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ESSENTIAL CHANGES IN THE COMPOSITION OF COPPER ALLOYS REVEAL TECHNOLOGICAL DIVERSITIES IN THE TRANSITION FROM THE EARLIEST IRON AGE TO THE EARLY ROMAN PERIOD IN LITHUANIA

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Keywords

Copper alloys, X-ray fluoresence spectrometry, technologies, jewellery, major places, exchange network, Earliest Iron Age, Early Roman period, Lithuania

Abstract

In the context of archaeometallurgical studies of copper alloys, it is relevant to record the essential changes in the elemental composition of copper alloys that occur during changes in technology and transitions in human history. This article presents the shift in the elemental composition of copper alloy from bronze-based alloys to brass ones during essential changes in archaeological material which happened at the turn of the Earliest Iron Age (500–1 BC) and the Early Roman period, from the 1st century BC to the middle of the 1st century AD. As early as the 2nd and 1st centuries BC, in the Antique world and the Roman Empire and its provinces, brass was already starting to partly replace bronze. Even if the Earliest Iron Age is the least knowable period in Lithuanian prehistory, the few pieces of jewellery attributed to this period show the changes in the composition of the copper alloy. The territorial growth of the Late Antique world and internal contacts within the Barbaricum led to the expanding strength of commodities, including raw materials, technologies, cultural ideas and ideological attitudes. Goods and ideas spread throughout the vast barbarian lands, and eventually reached the forest zone of northeast Europe. Sudden changes during the Early Roman period were first of all connected with the development of settlement structure, and this has therefore made it possible to identify some major places of the production of artefacts and partly changed directions of exchange. All this was accompanied by the emergence of new jewellery types produced by skilled jewellers according to sophisticated techniques. These changes are clearly visible in Early Roman period Lithuanian archaeological material, including the elemental composition of copper alloys. The present article uses X-ray fluorescence (XRF) spectrometry to investigate the composition of copper alloys. Radiography was used to understand the construction of artefacts, and to assess the degree of their inner corrosion and sophisticated manufacturing techniques. Solder samples were taken from the surfaces of several finds, and were analysed by qualitative microchemical analysis.

Introduction

On the basis of published copper alloy artefacts from the Late Bronze Age to the Earliest Iron Age, we should acknowledge that there are only a small number of such finds in the east Baltic region compared to Scandinavia and the southwest edge of the Baltic Sea shore (Grigalavichene 1980, pp. 48–88; Luchtanas 1981; 1992, p. 68; 1998; Grigalavičienė 1986a, p. 77, Fig. 22.1–8, 17; 1992, p. 91, Fig. 11.1,3,6; 1995, pp. 172–188; Merkevičius 1986; Volkaitė-Kulikauskienė 1986, pp. 32–36; Merkevičius 2011; Čivilytė 2014, pp. 110–112; Podėnas and Čivilytė 2019).

In the Late Bronze Age, hillforts or hilltop settlements in east and northeast Lithuania are quite contrasting

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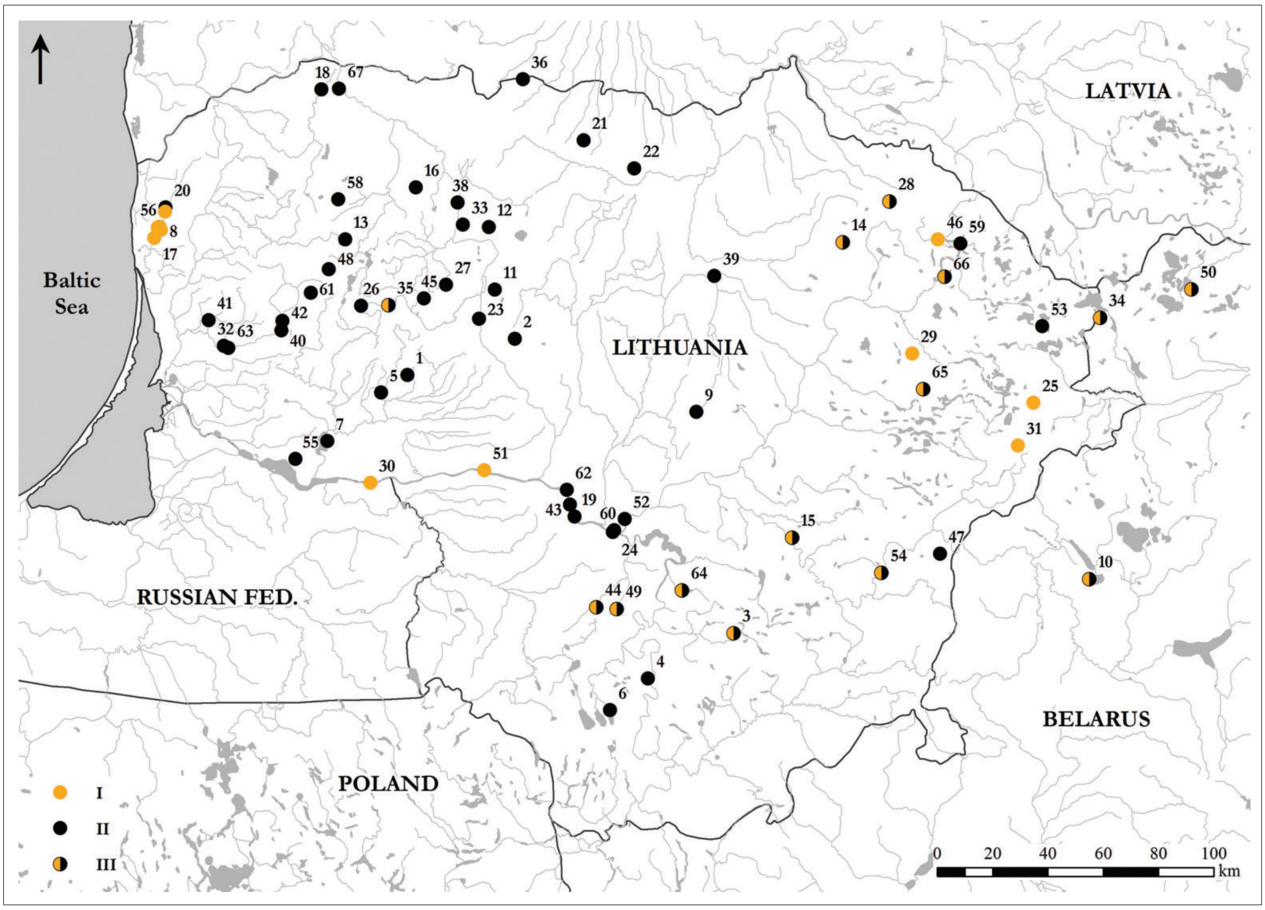

Figure 1. Sites mentioned in the article, dating from the Earliest Iron Age (I), the Early Roman period (II), and from the Earliest Iron Age to the Early Roman period (III). For the site numbers on the map, see Appendix (drawing by G. Petrauskas).

(Podėnas 2020) (Fig. 1; Appendix). In contrast, in the coastal lowlands of west Lithuania and the Lower Nemunas region, the archaeological material comes mainly from burial sites, although there were undoubtedly lived-in hillforts and unfortified settlements (Grigalavičienė 1979; Bliujienė et al. 2012; Šiaulinskas 2016; Jovaiša 2020; Minkevičius et al. 2020; Vengalis et al. 2020; Piličiauskas et al. 2021). However, it should be admitted that, in terms of material, chronology and settlement structure, the Earliest Iron Age remains the least-known archaeological period in Lithuania. On one hand, it is difficult to assess more precisely the transition from the Late Bronze Age to the Earliest Iron Age, especially since some of the bronze jewellery was found by chance, and its chronology is defined only by analogies. On the other hand, with the disappearance of bronze axes and other heavy objects characteristic of the Bronze Age, Earliest Iron Age ornaments appear small, which means that they did not require a large amount of copper alloy as a raw material. The low weight of Earliest Iron Age artefacts, mostly jewellery, can be interpreted as a shortage of raw material, most likely due to a disturbance in the raw material exchange network. It could be that bronze ceased to exist on the raw material exchange network in the middle of the 1st millennium BC. In addition, the spread of iron artefacts, including working tools in the Earliest Iron Age, could have influenced changes in people's way of life. Moreover, there is not a great variety of types and shapes among the finds from this period, because the predominant jewellery is pins with cylindrical heads, pins with ring-shaped heads, pins of other shapes, neck-rings, bracelets and ring-shaped temple ornaments. Only a few imported iron fibulae typical of the period in question are known (Grigalavičienė 1995, p. 189, Fig. 108.8). However, the archaeological evidence shows that there was a shortage of iron fibulae in Lithuania during the Earliest Iron Age. This feature is particularly evident, because eye and other fibulae types, and various other kinds of jewellery, spread widely from the Early Roman period onwards. According to data from the 1990s, artefacts made of copper alloys and iron in the hilltop settlements of east and northeast Lithuania accounted for only 2.4% of the total finds (Luchtanas 1992, p. 68). Although the number of metallic artefacts has increased in recent years, they have not substantially altered our knowledge of this archaeological period. However, the material from barrows (technical ceramics [moulds, crucibles etc], metal drops and various kinds of production waste) indicates the presence of local production, which is indicative of a fairly high level of jewellery making, although no permanent production places have yet been found. A reasonable hypothesis is therefore put forward about highly skilled jewellers travelling with the raw materials (Luchtanas et al. 2019; Podėnas and Čivilytė 2019). The abundance of technical ceramics and technological studies suggests that most Late Bronze Age artefacts were cast. Bronze was most suitable for casting. By contrast, at the end of the Earliest Iron Age, in addition to casting, the number of artefacts produced from hammered wire and thin tin sheets increased. Technically, malleable brass was most suitable for the production of artefacts by forging. Thus, the change in the elemental composition of copper alloys may have been due to the greater variety of artefacts produced in the east Baltic region at the end of the Earliest Iron Age. The change in alloy, on the other hand, was a European trend that reached northeast Europe fairly quickly.

Artefact production techniques and a reduction in size were the reasons why jewellery came to be shredded. Elemental composition analyses by Optical Emission (OES) and X-ray fluorescence spectrometry (XRF) of a sufficiently representative series of copper alloy ornaments show that Late Bronze Age finds were made of bronze, while in the range of the Earliest Iron Age, jewellery made from brass emerged and spread (Miarkiavichius 1980, pp. 107–109, Table 1; Merkevičius 1986).

