object 402/09	A.60		864/09 [90]	
18624	Czarnówko	object 529/09	A.60		1145/09 [73]	
18625	Czarnówko	object 529/09	A.60		1143/09 [74]	
18623	Czarnówko	object 530/09	A.57		1150/09 [72]	
18685	Czarnówko	object 900/10	A.60		1714/10 [140]	
18734	Czarnówko	object 1084A/10	A.60		2093/10 [196]	
18735	Czarnówko	object 1084A/10	A,57		2094/10 [197]	
18736	Czarnówko	object 1084A/10	A.60		2092/10 [198]	
18668	Czarnówko	object 1384/10	A.60		2653/10 [121]	
18670	Czarnówko	object 1384/10	A.60		2655/10 [124]	
18679	Czarnówko	object 1384/10	A.61		2654/10 [133]	
7757	Domaradzice	grave 83	A.58-60		1959:767	Kostrzewski 1954, 197-198 fig. 78: 6.
9163	Drawsko Pomorskie	grave III	A.59		R211/45	Chrupek 2019, 127, 206 fig. 6: 7 (with older literature).
9164	Drawsko Pomorskie	grave III	A.60		R212/45	Chrupek 2019, 127, 206 fig. 6: 6 (with older literature).
7020	Garwolin	grave 31	A.57-60		IV7097/43	Niewęgłowski 1991, 30-31 fig. 15: c
7027	Garwolin	grave 47	A.61			Niewęgłowski 1991, 41-44 fig. 27: a.
7032	Garwolin	grave 61	A.58		7097/87	Niewęgłowski 1991, 54-57 fig. 37: d.
12148	Grzybnica	barrow A, grave A	A.57		12896,00	Hahuła and Wołągiewicz 2001, 18, 104 pl. XVI: 1.
12162	Grzybnica	grave 19B	A.59	specimen 1	15038	Hahuła and Wołągiewicz 2001, 22-23, 123 pl. XXXV: 1.

Cl no.	Site	Contex	Type	Comments	Other	Literature
12163	Grzybnica	grave 19B	A.59	specimen 2	15039	Hahuła and Wołągiewicz 2001, 22-23, 123 pl. XXXV: 2.
12164,01	Grzybnica	grave 19B	A.59	upper part of bow, specimen 3	15040	Hahuła and Wołągiewicz 2001, 22-23, 123 pl. XXXV: 3.
12164,02	Grzybnica	grave 19B	A.59	spring, specimen 3, second analysis	15040	Hahuła and Wołągiewicz 2001, 22-23, 123 pl. XXXV: 3.
12166	Grzybnica	grave 19C	A.60		15049	Hahuła and Wołągiewicz 2001, 23, 124 pl. XXXV: 1.
12167	Grzybnica	grave 29	A.60	specimen 1	15070	Hahuła and Wołągiewicz 2001, 24, 129 pl. XLI: 1.
12168	Grzybnica	grave 29	A.60	specimen 2	15069	Hahuła and Wołągiewicz 2001, 24, 129 pl. XLI: 2.
12171	Grzybnica	grave 50	A.59		15084	Hahuła and Wołągiewicz 2001, 26-27, 137 pl. XLIX: 2
6854	Kamieńczyk	grave 12	A.60		IV/7368	Dąbrowska 1997, 13, 138 pl. VIII: 1.
6850	Kamieńczyk	grave 16	A.52/59	one of the two brooches shown on the pl. . IX/16: 1-2	IV/7368	Dąbrowska 1997, 14, 139 pl. IX/16: 1-2.
6855	Kamieńczyk	grave 52	A.61		244	Dąbrowska 1997, 20, 155 pl. XXV/52: 1.
6856,01	Kamieńczyk	grave 55	A.60		265	Dąbrowska 1997, 20-21, 156 pl. XXVI/55: 1.
6857,01	Kamieńczyk	grave 171	A.61		1001	Dąbrowska 1997, 42-43, 221 pl. XCI/171: 3.
6858	Kamieńczyk	grave 174	A.60-61			Dąbrowska 1997, 43, 223 pl. XCIII/174: 1.
9301	Karczewiec	grave 13	A.60-61		PMAIV/6557	Dąbrowska 1973, 389, 395 pl. III: 10.
9302	Karczewiec	grave 36	A.60?		PMAIV/6557	Dąbrowska 1973, 400, 405 pl. VI: 2.
9303	Karczewiec	grave 48b	A.61		PMAIV/6557	Dąbrowska 1973, 403, 408, 414 pl. IX: 10.
9304	Karczewiec	grave 48b	A.61		PMAIV/6557	Dąbrowska 1973, 403, 408, 414 pl. IX: 20.
9305	Karczewiec	grave 48b	A.61		PMAIV/6557	Dąbrowska 1973, 403, 408, 414 pl. IX: 21.
7682	Kołozą b	grave 153	A.60			Twardo 2003, 200 no. 12.1.
9523	Krupice	grave 3	A.57-61		MB/A/389	Jaskanis 2005, 12, 138 pl. II: 1.
9519	Krupice	grave 5	A.61		MB/A/389	Jaskanis 2005, 13, 140 pl. IV: 1.
9521	Krupice	grave 5	A.57-61		MB/A/389	Jaskanis 2005, 13, 140 pl. IV: 2.
9528	Krupice	grave 131A	A.60?		MB/A/389	Jaskanis 2005, 38, 173 pl. XXXVII/131A: 1.
9511	Krupice	grave 295	A.57 lub A.59		MB/A/613	Jaskanis 2005, 67, 210 pl. LXXIV/295: 1.

9510	Krupice	grave 328	A.60?		MB/A/615	Jaskanis 2005, 73, 220 pl. LXXXIV/328: 1.
9524	Krupice	grave 367	A.61		MB/A/615	Jaskanis 2005, 79, 231 pl. XCV/367: 1.
7107,1	Łajski	grave 93	A.60		705/78	Twardo 2003, 201 no. 13.3.
7107,2	Łajski	grave 93	A.60	the second sample from the same brooch	838/79	Twardo 2003, 201 no. 13.3.
7108	Łajski	grave 121	A.57-60		594/78	Twardo 2003, 201 no. 13.4.
7110	Łajski	grave 143	A.60		594/78	Twardo 2003, 202 no. 13.6.
19951	Malbork-Wielbark	grave 2008/18	A.57	upper part of bow		unpublished excavations J. Kleemann and P. Łuczkiewicz
19952	Malbork-Wielbark	grave 2008/18	A.61	upper part of bow		unpublished excavations J. Kleemann and P. Łuczkiewicz
20797	Malbork-Wielbark	grave 2019/22	A.58			unpublished excavations J. Kleemann and P. Łuczkiewicz
20798	Malbork-Wielbark	grave 2019/22	A.60			unpublished excavations J. Kleemann and P. Łuczkiewicz
20799	Malbork-Wielbark	grave 2019/34	A.60			unpublished excavations J. Kleemann and P. Łuczkiewicz
20800	Malbork-Wielbark	grave 2019/43	A.57			unpublished excavations J. Kleemann and P. Łuczkiewicz
20802	Malbork-Wielbark	grave 2019/59	A.59			unpublished excavations J. Kleemann and P. Łuczkiewicz
9779	Modła	grob 32/78 (75)	A.57	in parentheses the numbers of graves according to J. Andrzejowski	MZZ/A/459	Grzymkowski 1986, 235 fig. 11: c; Twardo 2003, 202 no. 14.1; Andrzejowski 2009, 108-108.
9781	Modła	grave 17/80 (114)	A.57		MZZ/A/528	Grzymkowski 1986, 238 fig. 14: d; Twardo 2003, 203 no. 14.5; Andrzejowski 2009, 132.
9784	Modła	grave 1/82 (186)	A.58-59?		MZZ/A/772	Andrzejowski 2009, 168.
9789	Modła	grave 3/82 (188)	A.58-59		MZZ/A/774	Twardo 2003, 203 no. 14.6; Andrzejowski 2009, 169.
9787	Modła	grave 50/82 (222)	A.57-60		MZZ/A/803	Twardo 2003, 204 no. 14.8; Andrzejowski 2009, 188.
9792	Modła	grave 1/84 (264)	A.60		MZZ/A/1070	Andrzejowski 2006, 26, 43 fig. 18: 1.

Cl no.	Site	Contex	Type	Comments	Other	Literature
8176	Nadkole	grob 22A-B	A.61?			Andrzejowski 1998, 21, 168 pl. XVII: 5.
8178	Nadkole	grave 24	A.60-61			Andrzejowski 1998, 21-22, 171 pl. XX: 4.
PS88	Nadkole	grave 26	A.60-61			Andrzejowski 1998, 22, 173 pl. XXII: 6.
PS89	Nadkole	grave 30	A.60			Andrzejowski 1998, 23, 174 pl. XXIII/30:6.
PS87	Nadkole	grave 56	A.57/58			Andrzejowski 1998, 30, 192 pl. XLI: 8.
8192	Nadkole	grave 57	A.60-61			Andrzejowski 1998, 30, 191 pl. XL/57: 4.
8193	Nadkole	grave 58A	A.60-61			Andrzejowski 1998, 30, 194 pl. XLIII/58A: 3.
8194	Nadkole	grave 58A	A.60-61			Andrzejowski 1998, 30, 194 pl. XLIII/58A: 4.
8195	Nadkole	grave 58A	A.60-61			Andrzejowski 1998, 30, 194 pl. XLIII/58A: 5.
8197	Nadkole	grave 59	A.61			Andrzejowski 1998, 31, 195 pl. XLIV/59: 5.
8204	Nadkole	grave 68	A.61			Andrzejowski 1998, 33, 196 pl. XLV/68: 7.
8207	Nadkole	grave 94	A.60-61			Andrzejowski 1998, 38, 210 pl. LIX/94: 8.
8216	Nadkole	grave 113	A.60			Andrzejowski 1998, 42, 219 pl. LXVIII/113: 9.
8217	Nadkole	grave 113	A.60			Andrzejowski 1998, 42, 219 pl. LXVIII/113: 10.
8224	Nadkole	grave 114	A.60			Andrzejowski 1998, 42-43, 221 pl. LXX/114: 5.
PS85	Nadkole	grave 114	A.60?			Andrzejowski 1998, 43, 221 pl. LXX/114: 6.
8225	Nadkole	grave 120	A.61			Andrzejowski 1998, 45, 222 pl. LXXI/120: 5.
8228	Nadkole	grave 124	A.61			Andrzejowski 1998, 46, 228 pl. LXXVII/124: 9.
ps135	Nadkole	grave 141B	A.58/59			Andrzejowski 1998, 49-50, 236 pl. LXXXV/141B: 3.
ps86/1	Nadkole	stray find	A.60-61			Andrzejowski 1998, 51, 129 nr 111-112.
12753	Oblin	grave 31	A.61			Czarnecka 2007, 18, 194 pl. XXX: 2.
12754	Oblin	grave 31	A.60			Czarnecka 2007, 18, 194 pl. XXX: 1.
12755	Oblin	grave 170	A.57-61			Czarnecka 2007, 47, 328 pl. CLXIV/170: 1.
12756	Oblin	grave 174	A.61			Czarnecka 2007, 47, 332 pl. CLXVIII/174: 1.
12757	Oblin	grave 174	A.61			Czarnecka 2007, 47, 332 pl. CLXVIII/174: 2.
12758	Oblin	grave 176a	A.59			Czarnecka 2007, 47-48, 331 pl. CLXVII/176a: 1.

8481	Pruszcz Gdański, site 7	grave 42	A.60/61		1984:39/82	unpublished, from research by M. Pietrzak and M. Tuszyńska, analyzes from the archives of CL IAE PAN.
8483	Pruszcz Gdański, site 7	grave 70	A.61		1984:39/150	
8488	Pruszcz Gdański, site 7	grave 89	A.60/61		1984:39/196	
8489	Pruszcz Gdański, site 7	grave 94	A.60/61		1984:39/216	
8490	Pruszcz Gdański, site 7	grave 127	A.60		1985:56/94	
8493	Pruszcz Gdański, site 7	grave 145a	A.61		1985:56/139	
8494	Pruszcz Gdański, site 7	grave 153	A.60		1985:56/126	
8499	Pruszcz Gdański, site 7	grave 159b	A.57	specimen 1	1985:56/229	
8500	Pruszcz Gdański, site 7	grave 159b	A.57	specimen 2	1985:56/230	
8506	Pruszcz Gdański, site 7	grave 279	A.57	specimen 1	1985:56/463	
8507	Pruszcz Gdański, site 7	grave 279	A.57	specimen 2	1985:56/464	

Cl no.	Site	Contex	Type	Comments	Other	Literature
7180,01	Pruszcz Gdański, site 10	grave 45A	A.59		1967:1/61	Pietrzak 1997, 16, 106 pl. VIII/45A: 2.
7182	Pruszcz Gdański, site 10	grave 75	A.59		1967:1/125	Pietrzak 1997, 20, 118 pl. XX/75: 1.
8474	Pruszcz Gdański, site 10	grave 291	A.59	one of the three brooches shown on the table CI/291: 2-4.	1969:27/274	Pietrzak 1997, 47, 199 pl. CI/291: 2-4.
9406	Przyrownica	stray find	A.60-61		MP/A/419	unpublished, analyzes from the archives of CL IAE PAN.
16208	Weklice	stray find	A.60		68/175	Natuniewicz 2000, 154, pl. III:10, fig. 5: 1; Natuniewicz 2017, pl. 3: 63.
16144	Weklice	grave 492	A.57		2527	Natuniewicz-Sekuła and Okulicz-Kozaryn 2011, 120, 405 pl. CCXIX: 1.
16219	Weklice	stray find	A.57		2902,00	Natuniewicz 2017, pl. 3: 73.
9743	Węsiory	barrow 4	A.60		1969:73	Kmieciński 1966, pl. XXXIX: 7.
9744	Węsiory	barrow 4	A.60		1969:73	Kmieciński 1966, pl. XXXIX: 5.
9751	Węsiory	barrow 13, grave 1	A.59/60		1969:73	Kmieciński 1966, pl. XXXIX: 1.
9752	Węsiory	barrow 13, grave 1	A.59/60		1969:73	Kmieciński 1966, pl. XXXIX: 2.

Table 2. Summary of the chemical analyses of the Prussian series eye brooches from the area of Wielbark and Przeworsk cultures. M, A, B – types of metals

Laboratory no.	Site	Cu	Al	Cr	Mn	Fe	Ni	Zn	As	Ag	Sn	Sb	Pb	Au	Co	Bi	Remarks	Metal
8313	Bieńkowice	85.00	0.08	0.09	0.01	1.20	0.08	10.00	0.11	0.62	2.70	0.07	0.35	0.00	0.01	0.00		M
7855	Brzeźce	80.54	0.75	0.22	0.00	2.30	0.04	15.00	0.03	0.07	0.54	0.07	0.45	0.00	0.00	0.00		M
18591	Czarnówko	80.15	0.28	0.02	0.00	0.28	0.18	15.20	0.00	0.03	2.95	0.35	0.28	0.14	0.00	0.00		M
18623	Czarnówko	81.60	0.16	0.05	0.10	0.60	0.07	16.33	0.00	0.14	0.50	0.00	0.27	0.00	0.00	0.00		M
18624	Czarnówko	82.74	0.11	0.00	0.02	0.38	0.03	14.85	0.00	0.23	1.46	0.00	0.00	0.00	0.00	0.00		M
18625	Czarnówko	82.08	0.02	0.02	0.06	0.10	0.01	14.41	0.00	0.00	3.05	0.00	0.19	0.00	0.00	0.00		M
18638	Czarnówko	82.97	0.14	0.01	0.01	0.22	0.27	9.43	0.39	0.00	5.76	0.45	0.00	0.00	0.00	0.00		A
18642	Czarnówko	81.61	0.08	0.04	0.01	0.29	0.17	15.86	0.46	0.12	1.13	0.20	0.02	0.00	0.00	0.00		M
18668	Czarnówko	80.89	0.08	0.00	0.12	0.17	0.03	16.06	0.00	0.00	2.35	0.24	0.00	0.00	0.00	0.00		M
18670	Czarnówko	82.66	0.02	0.08	0.00	0.29	0.07	13.74	0.15	0.09	2.32	0.32	0.26	0.00	0.00	0.00		M
18679	Czarnówko	82.47	0.06	0.01	0.02	0.40	0.13	14.55	0.23	0.03	1.46	0.28	0.18	0.00	0.00	0.00		M
18685	Czarnówko	78.65	0.02	0.00	0.00	0.36	0.39	12.64	0.28	0.10	6.06	0.15	0.95	0.00	0.00	0.00		M
18734	Czarnówko	82.04	0.17	0.00	0.00	0.20	0.00	15.26	0.00	0.00	2.03	0.07	0.06	0.00	0.00	0.00		M
18735	Czarnówko	82.11	0.09	0.05	0.20	0.20	0.09	13.91	0.00	0.07	2.87	0.00	0.16	0.00	0.00	0.00		M
18736	Czarnówko	78.96	0.09	0.00	0.09	0.25	0.30	17.14	0.16	0.00	2.64	0.29	0.05	0.00	0.00	0.00		M
7757	Domaradzice	85.03	0.68	0.10	0.00	0.65	0.03	9.50	0.08	0.05	3.00	0.18	0.70	0.00	0.00	0.00		A
9163	Drawsko Pomorskie	77.25	0.38	0.23	0.01	2.20	0.03	18.00	0.08	0.06	1.50	0.09	0.16	0.00	0.01	0.00		M
9164	Drawsko Pomorskie	78.07	0.45	0.16	0.01	1.60	0.02	17.00	0.08	0.08	2.30	0.08	0.15	0.00	0.00	0.00		M
7020	Garwolin	90.66	0.42	0.00	0.00	0.62	0.04	4.20	0.07	0.10	3.50	0.04	0.35	0.00	0.00	0.00		A
7027	Garwolin	87.02	0.35	0.00	0.01	1.30	0.05	8.00	0.06	0.05	2.70	0.11	0.16	0.00	0.00	0.00		A
7032	Garwolin	90.58	0.85	0.00	0.01	1.10	0.06	6.00	0.04	0.06	1.20	0.04	0.08	0.00	0.00	0.00		A
12148	Grzybnica	77.41	0.00	0.00	0.00	0.19	0.09	20.89	0.00	0.08	0.73	0.00	0.30	0.00			Si 0.30	B
12162	Grzybnica	78.66	0.00	0.00	0.04	0.22	0.14	18.10	0.00	0.18	2.26	0.00	0.20	0.00			Si 0.20	B