However, a distinct shift from bronze to brass alloys can be seen from the middle of the 1st century AD. In other words, the shift to brass coincides with the beginning of the Early Roman period, around circa 40 to 70 AD (i.e. period B1b) (Merkevičius 1973; Vaitkunskienė and Merkevičius 1978, pp. 96–97, Table 1; Čivilytė 2014, p. 44, Table IV.21). The Early Roman period is a time when a sudden jump in the settlement structure covering most of Lithuania is observed, when cultural areas begin to emerge, when a certain divide between the western and eastern parts of the region appears, when striking changes in burial sites and burial customs can be seen, and when a whole range of new forms and types of jewellery appear. These dress accessories might be called pins with a spool-shaped head, neck-rings with hollow shaped trumpet terminals, eye fibulae and several fourth group fibulae according to O. Almgren (1897), temple ornaments, bracelets with bud-shaped terminals (Merkevičius 1973; 1986; Vaitkunskienė and Merkevičius 1978, Table 1; Bliujienė 2013, pp. 27–28, Table 7, Figs. 335–339). In addition, jewellery manufacturing techniques became more complex. In Lithuania, as in the adjacent regions, in Central Europe, and, of course, in the Roman Empire, brass begins to dominate, and this process coincides with Roman military production, and fits perfectly with the 'industrialisation' of brass, or almost pure brass production in the Roman Empire during the 1st century BC (Craddock 1978, pp. 5–9; Bayley and Butcher 2004, p. 152, Fig. 118). However, in the Roman Empire and provinces, together with brass, some Almgren-type fibulae dating from the mid-1st century to the 2nd century AD were produced from bronze and gunmetal (Roxburgh et al. 2016, p. 419). A very similar situation in the use of copper alloys is observed for Early Roman period artefacts from Lithuania (Bliujienė et al. 2020, Fig. 7).

Materials and methods

X-ray fluorescence analysis

The analysis of copper alloys was carried out on the surface of the artefact by a portable XRF spectrometer Niton XL3t (power 2 W, voltage 50kV, detector area ~ 50 mm^2, producer Thermo Fisher calibration mode 'General Metals'). Each artefact spot was irradiated for 30-35 s (the results did not change after this time). Depending on the configuration and complexity of the artefact, between two and five or more points are examined. This well-known technique of non-destructive surface analysis of objects has already been used widely for several decades (Bayley and Butcher 2004, pp. 21–25; Roxburgh 2016; Roxburgh and Olli 2018). Copper alloys are characterised by their principal alloying elements (Zn, Sn and Pb), and the presence of small amounts added main impurities. In the present investigations, use was made of a set of Certified Reference Materials (CRMs), the Cultural Heritage Alloy Reference Material Set (CHARM), originally designed for the analysis of ancient copper alloys, as well as other standard metal reference materials. CRMs provide the possibility to systematically interlink the analytical results of any study (Craddock and Eckstein 2003; Heginbotham et al. 2015).

The results of the analysis of Cu, Zn, Sn, Pb, Fe, Sb, Ag and Ni were applied in order to compare the composition of all alloys, although almost all Ag and Ni values are below the detected limit, despite the fact that these elements belong to important impurities. Other elements fixed below the setting limit <LOD and/or 0.01–0.1%, or elements that do not affect the composition of the copper alloy and possibly come from the archaeological environment, are not shown in the tables. The mathematical procedure for processing the results and proposing principal conversion formulas is recommended by Pollard et al. (2018, pp. 181–183). The XRF results obtained allow for the classification of alloys into copper alloy types according to the main alloying elements (Zn, Sn, Pb) (Bayley and Butcher 2014, p. 14, Fig. 5).

Technological analysis

Manufacture techniques and decoration of ornaments were defined through the visual examination of artefacts in museums, and by photographing with a digital microscope (Q-scope 9.0 MP, 200×). During this survey, specific manufacturing features and surface treatment techniques and methods of ornamentation were determined. A detailed visual examination of ornaments, especially for dress pins with wheel-shaped and spool-shaped heads, revealed differently made wax models in casting by the lost-wax or *cire-perdue* technique.

Also, several dress pins were examined, in order to assess their inner construction and the corrosion degree of the iron clasp needle. Radiography was used for understanding the construction of a neck-ring with hollow trumpet-shaped terminals. For this task, a portable diagnostic X-ray device IMD E-100R HF E7846 was used. Considering the differences in the thickness of copper alloys and iron, a voltage of 120kv, and exposure of 4 mAs were used. The X-ray images were digitally edited using Adobe Creative Suite software.

Samples of solder, analysed by qualitative micro-chemical analysis, were taken from the neck-ring with hollow trumpet-shaped terminals (see Fig. 11). The microscopic reactions of the samples were observed under reflected light using a microscope with a magnification of six to 50 times. Tin and lead metal ions were found in the alloy samples, and this means that a tin-lead solder was used to strengthen components of this neck-ring altogether.

Results and discussion

The change in the copper alloys and exchange directions

The elemental composition of copper alloys from the Late Bronze Age and the Earliest Iron Age in northeast and east Lithuania shows that, although bronze-type alloys predominate, there is considerable variety in their percentage expression (Table 1; Fig. 2.2). In addition to bronze alloys, artefacts made from leaded bronze and bronze/gunmetal were recorded. Besides this, the first brass-type alloys of brass/gunmetal appear in already the Earliest Iron Age. These are artefacts such as sash-like bracelets with tapered ends found in Nevieriškė hillfort, as well as dress pins with

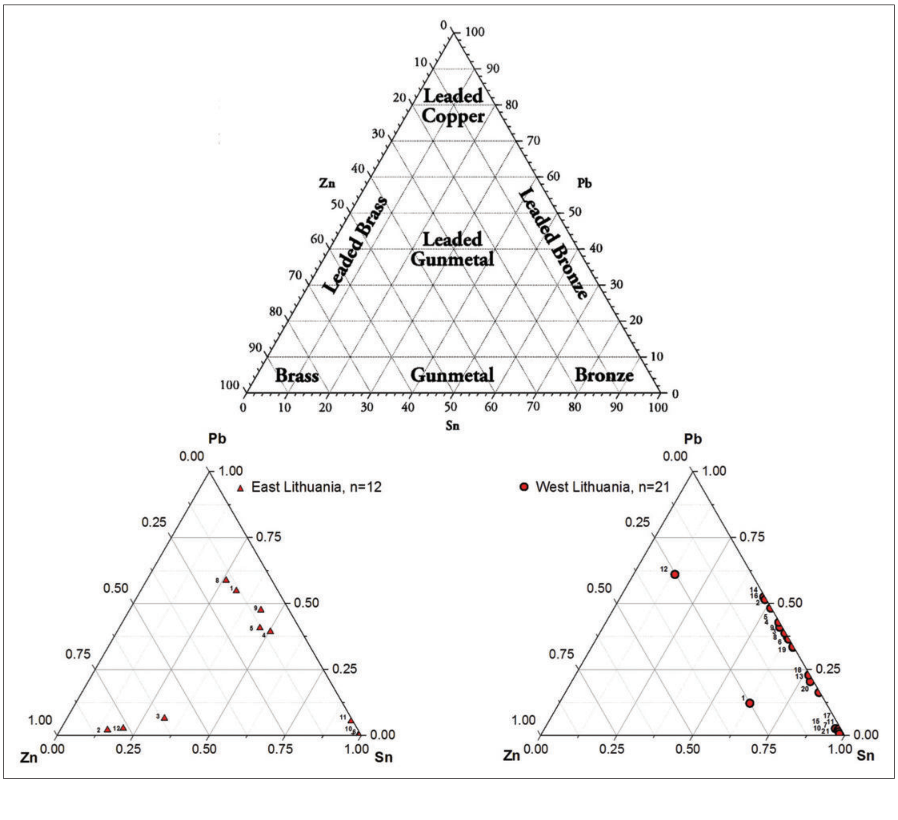

Figure 2. Ternary diagram displaying the Sn, Pb and Zn ratios estimated in alloys of artefacts dated to the Late Bronze Age and the Earliest Iron Age: 1. the alloy classification scheme (after Bayley and Butcher 2004, Fig. 5); 2. artefacts found in east Lithuania; 3. artefacts found in west Lithuania (diagrams by J. Bagdzevičienė).

Table 1. The results of the X-ray fluorescence analysis of artefacts dated to the end of the Late Bronze Age and the Earliest Iron Age (concentration given in wt%). For site locations, see Figure 1.

Artefact ID	Site name	Site	Artefact	Museum inv. No	Ternary diagram ID	Cu	Zn	Sn	Pb	Fe	Sb	Ag	Ni	Alloy type
Artefacts from northeast and east Lithuania														
Maz.938.5	Mažulonys	Foot settlement	Dress pin	LNM AR 938:5	1▲	75.17	3.19	7.37	12.77	1.07	0.28	<LOD	<LOD	Leaded bronze/gunmetal
Nev.597.584	Nevieriškė	Hillfort	Bracelet	LNM AR 597:584	2 ▲	83.84	13.04	2.45	0.34	0.22	0.05	<LOD	<LOD	Brass
Nev.597.585	Nevieriškė	Hillfort	Bracelet	LNM AR 597:585	3▲	84.67	9.00	4.70	0.95	0.54	0.06	<LOD	<LOD	Gunmetal
Sta.109	Staviškės	Settlement	Raw material	LNM (r. s. 109)	4▲	85.86	1.17	5.84	4.56	1.72	0.25	0.50	<LOD	Leaded bronze
Sta.229	Staviškės	Settlement	Raw material	LNM (r. s. 229)	5▲	72.20	3.32	11.89	10.46	1.68	0.30	<LOD	0.03	Leaded bronze
KerK.1027	Kernavė	Kernavė cemetery	Dress pin	KMR A 1027	6▲	68.93	0.14	29.15	0.17	1.13	0.04	<LOD	<LOD	Bronze
KerK.1087	Kernavė	Kernavė cemetery	Temple ornament	KMR A 1087	7▲	67.18	0.00	29.86	0.00	2.14	<LOD	<LOD	<LOD	Bronze
KerK.1451	Kernavė	Kernavė cemetery	Finger-ring	KMR A 1451	8▲	80.68	2.34	4.09	9.18	1.73	0.07	1.43	<LOD	Leaded bronze/gunmetal
KerK.3896	Kernavė	Kernavė cemetery	Fragment of unknown purpose	KMR A 3896	9▲	68.92	2.59	12.17	13.37	1.98	0.40	0.24	<LOD	Leaded bronze
KerK.1324	Kernavė	Kernavė cemetery	Fragment of unknown purpose	KMR A 1324	10▲	30.22	0.21	63.55	0.26	2.55	0.21	<LOD	0.25	Bronze
KerK.4420	Kernavė	Kernavė cemetery	Staples	KMR A 4420	11▲	75.36	0.12	22.59	1.33	0.25	0.05	<LOD	<LOD	Bronze
Petr.1505.47	Petrešiūnai	Hillfort	Dress pin	VDKM AR 1505:47	12▲	83.09	12.35	3.28	0.43	0.63	0.09	<LOD	<LOD	Brass/gunmetal
Artefacts from west Lithuania														
Paa.136	Paalksniai	Barrow cemetery	Dress pin	LNM (r. s 136)	1 ●	63.66	7.10	17.77	3.47	7.43	0.14	0.09	0.04	Bronze/gunmetal
Vilu.2021.1.3	Vilūnai	Find spot	Dress pin	LNM	2 ●	43.42	0.08	27.61	25.89	1.85	0.47	0.43	0.07	Leaded bronze
Egl.636.1	Ėgliškiai	Barrow cemetery	Temple ornament	LNM AR 636:1	3 ●	60.11	0.06	23.89	14.26	0.89	0.32	0.33	0.05	Leaded bronze
Egl.636.2	Ėgliškiai	Barrow cemetery	Dress pin	LNM AR 636:2	4 ●	44.95	0.44	30.64	21.65	0.69	0.31	0.19	0.06	Leaded bronze
Egl.636.3	Ėgliškiai	Barrow cemetery	Bracelet	LNM AR 636:3	5 ●	53.74	0.10	26.02	19.61	0.16	0.25	<LOD	0.03	Leaded bronze
Egl.636.4	Ėgliškiai	Barrow cemetery	Bracelet	LNM AR 636:4	6 ●	44.71	0.15	35.33	17.85	1.17	0.09	0.49	<LOD	Leaded bronze
Egl.636.7	Ėgliškiai	Barrow cemetery	Neck-ring	LNM AR 636:7	7 ●	82.08	0.17	16.96	0.34	0.12	0.08	<LOD	0.07	Bronze
Egl.636.9	Ėgliškiai	Barrow cemetery	Bracelet	LNM AR 636:9	8 ●	43.91	0.08	34.45	19.92	0.35	0.64	0.37	0.06	Leaded bronze
Egl.636.11	Ėgliškiai	Barrow cemetery	Temple ornament	LNM AR 636:11	9 ●	70.19	0.06	17.02	10.84	1.53	0.18	<LOD	0.04	Leaded bronze
Egl.636.12	Ėgliškiai	Barrow cemetery	Pendant	LNM AR 636:12	10 ●	94.54	0.07	4.03	0.11	0.99	0.05	<LOD	0.14	Bronze
Egl.636.13	Ėgliškiai	Barrow cemetery	Pendant	LNM AR 636:13	11 ●	93.09	0.08	6.30	0.14	0.12	0.02	<LOD	0.04	Bronze
Egl.636.16	Ėgliškiai	Barrow cemetery	Bracelet	LNM AR 636:16	12 ●	82.16	4.33	2.33	10.45	0.31	0.16	0.22	<LOD	Leaded gunmetal
Egl.636.17	Ėgliškiai	Barrow cemetery	Workpiece	LNM AR 636:17	13 ●	67.56	0.35	24.87	6.48	0.25	0.20	0.22	0.05	Leaded bronze
Egl.636.25	Ėgliškiai	Barrow cemetery	Neck-ring	LNM AR 636:25	14 ●	56.40	0.15	20.07	22.35	0.47	0.31	<LOD	0.08	Leaded bronze
Egl.636.39	Ėgliškiai	Barrow cemetery	Pendant	LNM AR 636:39	15 ●	86.18	0.08	12.57	0.33	0.59	0.13	<LOD	0.05	Bronze
Egl.636.40	Ėgliškiai	Barrow cemetery	Pendant	LNM AR 636:40	16 ●	80.02	0.08	9.38	10.06	0.33	0.06	<LOD	0.09	Leaded bronze
Egl.636.45	Ėgliškiai	Barrow cemetery	Dress pin	LNM AR 636:45	17 ●	92.87	0.07	6.06	0.09	0.72	0.04	<LOD	0.05	Bronze
Rau.530.8	Raudonėnai	Cemetery	Temple ornament	LNM AR 530:8	18 ●	53.58	0.12	30.31	9.03	6.58	0.16	<LOD	<LOD	Leaded bronze
Rau.530.9	Raudonėnai	Cemetery	Temple ornament	LNM AR 530:9	19 ●	43.42	0.09	36.50	18.56	1.13	0.12	<LOD	0.07	Leaded bronze
Naud.27	Naudvaris	Cemetery	Temple ornament	LNM (r. s. 27)	20 ●	68.19	0.08	25.99	5.09	0.44	0.14	<LOD	<LOD	Leaded bronze
Naud.28	Naudvaris	Cemetery	Temple ornament	LNM (r. s. 28)	21 ●	63.84	0.46	32.00	0.20	324	<LOD	<LOD	0.07	Bronze

Figure 3. Ornaments found in inhumation and cremation graves dating from the 5th century BC to the 1st century AD: 1, 2. Naudvaris cemetery, grave 8 (LNM GRD 98389); 3, 4. Raudonėnai cemetery, grave 3 (LNM AR 530:8, 9); 5. Paalksniai barrow cemetery, stray find in barrow 5 mound (LNM GRD 68594); 6. Mažulonys, foot settlement, trench 18 (LNM AR 938:5); 7. Kernavė cemetery, grave 9 (KMR A 1027); 8. Kernavė cemetery, grave 8 (KMR A 1087); 9, 10. Kernavė cemetery, stray finds (KMR A 1451); 11. Piliškės barrow cemetery, barrow 1, grave 1 (LNM AR 906:1); 12. Vilūnai, stray find (LNM); 13, 14. Nevieriškės hillfort, trench 5 (LNM AR 597:584, 585). Spots investigated by XRF method marked with green arrows (photographs by A. Bliujienė, drawing from the LNM, Departament of Prehistoric Archaeology Collections cards catalogue).

Figure 4. The bronze dress pin with a spool-shaped head from Petrešiūnai hillfort (VDKM AR 1505:47) (photographs by A. Bliujienė, enlarged 50× photographs by E. Babenskas).

spool-shaped heads and an iron clasp needle of a similar chronology found in Petrešiūnai hillfort (Figs. 3.13, 14 and 4). The emergence of brass in Lithuania in the 1st century BC is not an exceptional fact, because during the 1st millennium BC the use of brass alloys spread across a wide geographical area touched by Roman civilisation (Craddock 1978).

The variation in the northeast and eastern alloys studied may not be due to changes in the sources of the raw material, but rather to the use of scrap metal and the remelting of alloys. However, it is clear that there were some links between the inhabitants of northeast and eastern Lithuania and northeast forest zone societies, as is evident by the exchange of artefacts and cultural ideas (Fig. 3.5). It is possible that the Baltic Sea region was already part of the chain of the exchange of metal raw materials between Scandinavia via the Baltic islands (Öland, Gotland, Saaremaa) to Daugava, and further northeast and the Volga-Kama region, in the Bronze Age. That would explain how in the Earliest Iron Age the same communication chain functioned, thus at least partly elucidating the relations between east Lithuania and the forest zone of northeast Europe (Luchtanas and Sidrys 1999, p. 26; Lang 2007, p. 184; Vasks 2010, pp. 156–158; Čivilytė 2014, pp. 52–53, 146; Podėnas and Čivilytė 2019). Therefore, it is probable that the axes and large rings that spread in the east Baltic region in the context of the Bronze Age were part of this exchange network. However, there is not enough data so far to show that the metal raw material came from the east, although the Kargaly ore mines (the steppes of the southern Urals), where copper ore was mined in the Bronze Age, was one of the centres (Čivilytė 2014, pp. 52–53). Still, copper ore from the Kargaly mines was used by locals (Kuzminykh 1983, pp. 157–161; Chernykh 2002), so it is likely that the exchange going down the line, or even directional exchange networks, had to have a reverse exchange product, which could have been metal products or raw material. Of course, it is not easy to determine what exchange equivalent was used by societies in east Lithuania in the Bronze Age.

The elemental composition of copper alloys from the Late Bronze Age to the Earliest Iron Age in west

Lithuania shows that, although leaded bronze and bronze-type alloys predominate, these alloys are more homogeneous (Figs. 2.3 and 5). The archaeological material shows that during this period, west Lithuania was in contact with south and southwest regions, central Scandinavia, and the Baltic Sea islands. It can therefore be assumed that non-ferrous metals were obtained from western and Central European ore mines (Miarkiavichius 1980, p. 110; Vasks 2010, p. 156; Čivilytė 2014, p. 140). The largest tin deposits in Europe are in the west of the Iberian Peninsula and in Cornwall in southwest Britain, and in the Erzgebirge crossing Bohemia and Germany. There were also smaller occurrences of tin ore in Brittany, southeast France, Serbia, Tuscany in northwest Italy, on Sardinia, and in western Slovakia (Radivojević et al. 2018, Figs. 1 and 4; with references therein; Stos-Gale 2019, pp. 98–104, Fig. 3).

Since brass products appeared in Lithuania at the end of the Earliest Iron Age, it seems that the spread of brass in Europe was encouraged by exports and influences from the Middle East and the eastern Mediterranean, where the production of brass alloys from metallic copper and zinc ore was initiated (Stos-Gale 2019). However, the Romans made brass (*auricalcum*) famous and affordable when they came up with the invention of a new technique called cementation, and began making brass coins and military equipment at a state level (Dungworth 1997, p. 903; Bayley and Butcher 2004, p. 13). In technical terms, *auricalcum* was an alloy of copper and zinc, which was absorbed into the metal in a specialised metallurgical process called cementation. It appears that the use of brass increased over this period, making up around 40% of all copper alloys used in the Roman world by the 4th century AD (Stos-Gale 2017).