Laboratory no.	Site	Cu	Al	Cr	Mn	Fe	Ni	Zn	As	Ag	Sn	Sb	Pb	Au	Co	Bi	Remarks	Metal
12163	Grzybnica	78.47	0.00	0.00	0.05	0.21	0.14	18.21	0.00	0.14	2.32	0.00	0.15	0.00			Si 0.32	B
12164.01	Grzybnica	80.66	0.00	0.00	0.00	0.15	0.00	16.71	0.00	0.74	1.51	0.00	0.00	0.00			Si 0.24	B
12164.02	Grzybnica	80.92	0.00	0.00	0.00	0.11	0.11	16.27	0.00	0.05	2.12	0.00	0.14	0.00			Si 0.27	M
12166	Grzybnica	81.45	0.00	0.00	0.00	0.34	0.18	15.20	0.00	0.11	1.81	0.00	0.69	0.00			0.22	B
12167	Grzybnica	79.26	0.00	0.00	0.00	0.14	0.10	17.47	0.00	0.09	2.43	0.00	0.17	0.00			Si 0.33	B
12168	Grzybnica	81.50	0.00	0.00	0.00	0.08	0.03	15.29	0.00	0.14	2.39	0.00	0.33	0.00			Si 0.24	M
12171	Grzybnica	77.85	0.00	0.00	0.02	0.16	0.14	20.04	0.00	0.12	1.14	0.00	0.28	0.00			Si 0.26	B
6854	Kamieńczyk	88.41	1.30		0.00	1.10	0.06	7.50	0.03	0.05	1.05	0.07	0.44	0.00	0.00	0.00		A
6850	Kamieńczyk	86.88	0.44		0.00	0.65	0.03	11.00	0.04	0.04	0.48	0.04	0.40	0.00	0.00	0.00		A
6855	Kamieńczyk	80.43	0.85		0.00	1.45	0.05	16.00	0.08	0.06	0.65	0.08	0.35	0.00	0.00	0.00		M
6856.01	Kamieńczyk	87.30	0.23		0.00	1.40	0.02	9.00	0.05	0.05	1.25	0.07	0.62	0.00	0.00	0.00		A
6856.02	Kamieńczyk	89.06	0.28		0.00	0.80	0.02	8.00	0.03	0.06	1.15	0.06	0.55	0.00	0.00	0.00		A
6857.01	Kamieńczyk	88.52	0.35		0.00	0.90	0.03	9.00	0.04	0.05	0.80	0.06	0.24	0.00	0.00	0.00		A
6857.02	Kamieńczyk	86.38	0.62		0.00	0.90	0.04	10.00	0.04	0.09	1.15	0.14	0.65	0.00	0.00	0.00		M
6858	Kamieńczyk	80.80	1.15		0.00	0.90	0.03	16.00	0.06	0.06	0.75	0.08	0.18	0.00	0.00	0.00		M
9301	Karczewiec	86.55	0.50	0.12	0.01	0.95	0.01	9.50	0.04	0.06	2.10	0.05	0.12	0.00	0.00	0.00		A
9302	Karczewiec	85.10	1.20	0.35	0.02	1.90	0.03	9.00	0.03	0.05	2.20	0.05	0.07	0.00	0.01	0.00		A
9303	Karczewiec	86.72	0.38	0.35	0.02	2.10	0.02	8.50	0.03	0.05	1.60	0.07	0.16	0.00	0.00	0.00		A
9304	Karczewiec	86.81	0.48	0.17	0.00	1.20	0.01	8.50	0.02	0.04	2.50	0.06	0.20	0.00	0.00	0.00		A
9305	Karczewiec	67.61	0.90	0.50	0.06	4.00	0.03	25.00	0.04	0.22	1.20	0.11	0.32	0.00	0.01	0.00		B
7682	Kołoząb	82.30	0.50	0.30	0.00	2.20	0.04	10.00	0.07	0.12	3.60	0.18	0.70	0.00	0.00	0.00		A
9510	Krupice	81.49	0.32	0.25	0.01	1.80	0.02	14.00	0.03	0.05	1.80	0.06	0.18	0.00	0.01	0.00		M
9511	Krupice	78.93	0.50	0.22	0.01	1.60	0.01	15.50	0.03	0.06	2.80	0.08	0.26	0.00	0.00	0.00		M
9519	Krupice	82.27	0.12	0.20	0.01	1.30	0.01	14.00	0.02	0.05	1.80	0.07	0.15	0.00	0.00	0.00		M
9521	Krupice	80.54	0.13	0.25	0.13	1.50	0.02	16.00	0.04	0.05	1.20	0.05	0.11	0.00	0.01	0.00		M
9523	Krupice	82.23	0.05	0.10	0.00	1.10	0.01	14.00	0.06	0.04	2.10	0.07	0.25	0.00	0.00	0.00		M

9524	Krupice	84.12	0.13	0.22	0.01	1.40	0.01	13.00	0.03	0.04	0.90	0.06	0.08	0.00	0.01	0.00		M
9528	Krupice	76.53	0.05	0.10	0.00	0.95	0.01	20.00	0.05	0.06	2.00	0.09	0.15	0.00	0.00	0.00		B
7107.1	Łajski	88.22	0.65	0.04	0.00	1.40	0.03	7.00	0.06	0.04	1.90	0.06	0.60	0.00	0.00	0.00		A
7107.2	Łajski	89.13	0.60	0.08	0.00	1.40	0.03	6.50	0.09	0.04	1.80	0.09	0.25	0.00	0.00	0.00		A
7108	Łajski	86.24	0.65	0.12	0.00	0.65	0.05	8.00	0.18	0.10	3.30	0.15	0.56	0.00	0.00	0.00		A
7110	Łajski	84.03	0.40	0.20	0.00	0.90	0.04	8.50	0.19	0.06	4.40	0.18	1.10	0.00	0.00	0.00		A
19951	Malbork-Wielbark	81.06	0.07	0.01	0.02	0.33	0.03	15.05	0.21	0.12	2.54	0.07	0.39	0.00			Si 0.07; Ti 0.03	M
19952	Malbork-Wielbark	79.05	0.20	0.04	0.07	0.12	0.37	16.63	0.00	0.08	2.12	0.38	0.94	0.00				M
20797	Malbork-Wielbark	82.61	0.18		0.03	0.31	0.02	12.25	0.02	0.00	3.28	0.20	0.09				Si 0.22	M
20798	Malbork-Wielbark	84.12	0.29		0.03	0.36	0.04	11.04	0.03	0.04	3.89	0.06	0.10					M
20799	Malbork-Wielbark	83.84			0.03	0.28	0.02	11.16	0.04	0.03	4.22	0.24	0.13					A
20800	Malbork-Wielbark	83.82	0.32		0.03	0.14	0.00	11.14	0.01	0.04	3.70	0.16	0.10				Si 0.27; S 0.27	M
20802	Malbork-Wielbark	86.48			0.05	0.14	0.01	7.90	0.04	0.00	4.62	0.17	0.13				Si 0.21; S 0.26	A
9779	Modła	81.57	0.42	0.27	0.02	2.00	0.01	13.50	0.09	0.05	1.70	0.06	0.30	0.00	0.00	0.00		M
9781	Modła	85.18	0.25	0.22	0.01	1.60	0.01	11.00	0.00	0.05	1.50	0.04	0.13	0.00	0.00	0.00		M
9784	Modła	82.91	0.35	0.27	0.00	2.20	0.01	12.50	0.00	0.05	1.40	0.05	0.25	0.00	0.01	0.00		M
9787	Modła	84.86	0.32	0.30	0.02	2.50	0.01	10.00	0.05	0.05	1.80	0.06	0.03	0.00	0.01	0.00		A
9789	Modła	84.56	0.30	0.22	0.01	1.70	0.03	11.50	0.08	0.11	1.20	0.05	0.24	0.00	0.00	0.00		M
9792	Modła	84.52	0.38	0.27	0.02	2.30	0.02	10.00	0.04	0.04	2.00	0.06	0.35	0.00	0.01	0.00		A
8176	Nadkole	86.65	0.35	0.15	0.01	1.60	0.05	9.00	0.14	0.06	1.70	0.12	0.16	0.00	0.00	0.00		A