In Lithuania, a significant change in the elemental composition of copper alloys and the production of artefacts took place in the middle of the 1st century AD, and this was an epoch-making change. As is evident from Lithuanian archaeological material, brass started to dominate in the Early Roman period. However, although brass-type alloys predominate, it is obvious that gunmetal was equally popular (Tables 2, 3; Figs. 6 and 7). It is important to note that the elemental alloy composition of eye fibulae of the second half of the 1st and the 2nd century AD found in Lithuania, in general, corresponds to that of the copper alloys used in northern Roman provinces, and Central and northeast Europe (cf. Pietrzak 1997; Andrzejowski 1998; Gan 2015; Pauli 2019; Bliujienė et al. 2020; Łuczkiewicz et al. 2022 in press). Also, it should be mentioned that the zinc content in Roman brass (*auricalcum*) was around 17% to 21%, or from 22% to 28%. However, it seems that craftsmen could then add further alloying elements, such as tin or lead obtained from scrap bronze. Therefore, the absorption of zinc in the cementation process was reduced due to the lower melting point of copper (Craddock 1978; Joutsijärvi 2009; 2017; Hammer and Voß 2011; Łuczkiewicz et al. 2022 in press). As far as is known, during the 1st and 2nd centuries AD and later in the Roman Empire and the Barbaricum, the zinc content in copper alloys was steadily declining, and the composition of the alloy was changing over time for different reasons (cf. Dungworth 1997, p. 907; Pollard et al. 2015, pp. 700–706). Recycling copper alloys affected scieties living in Lithuania and the east Baltic region, where raw materials were only acquired via exchange. The process of recycling copper alloys can also be seen in the XRF results. Alloys and/or scrap metal reached present-day Lithuania through a complex and long exchange chain, using different exchange equivalents. The elemental composition of copper alloys in the Bronze and Earliest Iron Ages and the Early Roman period followed the same rhythm as in Europe.

The characterisation of the archaeological background applying to artefact production technologies

During the Late Bronze Age and Earliest Iron Age, dress pins with spiral heads, some with a small conical boss in the middle, pendants and spiral temple ornaments were common in the east Baltic region (Grigalavičienė 1995, Fig. 105; Lang 2007, Fig. 111.2) (Figs. 3.1–4, 7–9 and 5.1, 7–12). There were also neck-rings with pointed and hoofed ends, sash-like and spiral bracelets, and rings (Figs. 3.10–13, 14 and 5.6, 13, 14). Besides these common jewellery types, dress pins with wheel-shaped heads and open-work heads appear. At the end of the Earliest Iron Age, dress pins with spool-shaped heads and other finds close to this type are known from fortified settlements in northeast Lithuania. All these pins are characterised by iron clasp needles (Figs. 3.5, 12; 4; 5.5).

In terms of production technique, Earliest Iron Age artefacts continued to be cast using the *cire perdue* technique, but there was an increase in the use of hammered wire and small artefacts produced from thin tin sheets. A sophisticated cast-on technique also emerged, which was adapted for dress pins with wheel-shaped, spool-shaped and open-work heads, their massive heads being cast on to the iron clasping needle of the future pin (Figs. 4; 8.1; 9.1, 3, 4). The tightening copper alloy firmly encased the iron clasp needle, saving copper alloy. A piece of a dress pin with a wheel-shaped head was found at the Ėgliškiai burial mound site (barrow 2, inhumation grave 1) in west Lithuania. The pin has a wheel-shaped head and two loops on both sides of the iron clasp needle. Loops produced as an imitation of filigree plaited from two wires were made from a cutting wax model (Figs. 5.5 and 9.1). This is one of the first cases when an imitation of filigree work has been noted in the Earliest Iron Age. A clasp needle is inserted into the pin head up to the top of the wheel. In addition,

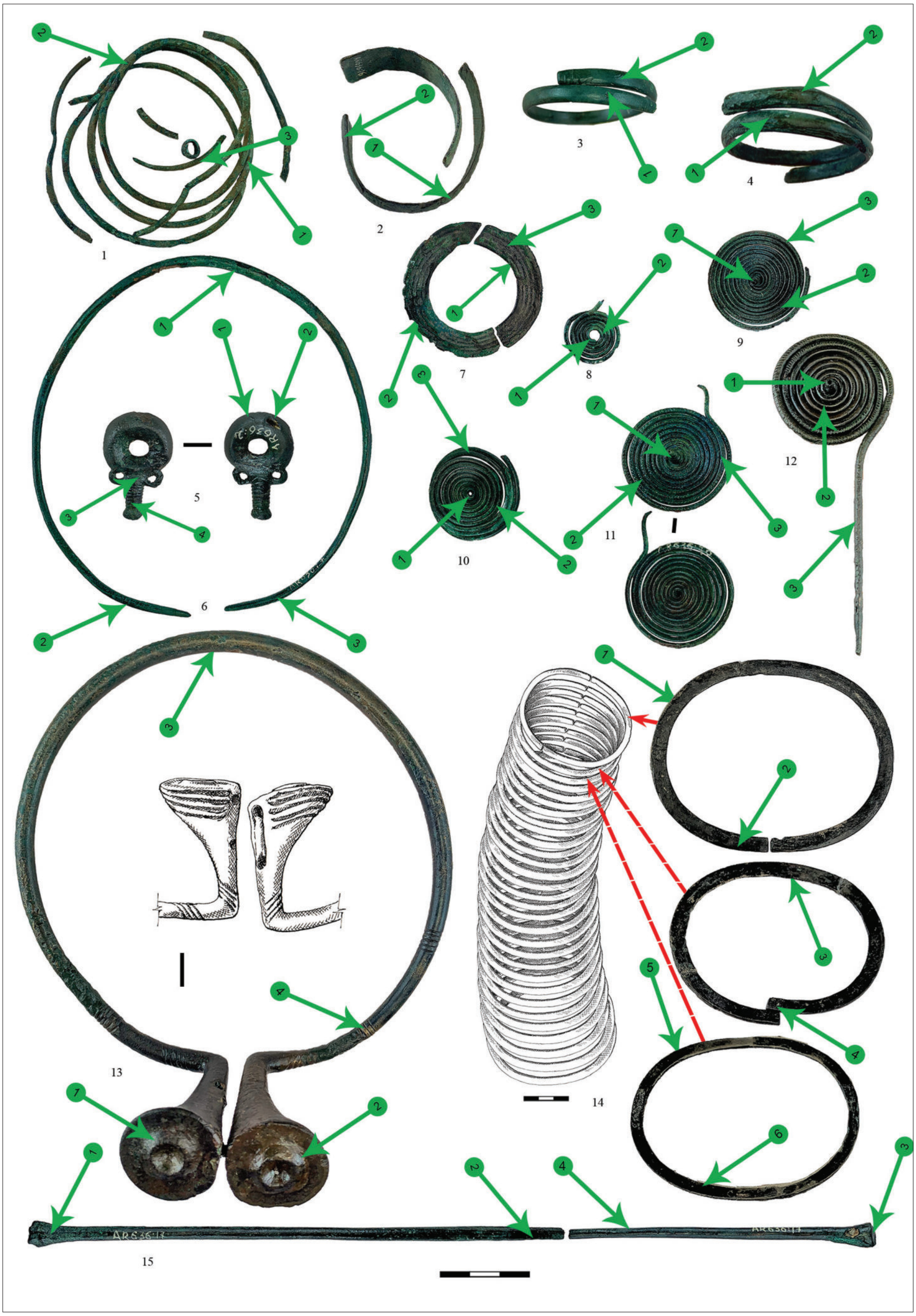

Figure 5. Ornaments found in inhumation graves in Ėgliškiai barrow cemetery from the 1st century BC to the turn of the 1st century AD: 1. barrow 1 in mound (LNM AR 636:1); 2, 15. barrow 3, grave 3 (LNM AR 636:16, 17); barrow 2, grave (LNM AR 636:4); 4, 6, 7. barrow 3, grave 1 (LNM AR 636:7, 9, 11); 5, 14. barrow 2, grave 1 (LNM AR 636:2, 3); 8, 9. barrow 3, grave 2 (LNM AR 636:12, 13); 10–12. barrow 3, grave 8 (LNM AR 636:39, 40, 45); 13. barrow 3, grave 5 (LNM AR 636:25). Spots investigated by XRF method marked with green arrows (photographs by A. Bliujienė, drawing from LNM, Departament of Prehistoric Archaeology Collections card catalogue).

Table 2. The results of the X-ray fluorescence analysis of (concentration given in wt%). dress pins with a spool-shaped head dated to the Early Roman period. For site locations, see Figures 1 and 10.

Artefact ID	Site name	Site	Museum inv. No	Ternary diagram ID	Cu	Zn	Sn	Pb	Fe	Sb	Ag	Ni	Alloy type
Paa.118	Paalksniai	Barrow cemetery	LNM (r. s. 118)	1 ■	79.01	4.20	12.22	2.36	1.94	0.13	<LOD	<LOD	Bronze/gunmetal
Paa.302	Paalksniai	Barrow cemetery	LNM (r. s. 302)	2 ■	83.85	8.21	4.87	0.58	2.26	0.13	<LOD	<LOD	Gunmetal
Pas.657.5	Paštuva	Cemetery	VDKM AR 657:5	3 ■	78.99	10.74	7.99	0.65	1.44	0.16	<LOD	<LOD	Gunmetal
San.1588.23	Akmenė (Sandrausiškė)	Barrow cemetery	VDKM AR 1588:23	4 ■	82.33	6.58	6.78	1.40	2.62	0.17	<LOD	<LOD	Gunmetal
Sar.1229.35	Sargėnai	Cemetery	VDKM AR 1229:35	5 ■	80.59	10.09	7.20	1.26	0.69	0.11	<LOD	<LOD	Gunmetal
Sar.1229.48	Sargėnai	Cemetery	VDKM AR 1229:48	6 ■	75.33	11.34	8.89	2.90	0.84	0.17	<LOD	0.04	Gunmetal
Sar.1229.54	Sargėnai	Cemetery	VDKM AR 1229:54	7 ■	85.57	7.10	1.99	0.38	4.86	0.09	<LOD	<LOD	Brass/gunmetal
Sar.1616.126	Sargėnai	Cemetery	VDKM AR 1616:126	8 ■	72.94	15.93	4.97	1.43	3.90	0.14	<LOD	0.02	Brass/gunmetal
Pri.641.2	Pribitka	Barrow cemetery	LNM AR 641:2	9 ■	71.09	6.48	3.91	0.41	17.89	0.11	<LOD	<LOD	Gunmetal
Cig.101	Cigoniškiai	Cemetery	LNM (r. s. 302)	10 ■	51.59	2.22	19.28	22.92	3.35	<LOD	0.24	0.06	Leaded bronze

Table 3. The results of the X-ray fluorescence analysis (concentration given in wt%) of Early Roman period ornaments.
Abbreviations for site names: Kur. – Kurmaičiai; Nik. – Nikėlai; Str. - Strazdai (Ječiškės); Pri. – Pribitka; Vie. – Vienragiai; Keg. – Kėgai; Ada. – Adakavas; Dau. – Dauglaukis; Bat. – Batakiai; Med. – Medvėgalis; Paju. – Pajūralis; Paa – Paalksniai; Per. – Perkūniškė; San. – Sandrausiškė; Kyb. – Kybartiškė; Jon. – Jonelaičiai; Mai. – Maironiai (Saudininkai); Vil. – Vilkija; Pas. – Paštuva; Sar. – Sargėnai; Kau. - Kaunas district; Vos. – Vosgėliai; Radn. – find site unknown; Pap. – Papiliai (Skomantai); Tel. – Telšiai; Nol. - Noliškiai; Zas. – Zastaučiai; Kuk. - Kukiai (Petreliai); Paba – Pabaliai; Gla. – Glaušiai; Par. – Paragaudis; Tol. – Toleikiai (Thaleiken-Jacob).

Artefact ID	Artefact types	Museum inv. No	Ternary diagram ID	Cu	Zn	Sn	Pb	Fe	Sb	Ag	Ni	Alloy type
Kur.1.63	Eye fibula A61 type	LNM AR 1:63	1 ○	86.04	4.14	8.33	0.75	0.59	0.14	<LOD	<LOD	Bronze/gunmetal
Kur.1.64	Eye fibula A61 type	LNM AR 1:64	2 ○	60.53	23.60	11.16	2.01	1.95	0.31	<LOD	0.03	Gunmetal
Kur.1.98	Triangular foot. third A group. close to A64 type	LNM AR 1:98	3 ○	81.16	7.64	8.95	0.83	1.13	0.20	<LOD	<LOD	Gunmetal
Kur.1.118	Eye fibula A61 type	LNM AR 1:118	4 ○	79.10	4.40	9.84	5.58	0.77	0.25	<LOD	<LOD	Leaded bronze/gunmetal
Kur.1.119	Eye fibula A60 type	LNM AR 1:119	5 ○	80.14	13.13	4.08	0.33	0.50	0.35	<LOD	<LOD	Brass/gunmetal
Kur.1.126	Eye fibula A61 type	LNM AR 1:126	6 ○	88.21	5.45	4.42	1.05	0.69	0.14	<LOD	<LOD	Gunmetal
Kur.1.129	Eye fibula A61 type (recomposed into a crossbow fibula)	LNM AR 1:129	7 ○	81.86	5.57	4.42	1.13	6.78	0.23	<LOD	<LOD	Gunmetal
Kur.1.156	Eye fibula A61 type	LNM AR 1:156	8 ○	79.46	14.70	4.40	0.52	0.47	0.14	<LOD	0.02	Brass/gunmetal
Kur.1.174	Fibula of A fourth group 93 type	LNM AR 1:174	9 ○	82.22	6.89	9.43	0.53	0.74	0.13	<LOD	<LOD	Gunmetal
Kur.1.175	Fibula of A fourth group	LNM AR 1:175	10 ○	84.55	9.10	3.80	0.94	1.26	0.15	<LOD	<LOD	Gunmetal
Nik.832.2	Fibula A second group. 42 type	VDKM AR 823:2	11 ○	82.15	8.97	6.48	0.99	0.75	0.15	<LOD	<LOD	Gunmetal
Nik.832.3	Fibula of A fourth group 72 type	VDKM AR 823:3	12 ○	88.29	4.34	4.68	0.97	1.46	0.23	<LOD	0.03	Gunmetal
Nik.832.4	Fibula of A fourth group 93 type	VDKM AR 823:4	13 ○	83.22	7.28	7.79	0.68	0.81	0.16	<LOD	<LOD	Gunmetal
Str.859.31	Fragment of fibula with a triangular foot	LNM AR 859:31	14 ○	83.67	3.24	7.32	1.18	3.76	0.36	0.23	<LOD	Bronze/gunmetal

Table 3. Continuation

Artefact ID	Artefact types	Museum inv. No	Ternary diagram ID	Cu	Zn	Sn	Pb	Fe	Sb	Ag	Ni	Alloy type
Pri.641.2	Dress pins with a spoon-like head	LNM AR 641:2	15 ○	71.09	6.48	3.91	0.41	17.89	0.11	<LOD	<LOD	Gunmetal
Pri.641.11	Fibula with a triangular foot	LNM AR 641:11	16 ○	85.98	6.87	5.54	0.48	0.52	0.16	<LOD	<LOD	Gunmetal
Pri.641.12	Triangular foot. third A group. close to A64 type	LNM AR 641:12	17 ○	86.56	6.36	4.56	0.72	1.19	0.20	<LOD	<LOD	Gunmetal
Pri.641.29	Fibula of fourth A group	LNM AR 641:29	18 ○	85.07	8.21	3.69	0.65	2.08	0.15	<LOD	<LOD	Gunmetal
Vie.620.1	Eye fibula A61 type	LNM AR 620:1	19 ○	71.98	3.97	20.65	1.51	1.08	0.16	0.32	<LOD	Bronze
Vie.620.8	Eye fibula A60 type	LNM AR 620:8	20 ○	79.45	2.95	15.10	0.70	1.11	0.24	0.26	<LOD	Bronze
Keg.917	Eye fibula A60/61 type (recomposed into a crossbow fibula)	VDKM AR 917	21 ○	81.56	4.60	11.26	0.83	1.34	0.24	<LOD	<LOD	Bronze/gunmetal
Ada.429.10	Fibula of third A group. 67 type	LNM AR 429:10	22 ○	87.80	9.73	0.32	0.39	0.33	0.02	<LOD	0.04	Brass
Ada.429.14	Fibula of second A group. A42 type	LNM AR 429:14	23 ○	85.68	8.15	4.45	0.90	0.56	0.11	<LOD	0.08	Gunmetal
Dau.666.5	Fibula of A fifth group	LNM AR 666:5	24 ○	86.79	6.42	5.39	0.34	0.43	0.17	<LOD	<LOD	Gunmetal
Dau.666.6	Fibula of A fifth group	LNM AR 666:6	25 ○	83.06	7.76	5.15	0.72	1.52	0.15	<LOD	<LOD	Gunmetal
Dau.666.47	Fibula of A fifth group. close to 120 type	LNM AR 666:47	26 ○	89.48	2.75	6.00	0.48	1.16	0.12	<LOD	<LOD	Bronze/gunmetal
Dau.666.48	Fibula with a triangular foot. Lawken type	LNM AR 666:48	27 ○	87.56	5.67	5.20	0.62	0.51	0.15	<LOD	<LOD	Gunmetal
Bat.19.1	Eye fibula of main series. A46 type	TKM GEK 9582	28 ○	87.85	5.61	3.39	0.77	1.36	0.15	<LOD	<LOD	Gunmetal
Med.9989	Eye fibula A60 type	ŠVSM GEK 9989	29 ○	79.67	4.39	13.30	1.13	0.92	0.20	<LOD	<LOD	Bronze
Paju.572.9	Eye fibula A61 type	LNM AR 572:9	30 ○	82.43	8.66	3.10	3.51	0.56	0.12	<LOD	<LOD	Leaded brass/gunmetal
Paa.128	Eye fibula A61 type	LNM GRD 68 594.128	31 ○	71.90	4.17	20.39	1.20	1.88	0.21	<LOD	<LOD	Bronze
Paa.301	Eye fibula A61 type	LNM GRD 70 822-301	32 ○	95.60	3.97	0.00	0.15	0.20	0.06	<LOD	<LOD	Brass
Paa.304	Eye fibula A59 type	LNM GRD 70 822. 304	33 ○	88.55	5.57	5.00	0.51	0.22	0.15	<LOD	<LOD	Gunmetal
Paa.621	Eye fibula A60 type	LNM (r. s. 621)	34 ○	86.03	8.18	4.19	0.83	0.61	0.15	<LOD	<LOD	Gunmetal
Paa.118	Dress pins with a spoon-like head	LNM GRD 68 594 (r. s. 118)	35 ○	79.01	4.20	12.22	2.36	1.94	0.13	<LOD	<LOD	Bronze/gunmetal
Paa.302	Dress pins with a spoon-like head	LNM GRD 70 822 (r. s. 302)	36 ○	83.85	8.21	4.87	0.58	2.26	0.13	<LOD	<LOD	Gunmetal
Per.489.11	Fibula of A fourth group 93 type	LNM AR 489:11	37 ○	80.88	11.52	5.32	1.01	0.81	0.25	<LOD	0.02	Gunmetal
San.1588.5	Neck-ring plaited with loop terminals	VDKM AR 1588:5	38 ○	76.67	20.76	1.57	0.53	0.32	0.11	<LOD	0.02	Brass
San.1588.10	Fibula of A238 type	VDKM AR 1588:10	39 ○	85.53	10.77	2.05	1.09	0.43	0.07	<LOD	<LOD	Brass
San.1588.18	Eye fibula A60 type	VDKM AR 1588:18	40 ○	83.80	3.21	9.23	1.16	1.85	0.38	0.29	<LOD	Bronze/gunmetal
San.1588.19	Eye fibula A60 type	VDKM AR 1588:19	41 ○	84.24	3.46	9.60	1.00	1.15	0.20	0.21	<LOD	Bronze/gunmetal
San.1588.23	Dress pins with a spoon-like head	VDKM 1AR 588:23	42 ○	82.33	6.58	6.78	1.40	2.62	0.17	<LOD	<LOD	Gunmetal
San.1588.24	Eye fibula A61 type	VDKM AR 1588:24	43 ○	79.94	5.68	11.79	1.01	1.31	0.17	<LOD	<LOD	Bronze/gunmetal
Kyb.496.3	Eye fibula of main series. A52 type	LNM AR 496:3	44 ○	93.68	5.07	0.17	0.23	0.65	0.07	0.12	<LOD	Brass
Kyb.496.4	Bracelets with bud-shaped terminals	LNM AR 496:3	45 ○	91.64	6.79	0.00	0.90	0.31	0.07	0.22	<LOD	Brass
Kyb.496.5	Eye fibula of main series. A52 type	LNM AR 496:5	46 ○	82.40	10.58	3.20	1.30	0.61	0.19	0.13	<LOD	Brass/gunmetal
Jon.645.14	Eye fibula A60 type	LNM AR 645:14	47 ○	90.49	6.68	1.32	0.73	0.66	0.07	<LOD	<LOD	Brass
Mai.460.1	Eye fibula A61 type	LNM AR 460:1	48 ○	73.05	22.65	0.64	0.73	0.31	0.14	<LOD	0.02	Brass
Mai.460.3	Bracelets with bud-shaped terminals	LNM AR 460:3	49 ○	82.78	11.30	1.30	0.34	1.19	0.09	<LOD	0.02	Brass
Vil.787.13	Eye fibula A61 type	LNM AR 787:13	50 ○	89.48	5.06	3.96	0.55	0.76	0.15	<LOD	0.03	Gunmetal
Pas.657.1	Eye fibula A61 type	VDKM AR 657:1	51 ○	80.45	13.86	4.54	0.30	0.35	0.14	<LOD	0.02	Brass/gunmetal
Pas.657.5	Dress pins with a spoon-like head	VDKM AR 657:5	52 ○	78.99	10.74	7.99	0.65	1.44	0.16	<LOD	<LOD	Gunmetal
Sar.1229.17	Fibula of A fourth group. close to A114 type	VDKM AR 1229:17	53 ○	83.93	10.20	3.91	0.86	0.77	0.13	<LOD	0.02	Brass/gunmetal
Sar.1229.18	Bracelets with bud-shaped terminals	VDKM AR 1229:18	54 ○	71.53	22.14	1.27	2.81	0.78	<LOD	<LOD	0.02	Brass
Sar.1229.35	Dress pins with a spoon-like head	VDKM AR 1229:35	55 ○	80.59	10.09	7.20	1.26	0.69	0.11	<LOD	<LOD	Gunmetal
Sar.1229.48	Dress pins with a spoon-like head	VDKM AR1229:48	56 ○	75.33	11.34	8.89	2.90	0.84	0.17	<LOD	0.04	Gunmetal
Sar.1229.54	Dress pins with a spoon-like head	VDKM AR 1229:54	57 ○	85.57	7.10	1.99	0.38	4.86	0.09	<LOD	<LOD	Brass/gunmetal
Sar.1229.61	Pennanular fibula with small spirals at the terminals	VDKM AR 1229:61	58 ○	93.34	3.12	3.02	0.18	0.26	0.06	<LOD	0.03	Gunmetal
Sar.1229.68	Eye fibula A61 type	VDKM AR 1229:68	59 ○	84.58	10.43	3.70	0.74	0.40	0.14	<LOD	<LOD	Brass/gunmetal
Sar.1616.55	Fibula with a triangular foot	VDKMAR 1616:55	60 ○	81.70	10.44	4.89	1.88	0.88	0.20	<LOD	<LOD	Gunmetal
Sar.1616.61	Eye fibula A61 type	VDKM AR 1616:61	61 ○	76.18	18.52	4.32	0.33	0.27	0.12	<LOD	<LOD	Brass
Sar.1616.63	Eye fibula A60 type	VDKM AR 1616:63	62 ○	84.26	9.58	4.47	0.94	0.62	0.11	<LOD	<LOD	Gunmetal
Sar.1616.64	Eye fibula A60 type	VDKM AR 1616:64	63 ○	85.73	12.46	1.07	0.36	0.29	0.07	<LOD	<LOD	Brass
Sar.1616.68	Eye fibula A61 type	VDKM AR 1616:68	64 ○	80.60	16.75	2.17	0.28	0.09	0.09	<LOD	<LOD	Brass
Sar.1616.69	Eye fibula A61 type	VDKM AR 1616:69	65 ○	80.50	15.41	3.60	0.20	0.11	0.10	<LOD	0.02	Brass
Sar.1616.80	Eye fibula A57 type	VDKM AR 1616:80	66 ○	85.98	11.78	1.52	0.35	0.21	0.10	<LOD	<LOD	Brass
Sar.1616.86	Fibula of A fifth group	VDKM AR 1616:86	67 ○	82.32	12.37	2.44	0.45	0.97	0.08	<LOD	0.02	Brass
Sar.1616.90	Eye fibula A61 type	VDKMAR 1616:90	68 ○	81.38	16.24	1.51	0.26	0.27	0.07	<LOD	0.02	Brass
Sar.1616.97	Eye fibula A61 type	VDKM AR 1616:97	69 ○	84.93	11.86	2.16	0.60	0.34	0.09	<LOD	<LOD	Brass
Sar.1616.102	Eye fibula A61 type	VDKM AR 1616:102	70 ○	72.41	23.15	3.11	0.65	0.14	0.16	<LOD	<LOD	Brass
Sar.1616.103	Eye fibula A61 type	VDKM AR 1616:103	71 ○	80.82	14.58	3.46	0.56	0.42	0.13	<LOD	0.02	Brass
Sar.1616.126	Dress pins with a spoon-like head	VDKM AR 1616:126	72 ○	72.94	15.93	4.97	1.43	3.90	0.14	<LOD	0.02	Brass/gunmetal
Sar.1616.129	Eye fibula A61 type	VDKM AR 1616:129	73 ○	87.31	8.26	3.59	0.57	0.18	0.10	<LOD	<LOD	Gunmetal
Sar.1616.138	Eye fibula A61 type	VDKM AR 1616:138	74 ○	75.42	20.55	2.86	0.15	0.20	0.11	<LOD	<LOD	Brass
Sar.1616.141	Eye fibula A57 type	VDKM AR 1616:141	75 ○	74.78	22.65	0.38	0.42	0.86	0.04	<LOD	<LOD	Brass
Sar.1616.151	Eye fibula A60 type	VDKM AR 1616:151	76 ○	86.05	8.67	3.72	0.67	0.75	0.13	<LOD	<LOD	Gunmetal