Laboratory no.	Site	Cu	Al	Cr	Mn	Fe	Ni	Zn	As	Ag	Sn	Sb	Pb	Au	Co	Bi	Remarks	Metal
8178	Nadkole	85.35	0.47	0.11	0.01	1.35	0.05	10.00	0.14	0.07	2.10	0.13	0.22	0.00	0.00	0.00		A
8192	Nadkole	84.85	0.26	0.26	0.02	2.10	0.08	10.00	0.10	0.11	1.80	0.22	0.20	0.00	0.01	0.00		A
8193	Nadkole	84.84	0.16	0.11	0.01	1.20	0.06	7.80	0.06	0.09	5.30	0.15	0.23	0.00	0.00	0.00		A
8194	Nadkole	83.50	0.52	0.17	0.01	1.40	0.06	11.00	0.05	0.09	3.00	0.13	0.09	0.00	0.00	0.00		M
8195	Nadkole	85.08	0.16	0.09	0.01	0.90	0.07	9.20	0.06	0.06	4.00	0.15	0.24	0.00	0.00	0.00		A
8197	Nadkole	87.15	0.52	0.27	0.03	2.30	0.08	8.50	0.06	0.12	0.62	0.11	0.24	0.00	0.01	0.00		A
8204	Nadkole	85.00	0.32	0.25	0.02	1.65	0.06	10.00	0.03	0.08	2.00	0.12	0.16	0.00	0.00	0.00		M
8207	Nadkole	84.29	0.27	0.16	0.01	1.70	0.06	10.00	0.06	0.05	3.00	0.12	0.28	0.00	0.00	0.00		A
8216	Nadkole	85.46	0.42	0.16	0.04	1.80	0.05	8.00	0.11	0.10	3.50	0.13	0.23	0.00	0.01	0.00		A
8217	Nadkole	87.19	0.18	0.10	0.01	1.05	0.05	8.20	0.04	0.06	2.70	0.11	0.32	0.00	0.00	0.00		A
8224	Nadkole	82.00	0.30	0.07	0.01	1.05	0.05	11.00	0.03	0.05	5.00	0.11	0.30	0.00	0.00	0.00		M
8225	Nadkole	84.00	0.62	0.09	0.01	1.15	0.06	11.00	0.04	0.08	2.60	0.14	0.30	0.00	0.00	0.00		M
8228.00	Nadkole	83.00	0.52	0.22	0.01	1.70	0.04	12.00	0.03	0.09	2.10	0.15	0.15	0.00	0.00	0.00		M
ps135	Nadkole	79.62	0.01	0.02	0.00	0.40	0.04	18.00	0.07	0.06	1.40	0.11	0.28	0.00	0.00	0.00		M
ps85	Nadkole	58.00	0.14	0.01	0.00	0.05	0.03	35.00	0.05	0.15	4.50	0.18	1.00	0.00	0.00	0.00		B
ps86.1	Nadkole	63.00	0.11	0.03	0.00	0.90	0.02	35.00	0.02	0.11	0.40	0.08	0.38	0.00	0.00	0.00		B
ps86.2	Nadkole	61.00	0.05	0.02		0.28	0.02	35.00	0.04	0.22	2.80	0.07	0.23	0.00	0.00	0.00		B
ps87	Nadkole	72.15	0.03	0.13		0.30	0.06	27.00	0.04	0.15	0.03	0.04	0.24	0.00		0.00		B
ps88	Nadkole	71.67	0.28	0.02		0.38	0.21	25.00	0.05	0.09	2.40	0.12	0.23	0.00	0.01	0.01		B
ps89	Nadkole	79.77	0.02	0.00		0.30	0.09	18.00	0.03	0.10	1.60	0.04	0.13	0.00				B
12753	Oblin	80.78	0.00	0.00	0.00	0.38	0.12	14.81	0.00	0.04	3.07	0.00	0.58	0.00		0.00		M
12754	Oblin	79.42	0.00	0.00	0.00	0.31	0.19	17.14	0.00	0.00	2.54	0.00	0.29	0.00		0.00		B
12755	Oblin	83.04	0.29	0.00	0.03	0.27	0.22	12.20	0.00	0.00	3.49	0.00	0.07	0.00		0.00		M
12756	Oblin	78.78	0.31	0.00	0.00	0.11	0.08	16.85	0.00	0.08	3.19	0.00	0.27	0.00		0.00		B
12757	Oblin	79.51	0.00	0.00	0.01	0.22	0.14	17.57	0.00	0.00	1.97	0.00	0.56	0.00		0.00		B
12758	Oblin	79.12	0.00	0.00	0.05	0.23	0.07	19.32	0.00	0.05	0.43	0.00	0.39	0.00		0.00		B

7180.01	Pruszcz Gdański 10	85.72	0.90	0.08	0.00	1.10	0.02	11.50	0.07	0.06	0.05	0.13	0.38	0.00	0.00	0.00		M
7180.02	Pruszcz Gdański 10	84.95	0.85	0.10	0.00	1.40	0.02	12.00	0.10	0.06	0.05	0.13	0.35	0.00	0.00	0.00		M
7182	Pruszcz Gdański 10	83.56	0.87	0.11	0.00	1.50	0.04	11.00	0.10	0.04	2.30	0.13	0.36	0.00	0.00	0.00		M
8474	Pruszcz Gdański 10	80.00	0.22	0.80	0.03	2.20	0.08	13.00	0.07	0.07	2.80	0.11	0.25	0.00	0.01	0.00		M
8481	Pruszcz Gdański 7	80.00	0.21	0.60	0.02	2.00	0.06	15.00	0.07	0.07	1.50	0.14	0.40	0.00	0.01	0.00		M
8483	Pruszcz Gdański 7	82.00	0.18	0.50	0.02	2.00	0.06	12.00	0.08	0.09	2.40	0.12	0.28	0.00	0.01	0.00		M
8488	Pruszcz Gdański 7	78.00	0.16	0.80	0.03	2.50	0.06	15.00	0.08	0.04	2.30	0.11	0.50	0.00	0.01	0.00		M
8489	Pruszcz Gdański 7	83.00	0.14	0.50	0.02	1.60	0.06	12.00	0.09	0.05	2.30	0.23	0.12	0.00	0.01	0.00		M
8490	Pruszcz Gdański 7	83.00	0.12	0.60	0.02	1.80	0.05	13.00	0.08	0.05	0.65	0.11	0.38	0.00	0.01	0.00		M
8493	Pruszcz Gdański 7	83.00	0.16	0.50	0.02	1.70	0.07	10.00	0.07	0.04	3.50	0.15	0.55	0.00	0.01	0.00		A
8494	Pruszcz Gdański 7	81.00	0.11	0.80	0.03	2.00	0.08	12.00	0.07	0.04	3.20	0.27	0.65	0.00	0.02	0.00		A
8499	Pruszcz Gdański 7	82.00	0.13	0.70	0.03	1.80	0.04	13.00	0.06	0.04	1.50	0.13	0.18	0.00	0.01	0.00		M
8500	Pruszcz Gdański 7	81.00	0.12	0.70	0.03	1.70	0.05	14.00	0.06	0.04	1.50	0.20	0.22	0.00	0.01	0.00		M
8506	Pruszcz Gdański 7	81.00	0.10	0.50	0.03	1.90	0.06	13.00	0.06	0.28	2.00	0.28	0.42	0.00	0.01	0.00		M
8507	Pruszcz Gdański 7	83.00	0.12	0.70	0.03	2.20	0.05	12.00	0.04	0.10	1.80	0.32	0.11	0.00	0.01	0.00		A
9406	Przyrownica	73.94	0.70	0.14	0.01	2.20	0.03	22.00	0.04	0.06	0.46	0.10	0.32	0.00	0.00	0.00		B

Laboratory no.	Site	Cu	Al	Cr	Mn	Fe	Ni	Zn	As	Ag	Sn	Sb	Pb	Au	Co	Bi	Remarks	Metal
16144	Weklice	76.85	0.15	0.08	0.02	0.22	0.00	21.28	0.30	0.00	0.55	0.00	0.53	0.00	0.00		S 0.02	B
16208	Weklice	78.93	0.13	0.02	0.04	0.16	0.03	20.06	0.00	0.00	0.37	0.00	0.00	0.16	0.00		Si 0.07; S 0.02	B
16219	Weklice	75.41	0.04	0.03	0.10	0.37	0.07	22.52	0.24	0.00	0.66	0.03	0.31	0.00	0.00		Si 0.07; Ti 0.07; S 0.07	B
9743	Węsiory	84.10	0.35	0.12	0.01	1.90	0.01	11.50	0.08	0.05	1.50	0.10	0.28	0.00	0.01	0.00		M
9744	Węsiory	82.30	0.22	0.03	0.01	1.50	0.01	15.00	0.04	0.04	0.60	0.05	0.20	0.00	0.01	0.00		M
9751	Węsiory	83.65	0.13	0.25	0.01	1.40	0.01	11.50	0.02	0.03	2.60	0.04	0.36	0.00	0.00	0.00		M
9752	Węsiory	81.39	0.18	0.18	0.00	1.30	0.01	12.50	0.03	0.03	4.00	0.05	0.42	0.00	0.00	0.00		M

they may indicate local manufacturing. The series of strong correlations between resources allow to indicate similar raw materials, show their regional nature as well as possible connections.