Table 3. Continuation

Artefact ID	Artefact types	Museum inv. No	Ternary diagram ID	Cu	Zn	Sn	Pb	Fe	Sb	Ag	Ni	Alloy type
Sar.1616.170	Bracelets with bud-shaped terminals	VDKM AR 1616:170	77 ○	79.36	14.85	0.33	0.17	0.34	0.10	<LOD	<LOD	Brass
Sar.1616.179	Eye fibula A61 type	VDKAR AR 1616:179	78 ○	72.25	19.05	5.47	1.57	1.07	0.13	<LOD	0.02	Brass/gunmetal
Sar.1616.185	Fibula of A fourth group. close to A72 type	VDKM AR 1616:185	79 ○	83.62	12.30	1.96	0.53	0.42	0.11	<LOD	0.01	Brass
Sar.1616.187	Eye fibula close to A57 type	VDKM AR 1616:187	80 ○	76.40	7.90	11.73	2.61	1.07	0.08	<LOD	<LOD	Gunmetal
Sar.1616.219	Fibula close to A238 type	VDKM AR 1616:219	81 ○	85.61	10.96	0.58	0.59	0.57	0.06	<LOD	<LOD	Brass
Sar.1616.224	Eye fibula close to A57 type	VDKM AR 1616:224	82 ○	81.93	11.99	2.39	0.46	0.24	0.05	<LOD	0.02	Brass
Sar.1616.225	Fibula of A238 type	VDKM AR 1616:225	83 ○	85.10	9.46	2.98	1.51	0.89	0.05	<LOD	<LOD	Brass/gunmetal
Sar.1780.10	Eye fibula A61 type	VDKM AR 1780:10	84 ○	84.79	9.00	4.48	0.57	0.98	0.13	<LOD	<LOD	Gunmetal
Sar.1780.11	Fibula of A fourth group. close to A72 type	VDKM AR 1780:11	85 ○	80.18	14.45	3.02	0.66	0.80	0.10	<LOD	0.02	Brass
Sar1817.75	Eye fibula A61 type	VDKM AR 1817:75	86 ○	75.66	13.94	8.98	0.67	0.55	0.14	<LOD	0.02	Gunmetal
Sar.1817.77	Eye fibula A59 type	VDKM 1817:77	87 ○	72.89	11.11	13.06	1.76	0.69	0.26	<LOD	<LOD	Gunmetal
Kau.58.6	Eye fibula A59 type	LNM AR 58:6	88 ○	66.69	27.59	0.12	0.74	0.67	0.22	<LOD	0.02	Brass
Kau.58.7	Eye fibula A61 type	LNM AR 58:7	89 ○	69.29	26.81	2.85	0.45	0.17	0.10	<LOD	<LOD	Brass
Kau.58.8	Eye fibula A59 type	LNM AR 58:8	90 ○	73.78	19.08	4.53	0.27	0.65	0.17	<LOD	0.02	Brass
Vos.75.16	Eye fibula A59 type	LNM AR 75:16	91 ○	89.09	7.15	1.47	0.42	1.05	0.13	<LOD	<LOD	Brass
Radn.710.17	Fibula of A fourth group 72 type	VDKM AR 710:17	92 ○	82.33	13.87	2.80	0.26	0.62	0.08	<LOD	0.02	Brass
Radn.1678.1	Eye fibula A57 type	VDKM AR 1678:1	93 ○	85.34	7.60	4.39	1.87	0.59	0.13	<LOD	<LOD	Gunmetal
Radn.2129	Fibula of A fourth group 72 type	VDKM AR 2129	94 ○	82.63	10.28	5.49	0.75	0.65	0.14	<LOD	0.03	Gunmetal
Pap.2055	Fibula of A fourth group	ŽAM A 2055	95 ○	83.11	7.31	6.27	1.62	1.03	0.22	0.16	0.07	Gunmetal
Pap.2063	Eye fibula A60 type	ŽAM A 2063	96 ○	87.23	8.75	2.51	0.79	0.60	0.10	<LOD	<LOD	Brass/gunmetal
Tel.723	Prussian series eye fibula fragment	ŽAM A 723	97 ○	74.60	6.38	14.37	1.80	2.04	0.27	0.13	<LOD	Bronze/gunmetal
KurL.45.184	Fibula with a triangular foot	JIKM AR 45:184	98 ○	77.44	12.77	3.70	0.77	0.86	0.15	<LOD	<LOD	Brass/gunmetal
KurL.45.183	Eye fibula A61 type	JIKM AR 45:183	99 ○	73.80	3.85	13.50	1.39	2.41	0.21	0.19	<LOD	Bronze
Nol.16.2	Eye fibula A61 type	ŠAM A-L 16:2	100 ○	78.53	11.51	7.70	0.65	1.11	0.22	<LOD	<LOD	Gunmetal
Zas.5146	Bracelets with bud-shaped terminals	MM GEK 5146	101 ○	84.63	8.45	4.49	0.65	0.55	0.52	0.28	0.20	Gunmetal
Zas.5105	Eye fibula A59 type	MM GEK 5105	102 ○	82.70	10.67	5.25	0.51	0.63	0.10	<LOD	<LOD	Gunmetal
Zas.5096	Eye fibula A60 type	MM GEK 5096	103 ○	82.59	4.95	9.22	1.41	1.44	0.21	<LOD	<LOD	Bronze/gunmetal
Zas.5084	Eye fibula A57 type	MM GEK 5084	104 ○	81.63	12.65	2.47	0.45	0.32	0.10	<LOD	<LOD	Brass
Zas.5099	Eye fibula A61 type	MM GEK 5099	105 ○	85.26	11.57	2.08	0.54	0.33	0.09	<LOD	<LOD	Brass
Zas.5105	Eye fibula A61 type	MM GEK 5105	106 ○	88.16	5.48	4.98	0.24	0.73	0.21	<LOD	<LOD	Gunmetal
Zas.5143	Eye fibula A59 type	MM GEK 5143	107 ○	74.55	6.89	13.44	2.60	1.48	0.32	0.31	<LOD	Bronze/gunmetal
Zas.5083	Fibula of A fourth group. close to 84 type	MM GEK 5083	108 ○	71.08	0.31	6.37	20.72	1.02	0.11	<LOD	0.07	Leaded bronze
Kuk.4220	Eye fibula A60 type	MM GEK 4220	109 ○	84.78	6.89	2.37	1.16	4.41	0.15	<LOD	<LOD	Brass/gunmetal
Paba.93	Fibula of A fourth group. 93 group	JIKM GEK	110 ○	83.12	7.02	6.91	0.67	1.82	0.14	0.13	<LOD	Gunmetal
Paba.92	Fibula of A fourth group. close to 92 type	JIKM GEK	111 ○	63.29	4.29	19.88	8.43	1.57	0.53	1.60	<LOD	Leaded bronze
Gla.830	Neck-ring with hollow terminals	KKM 830	112 ○	77.72	5.40	11.44	10.04	0.16	<LOD	<LOD	<LOD	Leaded bronze/gunmetal
Par.721.20	Eye fibula A57 type	LNM AR 721: 20	113 ○	82.45	6.39	9.88	0.47	0.57	0.14	<LOD	<LOD	Bronze/gunmetal
Par.721.49	Eye fibula A61 type	LNM AR 721: 49	114 ○	80.18	7.23	9.85	0.89	1.45	0.30	<LOD	<LOD	Gunmetal
Par.721.68	Eye fibula A60 type	LNM AR 721: 68	115 ○	82.78	3.70	8.81	0.84	3.48	0.30	<LOD	<LOD	Bronze/gunmetal
Par.721.81	Eye fibula A61 type	LNM AR 721: 81	116 ○	84.69	9.37	4.56	0.74	0.38	0.13	<LOD	<LOD	Gunmetal
Par.721.93	Eye fibula A57 type	LNM AR 721: 93	117 ○	71.81	3.88	22.14	0.66	0.78	0.30	0.31	<LOD	Bronze
Par.721.147	Eye fibula A52 type	LNM AR 721: 147	118 ○	84.38	11.91	2.31	0.46	0.62	0.12	<LOD	<LOD	Brass
Par.721.150	Eye fibula A52 type	LNM AR 721: 150	119 ○	90.03	5.16	3.11	0.74	0.77	0.15	<LOD	<LOD	Gunmetal
Par.721.167	Eye fibula A59 type	LNM AR 721: 167	120 ○	87.27	6.01	5.74	0.19	0.68	0.10	<LOD	<LOD	Gunmetal
Tol.70127	Eye fibula A46 type	MLIM GEK 70127	121 ○	86.09	8.24	2.72	1.20	0.90	0.15	<LOD	<LOD	Brass/gunmetal