The first distinguished factor has the strongest correlation with Cu, Sn, Pb, As and Sb, and a highly negative correlation with Zn (Fig. 5). This confirms that brass was obtained in the cementation process, by adding a separate zinc oxide ore to copper. The closeness between Sb and As indicates a common nature of the material, which is probably related to the contamination of copper. A similar contamination profile also characterises commonly occurring tennantite-tetrahedrite sulphide copper ore, which was already in use in the Bronze Age. The second factor emphasises the relevance of Ni and As and strengthens the correlation between Sn, Sb, and Pb. The third factor has the strongest correlation with Fe. Iron may contaminate zinc oxide ore, which would indicate that it originated from carbonate ore. They do not require initial processing in the metallurgical works, hence the contaminations may migrate to brass. Brass production in Roman metallurgy was based on such ore deposits located in Western Europe (Ponting 1999, 1317, 1318).

In order to distinguish groups with the most similar specimens, we used an additional statistical method of a minimum spanning tree, which connects points of similar weight. The emerging sequences were verified through the observation of further factors; in the end, the distinguished artefacts were required to display distinctiveness in terms of the manufacturing location or chemical composition in several generated diagrams. For clarity and to highlight the potential differences, a group of analyses was dedicated to the range -1/1 of the x-axis, where more than a half of the analysed brooches were assigned (Fig. 6). Such a high number indicates an existing strong relationship in both metallurgical and chronological terms. This particular type of metal was identified in material from nearly all of the researched burial grounds. The average content of the elements amounted to: 82.0% for Cu (reference range 77.3-86.4%); 1.1% for Fe (reference range 0.1-2.5%); 13.6% for Zn (reference range 10.0-18.0%); 2.1% for Sn (reference range 0.1-6.1%); 0.3% for Pb (reference range 0-1%); 0.1% for As (reference range 0-0.5%); 0.1% for Sb (reference range 0-0.4%). These values are virtually identical with the average references for the whole analysed data set. Hence, it may be assumed that they reflect the prevailing mode of manufacturing, indicating a particular type of metal, which could be related to the common raw materials inflow or the same manufacturing centre. The zinc content amounting to 13% was the most frequent in Roman metallurgy; according to Craddock (1979, 12), it is the result of mixing new pure brass with scrap bronze. This somewhat classical alloy was named type M (middle).

There is no visible correlation between the type M metal and specific types of brooches (*cf.* Table 3). However, it should be emphasised that 69% of the analysed brooches type A.57 and around 50% of type A.60 and A.61 were made of this metal. This alloy also prevails in the analysed artefacts from the burial grounds in Czarnówko (92% brooches out of 13 samples) and Krupice (86% out of 7 brooches). In Pruszcz Gdański (site 7), Malbork-

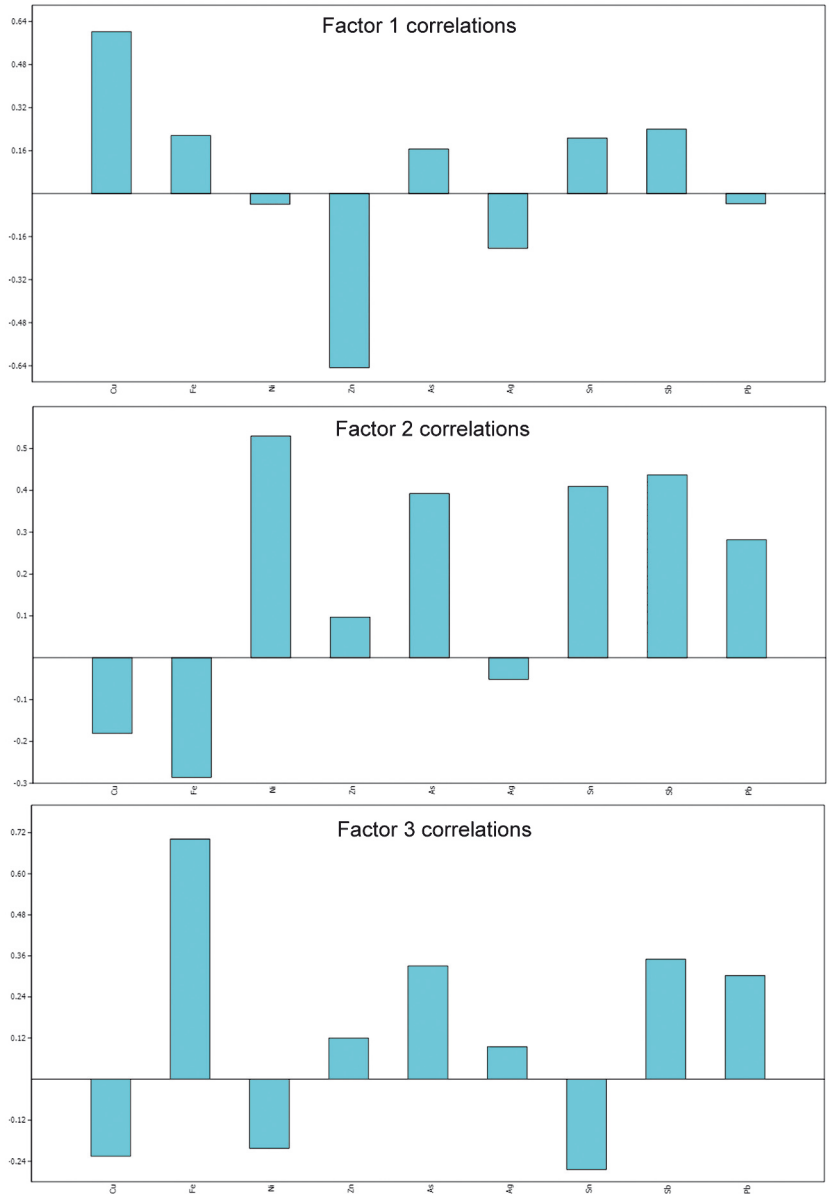

Fig. 5. The results of statistical analysis for the chemical profiles. Correlations between factors 1-3 and elements

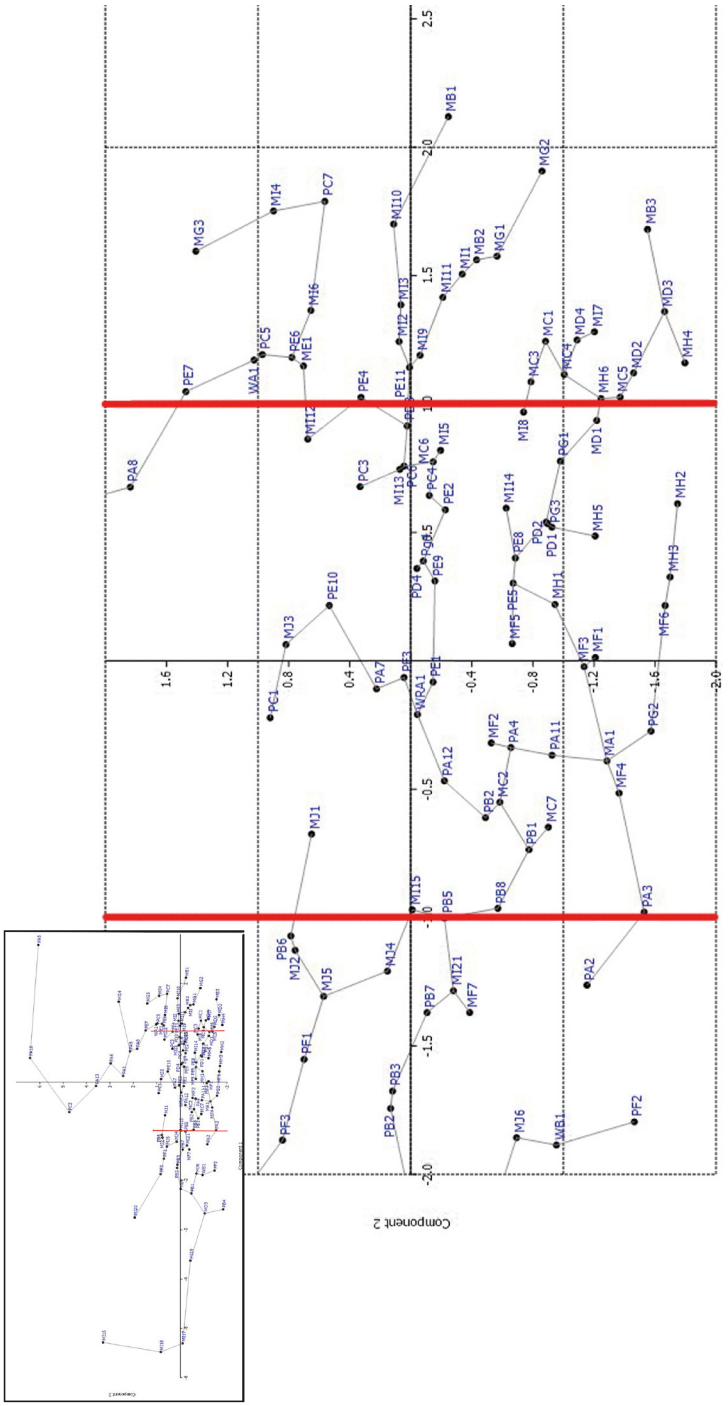

Fig. 6. The results of PCA analysis. Scatter plot of factors 1 and 2 with results between -1/1 on X-axis (type M metal). In the left corner, separate diagram with all results