in the production of the wax model, thin strips of wax are wrapped around an iron fastening needle. This technique of making pins creates an ornament of concentric circles around the iron clasp needle (Figs. 4 and 8.3, 4). Two more imitations of filigree wires were fixed on to a cast spiral-disc temple ornament found at Ėgliškiai barrow cemetery (barrow 3, grave 1), and a dress pin from Paalksniai (Grigalavičienė 1979, p. 28.1; Michelbertas 2010, Fig. 1; 2011, Fig. 35) (Figs. 3.5 and 5.7). The imitation of filigree was done by casting. Cast spiral-disc temple ornaments were ornamented in this way in the Early Roman period.

The dress pins with a wheel-shaped head and two loops from Ėgliškiai had no analogues in the archaeological material from the end of the Earliest Iron Age in Lithuania for quite a long time (Grigalavičienė 1979, Fig. 14; Grigalavichene 1980, p. 84, Table XXX.2; Merkevičius 2011, p. 33). In 2020, at the village of Vilūnai in southern Lithuania, during rescue excavations at the construction of an international gas pipeline, a similar pin type to the Ėgliškiai piece, with a wheel-shaped head and loops, was found (Figs. 3.12; 5.5; 8.3, 4). The Ėgliškiai and Vilūnai dress pins are linked not only by the shape of the jewellery, but also by the technique of wax model production, which is characteristic of the Earliest Iron Age. The Petrešiūnai dress pin with a spool-shaped head was cast using the same *cire perdue* technique, and thin strips of wax were wrapped around an iron fastening needle (Fig. 4). The dress pins with wheel-shaped heads from Ėgliškiai and Vilūnai fall within the cultural area of West Baltic barrows, which has been distinguished in west Lithuania mainly on the basis of burial sites (Grigalavičienė 1995, pp. 240–242; Brazaitis 2005, pp. 309–323). A technically close analogue of the pin is known in Estonia, found south of Tartu. This pin also has a wheel-shaped head and two loops in its lower part (Jaanits et al. 1982, pp. 186–187). According to Lang (2007, p. 184), pins made from a combination of bronze and iron originate in the Volga, Oka and Dnieper regions.

The next artefact examined in this paper was found in west Lithuania, at Paalksniai barrow cemetery, in destroyed barrow 5 mound. Only two artefacts, without any human remains, were found in this burial mound. One of these is a fragment of a dress pin with an open-work head and temple ornament in the shape of a spiral-disc (Michelbertas 2011, pp. 36–37). The pin is fragmented, with damage to its head and a lost iron clasp needle (Fig. 4.5). XRF analysis of the fragment indicates that its head is made of bronze/gunmetal. The head of the pin is trapeze-shaped open-work, with the edges adorned by cast granules. Two loops are formed at the lower part of the pin head, similar to the above-mentioned finds from Ėgliškiai and Vilūnai. The fragment of a pin head from Paalksniai has been incorrectly associated with the leaf-shaped pin found at Moškėnai (Laukupėnai) hillfort in northeast Lithuania (Krzywicki 1917, Table XIII; Michelbertas 2010, pp. 62–66; 2011, p. 75; Merkevičius 2011, p. 85). However, the pin found at Moškėnai (Laukupėnai) and the specimen from Paalksniai reveal differences in their shape and some technical aspects. In particular, the specimen from Moškėnai (Laukupėnai) lacks an open-work part of the pin, and the head does not contain loops formed on both sides of the iron clasp needle. The head of the Moškėnai (Laukupėnai) pin is directly linked with the shaft, whereas the Paalksniai piece extends to both sides, forming two wing-shaped features. The artefact found at Moškėnai (Laukupėnai) hillfort has direct analogies with pins found in the Smolensk and St Petersburg regions, and according to the typology compiled by A.A. Chubur (2012), they are classified as type seven. In this typology, the pin found at Paalksniai would most closely correspond to type four common to the territory between the rivers Desna and Seim (Sejm), and which has an open-work head with a wing-shaped widening in the lower part of the head (Chubur 2012, p. 119, Figs. 1 and 5; Shpilev 2018, and the references therein). Leaf-shaped pins of various types were common in the Earliest Iron Age in the vast area between the left bank of the Dnieper and the Oka. They all have their massiveness, their close shape and decorative elements in common; but above all, their iron clasp needles, like a vertical compositional axis, runs the entire length of the head of the pin, and, like a reflection in a mirror, divides the artefacts into two equal parts. There are no direct analogies so far between the pins found at Paalksniai and in the region on the left bank of the Dnieper and the Oka. However, the Paalksniai pin is definitely based on inherited production techniques and ornamental traditions. It cannot be ruled out that the pin came from the east as a commodity or raw material. The chronology of these pins here is also not entirely clear, but the aforementioned researchers place them between the 4th and 2nd centuries BC. The dress pin from Paalksniai might be dated to the Earliest Iron Age (Luchtanas and Sidrys 1999, Supplement 3). It is most likely that this pin came to Paalksniai already broken as scrap metal around the 2nd or 1st centuries BC. In Paalksniai barrow 5, where the fragment of pin was found, there are traces of a cultural layer, pieces of slag and shards of smooth-skinned moulded pottery. Shards of brushed pottery were also found in the filling of other Paalksniai barrows (Michelbertas 2011, pp.79-80). On the basis of the cultural layer recorded in the mound filling samples and the finds, it can be assumed that there was a settlement in the area dating from the 2nd or 1st century BC to the 1st century AD, before the barrows began to be built. Thus, the chronology of the pin may coincide with the chronology of the settlement, and does not contradict similar ornaments from those found between the Dnieper and the Oka.

Another type of late Earliest Iron Age and Early Roman period pin is dress pins with spool-shaped heads. This type of pin, judging by its prevalence, may have originated in the Earliest Iron Age in the area of Brushed Pottery culture. Its origins lie in the pins with antler or bone heads and iron needles known in northeast Lithuania. These tools could have served both as pins and as awls. Bone-headed pins have been found in the Gorani, Kereliai, Nurviany and Vorėnai hillforts (Kulikauskienė and Rimantienė 1958, Fig. 202; Grigalavičienė 1992, p. 90, Fig. 10.11; Egoreĭchenko 2006, p. 88, Table 61.1–3) (Figs. 1 and 10). The heads of spool-shaped pins found in Belarus, both bone and copper alloy, have holes (Egoreĭchenko 2006, Table 61.1–5). The head of the bone pins is coil-shaped (length about 3-5 cm, diameter of head about 2 cm), and is quite massive. Both bone and copper alloy spool-shaped pins found in Ratiunki have holes in their heads, and this feature connects them with the pin found in Petrešiūnai hillfort (Fig. 4) As was mentioned, the technique and shape of this pin is close to that of Earliest Iron Age pieces, although it is made of brass/gunmetal. This confirms the fact that the first brass alloys in Lithuania date from the 2nd or 1st century BC. A pin similar in shape to coils was found in the settlement at the foot of the Mažulionys hillfort (Kliaugaitė 2006, p. 30, Fig. 14) (Fig. 3.6). This pin has a hole in the head, into which a chain or a cord would have been inserted to secure the fastening of the garment. However, due to a casting defect, the hole was left open.

The Mažulionys pin is decorated with concentric circles clumsily incised in the wax model, while the edges of the pin are decorated with imitations of cast granules.