Table 3. Tabular summary of the distinguished types of metals (M, A, B) in terms of numbers and percentages against the background of archaeological sites and typological findings

Almgren typology	Number of chemical profiles on the sites																				number of analyzes by type	M-type metal – according typology	A-type metal – according typology	B-type metal – acording typology	% M	% A	% B
	Czarnówko	Pruszcz Gd. 7	Oblin	Malbork-Wielbark	Grzybnica	Krupice	Weklice	Garwolin	Pruszcz Gd.10	Drawsko	Bieńkowice	Kamieńczyk	Kołoząb	Karczewiec	Łajski	Modla	Nadkole	Węsiory	Przyrownica	Domaradzice	Brzeźce						
A57	2	4		2	1		2									2						**13**	9	1	3	69	8	23
A58				1				1														**2**	1	1	0	50	50	
A59			1	1	5				4	1												**12**	6	1	5	50	8	42
A60	10	2	1	2	3	2	1			1	1	3	1	1	3	1	5	2				**39**	19	14	6	49	36	15
A61	1	2	3	1		2		1				3		3			5					**21**	10	7	4	48	33	19
A60/61		3										1		1			9		1			**15**	5	6	4	33	40	27
A57-59-51			1			3		1							1	1	1					**8**	4	3	1	50	38	13
A58/59																2	1			1	1	**5**	4	1	0	80	20	
A59/60																		2				**2**	2	0	0	100		
52/57												1										**1**	0	1	0		100	
Sum	**13**	**11**	**6**	**7**	**9**	**7**	**3**	**3**	**4**	**2**	**1**	**8**	**1**	**5**	**4**	**6**	**21**	**4**	**1**	**1**	**1**	**118**	**59**	**35**	**23**	50	30	19
M-type metal on the site	12	8	2	5	2	6	0	0	4	2	1	3	0	0	0	4	6	4	0	0	1							
A-type metal on the site	1	3	0	2	0	0	0	3	0	0	0	5	1	4	4	2	9	0	0	1	0							
B-type metal on the site	0	0	4	0	7	1	3	0	0	0	0	0	0	1	0	0	6	0	1	0	0							
% M	92	73	33	71	22	86	0	0	100	100	100	38	0	0	0	67	29	100	0	0	100							
% A	8	27	0	29	0	0	0	100	0	0	0	63	100	80	100	33	43	0	0	100	0							
% B	0	0	67	0	78	14	100	0	0	0	0	0	0	20	0	0	29	0	100	0	0							

Wielbark and Modła, it was found in 70% of the artefacts. In some sites (Węsiory, Drawsko Pomorskie, Pruszcz Gdański, site 10, Brzeźce), this metal was found in even up to 100% of eye brooches; nevertheless, this score is relativised by a low number of the studied artefacts from these burial grounds.

The remaining 58 standing out analyses indicate a significantly higher zinc content, which may testify to the use of non-mixed brass (metal high in zinc – type B), or quite the opposite, they are characterised by a lower zinc content, which may imply further metallurgical works being conducted, perhaps related to the local manufacturing. This mixed alloy with lower zinc content was named type A. Detailed inspection of group A allows us to distinguish several raw material sequences, which show a tin content increasing from 0.6% to 5%, with an average zinc content not exceeding 9.6%. However, generally speaking, the chemical composition is very similar and any attempts of further categorisation do not provide significant information.

Most of the brooches made from metal A (28 out of 35 analysed) are from Mazovian sites. In Garwolin, Łajski and Karczewiec, all or nearly all of the investigated brooches were made from this metal. On the other hand, in Kamieńczyk, Nadkole and Modła, it was found in 63%, 43% and 33% of the brooches respectively. The mixed metal occurred definitely less often in the Pomeranian sites: in Pruszcz Gdański, site 7, and Malbork-Wielbark, it was found in only 30% of the artefacts. Considering the typology, the discussed set comprises only a few examples of types A.57 (Pruszcz Gdański, site 7, grave 279, CL8507), A.58 (Garwolin, grave 61, CL7032) and A.59 (Malbork-Wielbark, grave 2019/59, CL20802 – in this case the low amount of zinc could also be the result of the strong corrosion of this object); the percentage share of the types A.60 and A.61 amounts to *circa* 30%. Therefore, it can be assumed that the chronologically more recent types of eye brooches could have been manufactured in the local workshops on the basis of earlier stylistic patterns and made from an available, processed raw material – scrap. However, earlier local production may be indicated by hybrid brooch A.52/59 from Kamieńczyk, grave 16 (CL6850 analysis) which was also made from such processed raw material.

At least two groups/accumulations of raw material emerge within the brooches with a high amount of zinc (type B metal), in which the minimal zinc content exceeds 15%. The most prominent is a two-element CuZn compound and it comprises two brooches from Nadkole (grave 56, analysis PS87 and a loose artefact PS86/1) as well as one artefact from Oblin (grave 176a, analysis CL12758) and Przyrownica and all three analysed items from Weklice and its surrounding. However, a pair of A.57 brooches from Weklice (grave 492), accompanied by an A.53 brooch, would actually have to be described as a main series of the eye brooches in regard of their springs made of wire with a round section.

The group CuZnSn, characterised by a higher admixture of tin (reference range 1.14-4.50%), is undoubtedly bigger. It involves items from Grzybnica (graves 19B, 19C, 29, 50), Krupice (grave 131A), Karczewiec (grave 48b), Nadkole (graves 26, 30, 114), Oblin (graves 31, 174). Grave 19B in Grzybnica contained two A.59 brooches and one A.58; one of the

A.59 brooches was made from both type B metal (its bow) and type M metal (its spring), which means that the proportion of components could vary even within one object. Both of the brooches were covered by the same barrow as grave 19C with an A.60 brooch; grave 29 contained two brooches A.58 made from different brass and containing an average or high ratio of zinc, which might have been a secondary composed pair of brooches.

Both groups may be linked to the primary cementation process. In the first group, contaminated copper was used, whereas in the second – scrap bronze. It should be noted that artefacts high in zinc content constitute the smallest group in the whole analysed data set of eye brooches, amounting to only 19% of all items. In regard to the specific types of eye brooches, they constitute 23% of type A.57 and 42% of type A.59; their share did not exceed 20% in the case of the younger types A.60 and A.61.

It is worth mentioning the diversified distribution of the metal found in larger and more thoroughly researched burial grounds. All discussed metal types were identified only at the site in Nadkole. There were no items high in zinc (type B metal) found in Kamieńczyk, Modła, Czarnówko, Malbork-Wielbark and Pruszcz Gdański, site 7. On the other hand, in Oblin, Krupice and Grzybnica, both metal types M and B were found. The diversification in the findings may result from the access to the raw material as well as reflect the chronological differentiation of sites and the varying frequency of brooch types.

The juxtaposition of the results from the analyses of findings from eastern *Barbaricum* with the analyses of eye brooches from Augsburg, the eastern Baltic area and Moravia (see Riederer 2001, 233-235; 2002, 118-120; Roxburgh and Olli 2019; Zeman 2017a, 305-308, tab. 1; 2017b, 185) shows symptomatic differences. In Augsburg, there were virtually no artefacts low in zinc content. The reference range for Zn obtained from 59 artefacts was 11.04% to 30.95%; moreover, there were 12 brooches made of bronze with the admixture of tin and with the zinc content not exceeding 1%. Finally, one brooch was made of copper and one of *tenerrima*, an alloy of CuSnZnPb. Thus, that production was based on unlimited access to high-quality raw material and it was not necessary to use remelted metal (metal scrap). On the other hand, such recycling can be observed in the case of metal A findings from the burial grounds in Mazovia. A small group of the Prussian series eye brooches from Moravia is similar in this regard to the Mazovian findings. They are lower in zinc content, tin is present in the alloy, and for the first time, there is a significant admixture of lead (>2%) in one brooch type A.61 from Vesela (it must be noted that this data set must be viewed with caution due to the fact that the measurements were taken on the uncleaned surface of the objects and, therefore, contain up to 35% of silicon; the absolute percent values of the components are not recalculated concerning the metal, but including all corrosion products as well as the surrounding soil). This may testify to the existence of local workshops in the area of Mazovia and Moravia. However, there is no basis for the assumption that a proportionally high share of brooches made from metal types M or B found in Oblin and Krupice means their local manufacturing and the existence of specialised workshops in the area. The artefacts from these cemeteries were probably imported

from other workshops. Other sites with lone items made from metal types M or B could be subject to a similar interpretation.

The results of the analyses of the eye brooches from Latvia and Estonia should be treated with caution too. As the authors of the analyses indicate themselves, the surface analysis is not a proper method of classification; it might only signal what the prevailing trends were regarding the selected alloys (Roxburgh and Olli 2019, 218). The results are distorted due to patina, corrosion, decuprification and dezincification. It should be emphasised that the corrosion phenomena include also surface enrichment/pushing the compounds of tin and lead to the surface of the manufactured item (Janowski *et al.* 2019, 389-395). Hence, a direct comparative analysis of the received results is not possible and the suggested differences in the selection of gunmetal alloy for the brooches type A.60 and the brass alloy for the brooches type A.61 found among Estonian artefacts require further verification, especially considering that different types of metal were identified in both typological groups. Brooches A.61 (11 specimens in total) were mostly made from a metal designated by the authors as "brass," which seems to be similar to the metal type A – an alloy that was probably common in local workshops located in *Barbaricum*. There is only one brooch that is related to the M metal, with no addition of tin or lead. Another brooch was made of an alloy with high content of tin (18%) and the addition of zinc (3%) and lead (4%), which would indicate a different tradition or raw material. Such alloys are virtually non-existent in Roman metallurgy.

The similar metal was also noted among of brooches type A.60 (13 analyses in total). The remaining brooches were mostly manufactured with the quadruple alloy CuZnSnPb, containing an equal amount of Zn and Sn. Such metal, characterised by no visible extremes, was typical for some elements of Roman military equipment in the 2nd and 3rd centuries AD (Dungworth 1997, 906); hence, it should be linked to the reuse of raw material. Moreover, the group of type A.60 brooches from Latvia and Estonia include one specimen each corresponding to the metals types M and A distinguished here. Hence, we can assume that there are some links, yet there are significantly more differences, which are the result of geographical distance, slightly later chronological dating, but mostly different methods of analytical research, influencing the accuracy of measurements.

A stepping stone towards the identification of manufacturing centres in *Barbaricum* may undoubtedly be the presence of brooches made from raw material low in zinc with the simultaneous occurrence of brooches characterised by average and high zinc content. This was the case in the burial grounds in Malbork-Wielbark, Czarnówko, Pruszcz Gdański, site 7, Kamieńczyk, Modła, and Nadkole. Surely, this does not provide sufficient evidence that there was a local workshop near each of these cemeteries. These communities could have used the services of the same, larger centre. However, one should not exclude the existence of smaller, local workshops, such as Garwolin or Łajski, in the burial grounds at which only artefacts low in zinc content (metal A) were identified.

The material (chemical composition) differentiation visible in the analysed materials from the eastern part of *Barbaricum* corresponds with the morphological differentiation.

Even though the typological unification is quite considerable, 'hybrid' forms that blend the properties of several types are not that rare. Hence, the 'morphological' arguments might support the suppositions of dispersed manufacturing in many local centres, performed by artisans possessing various skills. The inventory of grave 34 from the burial ground in Kołacz (Dąbrowska 2002, 226, 234, 252, tab. 10: 1-4) might be a good example thereof. Two brooches, only small parts of which were preserved, must be classified as belonging to the Prussian series. The shape of one of the other brooches is reminiscent of the Prussian series; and so are the cord and the spring made of wire with rectangular cross-section, as well as a ladder ornamenton on the frontal part of the bow. However, the middle and the lower parts of the bow show highly unusual ornamentation with vertical grooves, which are bounded by horizontal grooves. There were probably two brooches constituting a pair, made in one workshop (or by one artisan). The second, poorly preserved specimen is also decorated with vertical grooves, which are bounded by horizontal grooves; however, it has a more fan-like shape. The horizontal grooves placed between the bow and the foot on both specimens, can be considered an imitation of a crest. The lack of a crest, as well as the narrowing of the upper part of the bow are characteristic for type A.61 brooches, which are the latest specimens of the Prussian series. By contrast, the non-decorated and plain foot is reminiscent of the main series of brooches, especially types A.52 and 53, which were not characterised by a widened foot as type A.61 and these examples. Both brooches from Kołacz should be considered as local products, which could have been inspired not only by eye brooches but also by the bow ornamentation of crest brooches from the area of the Bogaczewo culture.

In theory, grave 16 in Kamieńczyk (Dąbrowska 1997, 14, 139, tab. IX/16: 1-3) seems to confirm similar experiments. There were three eye brooches. On the basis of the eyes on the bow, two of them should be determined as type A.52; however, the bow ornamentation is reminiscent of type A.59. The third brooch blends the properties of types A.53 and few properties of A.57 (bow ornamentation) as well as A.52 (foot). The blending of types probably excludes a specialised workshop (*e.g.*, similar to the Augsburg manufacture) and points towards a smaller, local manufacturer who possessed only general knowledge regarding the features of this type of brooches. More so, one of these A.52/59 hybrids (analysis CL6850) was made of processed alloy with low zinc content (type A metal).

Both mentioned inventories (Kołacz and Kamieńczyk) are from the eastern part of Mazovia, which could suggest—along with the chemical analyses—the existence of some local workshop (or workshops). This particular mix of types and unusual ornamentation could have been the result of following the local tastes or independent experiments of the craftsman (or craftsmen).

Dispersed manufacturing, taking place in various local centres, might also be evidenced by a brooch from Husynne in Eastern Poland (Hrubieszów Basin). This loose artefact is most similar to the types A.62-63; however, the ornamentation of the bow and the foot is more reminiscent of the brooches from Almgren Group II (so-called spring-cover brooches/

Rollenkappenfibeln). The manner in which the cord of the spring is fastened is also quite unusual: with two cord-hooks made of thin metal strips and placed near the outer edges of the bow, which probably was not the result of a non-professional attachment (Niezabitowska 2005, 490-492, fig. 1: 1).

MANUFACTURING RESOURCES

Metallurgical analyses indicate that, in terms of the alloy composition, the artefacts found in the eastern areas of *Barbaricum* largely correspond to the Roman categories of alloys known, for example, from Augsburg. Is also confirmed that in the 1st century, a significant part of *sestertii* was made of fresh brass obtained through the cementation process (Craddock 1979, 13). Freely mixed (*i.e.* recycled) alloys were also quite relevant; they were obtained through melting together various raw materials. It is assumed that Germanic artisans used mostly Roman vessels and 'bronze'/*aes* coins as the main source of the raw materials in manufacturing (see Voss *et al.* 1998, 290, 291; Voss 2016, 141-145; also Fagner *et al.* 2015, 339). The same conclusions can be drawn from the data set of Moravian metal vessels (Zeman 2017a, 306, tab. 1). In Germania, there is no evidence from the Roman period that would confirm independent copper extraction and smelting. In this context, it is worth mentioning the calculations by E. Droberjar and J. Frána (2004, 457-459) that use the weight of the artefacts from the burial ground in Dobřichov-Pičhora. These indicate that from one Östland bucket (E.38 – 1.150 kg; E.39 – 1.518 kg), it was possible to make from 40 to 52 so-called spring-cover brooches (medium weight: 29 g), whereas from a situla (E.18b from grave II; 1.871 kg) – even up to 65 such brooches. Nevertheless, the composition of the alloys used for the manufacturing of metal vessels is unclear; the same is true for the mentioned group of the brooches. However, the question arises of how this can be related to the situation in the eastern areas of *Barbaricum*. In this area, bronze vessels occur essentially only in graves such as in Lubieszewo/Lübsow (*cf.* Schuster 2010), whose exceptionality and elitism is defined precisely based on the presence of such vessels. Therefore, local elites surely had access to imported goods. However, a further question should be posed as to whether the import was a scale large (and stable) enough for the elites to redistribute a part of these social status markers or to use them as a source of raw material for the production of significantly less prestigious ornaments. Moreover, east of the Odra river, *aes* coins do not occur in any considerable number. Hence, these two categories of sources should be excluded at least in relation to the Wielbark and Przeworsk culture.

For the same reasons, a theoretically sound example of the late Roman hoards from the Rhine such as in Neupotz should probably be discarded. This deposit (Künzl 1993) comprising over 10 kg of silver, nearly 200 kg of *aes*, nearly 1.5 kg of tin as well as almost 220 kg of iron; there is also a deposit of late Roman bronze vessels from the Elbe in the village

of Grieben (Voss 2016, 141, fig. 1, see earlier literature there). However, no examples of such deposits are present in the area of the Wielbark and Przeworsk culture in the 1st and 2nd century AD.

There is also another alternative possibility, namely a type of recycling, which is indicated by the hoard from Łubiana (Mączyńska 2011), containing nearly 14 kg of bronze artefacts robbed from numerous burial grounds of the Przeworsk and Wielbark culture. The deposit probably functioned as storage for raw materials designated for further remelting. It is also dated much later, i.e. to the beginning of the 5th century.

Perhaps vessels and coins were not the only sources of raw material in *Barbaricum*. There is a find from the grave 202 at the burial ground in Třebusice, Czechia (Droberjar and Frána 2004, 457-459, figs 6, 7), dated to the regional phase B1b on the basis of two brooches type A.45b and A.19aII, which might serve as a hint. A rectangular piece of brass sheet (4.6 x 2.2 cm; weight: 13.04 g; gauge: 2 mm) was found in the cinerary urn. It was very high in zinc content (31.3%), meaning it was of very high quality. This sheet, which had visible signs of cutting on three of its edges, was definitely not a part of a vessel or fitting but rather a supply of material for further manufacturing. Unless it was produced in the area or generally in *Barbaricum*, which would be contradicted by the zinc content being so high, this could be a hint regarding the influx (perhaps export or trade) of raw brass material (half-products) into *Barbaricum* that was not limited to ready-made dress accessories, vessels and coins. However, this example comes from a period that is slightly earlier than the one when the discussed eye brooches of the Prussian series were used.

SUMMARY AND CONCLUSION

The issue of whether eye brooches are the product of Germanic or Roman workshops is being constantly raised in the literature (lately: Steidl 2013, in relation to the earlier brooches A.45-46). The series of Prussian series eye brooches from Augsburg (*Augusta Vindelicum*) plays a particular role here. Their interpretations in terms of manufacturing, trade and use are widely different. Some presume that the brooches were manufactured by Provincial Roman artisans to be exported to the 'amber coast' (*e.g.*, Voss 2008, 343-345, fig. 1), similarly to the glass beads that served as the subject of exchange (*cf.* Łuczkiewicz *et al.* 2021). Others speculate that they were manufactured for export to Germania by Germanic specialists located in Augsburg (*e.g.,* Mączyńska 2011, 27) who were perhaps coming from the eastern part of the Elbian Circle (Bakker 1993, 106; 2002, 263, 264, fig. 3), though the latter supposition seems to be discredited by the fact that the Prussian series occurred mostly in the areas of the Wielbark and Przeworsk culture, which are located much further to the east.

As shown by M. Pauli's research, these brooches were certainly manufactured in Augsburg and decorated using identical stamps. At least one workshop, or many workshops,

since the discussed brooches were also found in other places and not only in one centre, functioned in the artisan district located in the south-western part of the *vicus*, while the manufacturing process was perhaps conducted by Germanic artisans. A relatively high percentage of repaired specimens as well as those showing evidence of having been used indicates that they were also worn by the local population. However, brooches found in one basement of a house that was destroyed in 69/70 AD show that late eye brooches of the main series, as well as early ones of the so-called Prussian series, were only a minority in the stock of wares at that time.

This case may not be proof of a presumed presence of Germanic traders in Augsburg; perhaps a minority of the brooches were worn by the presumed local Germanic population. They could have been the second or third generation (as indicated by the local occurrence of older and younger forms of eye brooches from the main series) of the descendants of Germanic *auxilia* stationed in the *castellum*, which was destroyed during the civil war in 69/70 AD. However, another possibility cannot be definitively ruled out, that the non-Roman inhumation graves with horse burials in the south-western part of the necropolis belong to Thracians rather than Germans in the *auxilia* (Bakker 2000, 89, 90).

There is also another (though quite similar) interpretation. Admittedly, there is no epigraphic evidence confirming that the Germanic – or, all the more, 'East-Germanic' – *auxilia* were stationed in Augsburg, or in the province of *Raetia*, or on the Danubian *Limes* in the 2nd century; neither there is evidence of tribal contingents. However, the discovered fittings of drinking horns, which are not that rare in *Raetia*, may be connected with the presence of 'Germanic' warriors. Such fittings are also found in grave inventories containing militaria, for instance, grave 17 in Wehringen with a ring pommel sword, lance point and conical shield boss (Maier 1985, 54, 55; Nuber 1985, 52, 53; see also Steidl 2013, 162-165, regarding the so-called Germanic discoveries from the phase B1). In this context, it also seems important to mention the so-called ring pommel swords from this and another grave in Wehringen, which are dated in the late 2nd century; nevertheless, this type of swords, though not foreign to the Roman military tradition, may not be linked solely to the 'Germanic' people (Miks 2007, 177-187, 758, pl. 47, A775). Perhaps the entire manufacturing of the eye brooches in Augsburg was not meant to partly satisfy the local needs and partly be distributed into the *Barbaricum*, including its east ends; instead, they were made for the 'Germanic' *auxilia*, since at least some of them were found in the area of the destroyed former *castellum*. The connection with the provincial burials in Wehringen that took place nearly a hundred years later seems very curious. Moreover, the eye brooches were never found in graves that could be in any sense connected with 'Germanic' *auxilia*. It does not appear to be provable that the 'Germanic' artisans had been living in Augsburg due to their kinsmen stationed in the province. However, the mass scale of this production, far exceeding the needs of *auxilia*, should be mentioned here as a counter-argument.

In the literature, it is also hypothesised (Roxburgh and Olli 2019, 226) that the brooches were manufactured for the Germanic soldiers serving in the Roman army, who would take

them back home after finishing military service. It should be remembered, however, that the eye brooches of the Prussian series were used by men (*e.g.*, Nadkole, graves 38, 57, 86: Andrzejowski 1998; Kamieńczyk, graves 92, 352: Dąbrowska 1997; Oblin, grave 176a: Czarnecka 2007), but were also commonly found in *Barbaricum* in female graves (*e.g.*, Nadkole, graves 36, 80A, 94: Andrzejowski 1998; Kamieńczyk, graves 55, 111, 174, 272: Dąbrowska 1997).

The models of production that emerge from the chemical analyses of the Prussian series eye brooches from the eastern part of *Barbaricum*, are highly diversified. More than half of the artefacts probably came from large centres, as they were made of a chemically homogeneous Roman raw material. This naturally evokes an analogy with Augsburg; it may be suspected that such a workshop (or workshops) was located outside of *Barbaricum*, in the Empire (*cf.* similar comments by Roxburgh and Olli 2019, 225-227, on the basis of the results of the alloys analysis of the typologically late eye brooches of the Prussian series, mostly A.61, found in Latvia and Estonia). However, high-quality raw material in the form of coins and vessels (and perhaps brooches too) was transported into *Barbaricum*; thus the possibility that there were large manufacturing centres operating also in *Barbaricum* cannot be fully excluded (this may also refer to late eye brooches of the Prussian series from Latvia and Estonia: Roxburgh and Olli 2019, 225-227). Nonetheless, this statement is relativised by a general lack of bronze coins as well as the fact that metal vessels occur in the researched area only in the elite graves from the older Roman Period. These potentially existing supra-regional workshops would have required the functioning of a wide network for the distribution by ware-exchange since these chemically homogeneous products were found in the burial grounds of both the Wielbark and Przeworsk cultures. Moreover, the fact that, so far, such a centre in these areas has not been discovered is not a strong argument in favour of this notion, regarding the present low state of research on the settlements, especially on the Wielbark culture.

The lack of a clear correlation between the typological classification of the analysed group of brooches and the type of the alloy, as well as the observed wide array of alloying additives, lead us to the conclusion that a significant number of the brooches was manufactured from a raw material that was accessible at the given time through mixing or recycling. Surely, some of the demand was also satisfied by small workshops that manufactured goods for a narrow circle of local consumers. An excellent example thereof is an increased presence of brooches made of mixed metal (type A) in the burial grounds of Mazovia. In Kamieńczyk and Modła (8 and 6 analyses respectively), no products with high zinc content (type B metal) were found; however, in the necropolis of Nadkole, which is the source for the most analyses from Mazovian burial grounds, both original Roman alloys (type M and type B) occur in considerable numbers of samples analysed.

A low number of brooches made from the mixed alloy (type A) or a complete absence of items with high zinc content (type B) in large Pomeranian burial grounds (Pruszcz Gdański, site 7, Malbork-Wielbark and, first and foremost, Czarnówko), where the original

Roman alloy (type M) prevails, poses the question regarding the possible differences in the patterns of distribution (and influx) of the brooches between the Przeworsk and the Wielbark culture. The communities of the Wielbark culture, or at least their part living in the bustling settlement microregions where the analysed cemeteries were located may have mostly received the products from large, supra-regional manufacturing centres, whose location cannot be clearly determined. Hypothetically, these might have been workshops in the Empire; it is not completely excluded that they could have functioned in *Barbaricum*, though they would have needed constant access to large quantities of high-quality raw material. For the most part, the population from the eastern Mazovian area of the Przeworsk culture might have supplied themselves through local workshops, yet the brooches made of the Roman alloy (type M) were also not rare there. This implies slightly different networks of (possibly external) relations existing in the two cultures. These hypotheses are, however, relativised by the partial nature of the resource base at our disposal (*cf.* Fig. 4 and Tab. 1).

In the light of the conducted chemical composition analyses of the artefacts from *Barbaricum*, it is not possible to unanimously answer the question of whether the eye brooches of the Prussian series were manufactured by Germanic or Roman workshops. However, a different question should be posed instead: how many of the analysed brooches were made in large, supra-regional workshops? And where were those workshops located? It has been proven that some of the workshops were located in Augsburg. However, our considerations should include the regions of *Barbaricum* which had close contact with the Empire and, above all, were able to secure a steady influx of Roman resources. On the other hand, it has also been demonstrated that there were smaller workshops using scrap metal as the source of their raw material,which could have been located anywhere in the *Barbaricum*. As evidenced by the occurrence in Kamieńczyk grave 16, these local or regional workshops in *Barbaricum* started their production along with the production of younger eye brooches of the main series such as A.52-53 at the latest. Therefore, in further research, the metal composition of the eye brooches of the main series in both the Empire and *Barbaricum* should be comparatively examined in order to investigate the beginning of this local production more closely. Afterwards, an investigation should be conducted of the metal composition of the spring-cover brooches simultaneously competing on the 'market' with the eye brooches of the Prussian series, in the Wielbark culture especially A.38 and A.42, as well as the secondary brooches from Almgren group V such as A.110, A.120 or A.148/150. This could broaden our understanding of the production structures at that time. Therefore, the analyses presented here can only be viewed as a contribution to further research.

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