In the Early Roman period, spool-shaped with copper alloy heads and iron needles are placed in group H or the first group (Beckmann 1969, Abb. 1; Michelbertas1986, pp. 124–127, Fig. 43.1, 2). These pins are made from brass and gunmetal, but there is evidence of when spool-shaped pins were produced from lead bronze (Table 2). Iron pins of this type were found in Aukštadvaris hillfort and in Sargėnai burial ground, grave No 280. The use of iron and copper alloy in the production of these pins is interpreted as saving raw material for copper alloy. Judging by the size of the heads of the dress pins with a spool-shaped head, these were massive ornaments, with heads weighing between either 14 and 37 grams, with an average of 27 grams. Pins with spool-shaped heads and iron clasp needles date from the second half of the 1st century to the middle of the 2nd century AD, and were spread in the area of Late Brushed Pottery culture in the northeast, east and southwest. Individual pins of this group are found in the western part of Belarus (Egoreĭchenko 2006, p. 88). However, west of the River Šventoji, the number of spool-shaped pins decreases, as does the spread of Brushed Pottery culture. Higher concentrations are known in cemeteries of Early Roman period centres at the confluence of the Nemunas and Neris and in the western area of Samogitian barrow cemeteries (Michelbertas1986, pp. 124–127). Spool-shaped pins did not spread in the burial sites of west Lithuania and the lower reaches of the Nemunas (Fig. 10). Therefore, it can be argued that the contact and influence of Late Brushed Pottery culture and in the forest zone of northeast Europe ended in the Samogitian highlands.

The neck-rings with hollow trumpet-shaped terminals worn in the Early Roman Iron Age are the most fashionable pieces of jewellery produced using multiplex techniques that required highly skilled jewellers (Fig. 11). The prototypes for these neck-rings came from the La Tène and Roman cultural legacy, and were later absorbed by Germanic people. In the lands of the Balts, the idea of such neck-rings was adopted from similar Scandinavian gold neck-rings (Rzeszotarska-Nowakiewicz 2010). In terms of territorial distribution and social significance, these technically elaborate neck-rings stand in contrast to the contemporaneous ornaments, such as the dress pins with spool-shaped heads or eye fibulae discussed in this article (Bliujienė et al. 2020). Simplified versions of these neck-rings made of copper alloy in the third quarter of the 1st century to the middle of the 2nd century AD spread to Lithuania, the Finno-Ugric *tarand* area in northern Latvia, and sometime later to northeast Estonia, as well as the southwest coast of Finland.

With regard to the manufacturing technique, neck-rings with hollow trumpet-shaped terminals are the most technically sophisticated, the largest (the diameter is from 22 to 26 cm), and the heaviest (they weigh between 213 and 314 grams, and even up to 508 grams) Early Roman period jewellery objects found in Lithuania. Much attention has been paid to the typology and chronology of neck-rings, although these issues have not yet been fully resolved. These ornate neck-rings are jewellery objects made from brass, gunmetal and leaded bronze, and lastly ascribed to type 1, subtypes 2a-c (Bliujienė et al. 2020, Fig. 7, Appendix 2). The trumpet-shaped terminals of this type of neck-ring are either cast or wrought from metal sheet using the repoussage metalworking technique, and therefore did not need to be joined by riveting or soldering (Bliujienė et al. 2020, Figs. 6 and 7).

The tin sheet soldered and soldering bow is clearly visible on Glaušiai (ascribed to type 1, subtype 2c) neck-rings with hollow trumpet-shaped terminals (Figs. 9.2 and 11). For the soldering, a mixture of tin and lead was used as solder. This is the first such early case of soldering so far found on an artefact in Lithuania. Only three neck-rings of this type and sub-type have been found in the region of their distribution in the east Baltic region, and all were found in Lithuania: one in Glaušiai and the other two in Linkuva (Bliujienė et al. 2020, Appendix 2). Their typological development clearly shows a drift towards the Finno-Ugric area of distribution, where a certain technical degradation of these ornaments was taking place: the neck-rings began to be moulded, and the trumpets of the neck-rings became full-bodied. However, this does not answer the question of their actual place of production and place of manufacture. In terms of manufacturing technique, and the typological variation of these fashionable ornaments, the neck-ring with hollow trumpet-shaped terminals may eventually have been distributed by Sambian-Natangian or travelling jewellers, who were capable of producing such complex-shaped items (Bliujienė et al. 2020). The earliest and most technically sophisticated versions of these neck-rings appear in the region of the Lower Nemunas (Vilkų Kampas), in the south of Samogitia (Adakavas and Paragaudis), and in central Lithuania (Glaušiai).

In Lithuania, these neck-rings are found in the graves (as is known from Paragaudis barrow cemetery, see Michelbertas 1989;1997) of people of a high social status, most likely women; or their find circumstances are unknown. Therefore, it is possible that neck-rings with hollow trumpet-shaped terminals come from a sacrificial area: offerings in water or from a wealth deposit in the land (see Bliujienė 2010; Oras 2015, pp. 173–195). In Estonia, these neck-rings are found in wealth deposits which contain artefacts common to the Balts (Lang 2007, p. 247; Oras 2015).

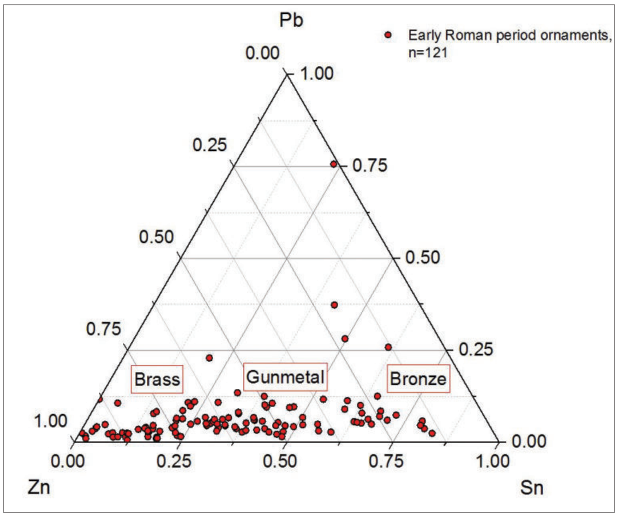

Figure 6. Ternary diagram displaying the Sn, Pb and Zn ratios in alloys of artefacts dating from the Early Roman period (n=121), according to the classification scheme by Bayley and Butcher (2004, Fig. 5) (diagrams by J. Bagdzevičienė).

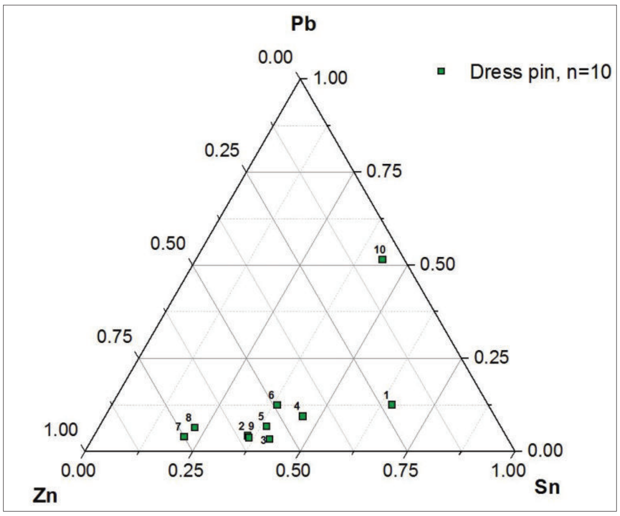

Figure 7. Ternary diagram displaying the Sn, Pb and Zn ratios in alloys of the spool-shaped dress-pins from the Early Roman period, according to the classification scheme by Bayley and Butcher (2004, Fig. 5) (diagrams by J. Bagdzevičienė).

Major places and their change

The density and distribution of the Late Bronze and Earliest Iron Ages artefacts described in this paper, finds of technical ceramics in the hillforts of northeast and east Lithuania, and burial grounds in west Lithuania and the Lower Nemunas area, make it possible to think about certain micro-regions, and to distinguish possible major places where various artefacts could have been manufactured. As was already mentioned above, the disruption to the bronze exchange network in the middle of the 1st millennium, and the spread of iron, changed the range of artefacts used during the Earliest Iron Age. In addition, it is obvious that the previously known burial grounds of west Lithuania and the lower reaches of the Nemunas area disappeared (Figs. 1 and 12). Clearly, there are not enough studied habitation sites excavated using modern methods in this area (Bliujienė et al. 2012; Vengalis et al. 2020). As a result of the rapid changes of settlement structure in the Early Roman period, new sites are emerging.

Meanwhile, in northeast and east Lithuania, some hillforts (e.g. Nevieriškė) were abandoned at the turn of epoch-making changes, and many major centres of the previous period continued to exist (Grigalavičienė 1986a). However, many hillforts were abandoned during the period at the end of the 2nd and the beginning of the 3rd century AD, because people moved to live at the foot of hillforts and unfortified settlements (Lukhtan 2001, pp. 24–26).

One major early centre in west Lithuania could have been in the area between Ėgliškiai, Šlažiai and Šlikiai barrow cemeteries. The Padvariai barrow cemetery, with early agricultural fields and the destroyed Kretingalė barrows, is adjacent to this centre (Merkevičius and Nemickienė 2011, pp. 40–43; Merkevičius 2014, pp. 56–58, 109–114; Muradian 2017). Together with settlements and isolated finds, these burial sites form a fairly compact micro-region of the Late Bronze and Earliest Iron Age in the Lithuanian coastal area (Figs. 1 and 12). Finds from inhumation graves in the Ėglišķiai barrow cemetery could have been produced in nearby settlements. This is supported by a 17.4-gram leaded bronze workpiece for a neck-ring or bracelet (barrow 3, grave 3) (Fig. 5.15). A bracelet consisting of 31 leaded bronze rectangular bracelets or rings (total weight over 400 grams, a single bracelet weighs between 13 and 14 grams) is a well-known find from Ėgliškiai barrow 3, grave 1. This set of bracelets is not a piece of jewellery, but it is possible to say that it is raw material or a leaded bronze ingot in the shape of a ring, and was used for exchange (Fig. 5.14). This statement might be confirmed by the elemental composition of the piece and other jewellery found in the Ėgliškiai barrows and other sites. Sash-like bracelets or rings of different weights have been found in Latvia, Estonia, Scandinavia and Gotland. It is believed that in Scandinavia such artefacts were of a certain weight; therefore, they already measured standardised weight units used in exchange during the Bronze Age (Lang 2007, pp. 118–120).

However, in the Early Roman period, only the Padvariai barrow cemetery still was in function, as an heirloom from the previous time major place at Ėgliškiai surroundings. At Padvariai, barrows contain inhumation burials with eye fibulae and other finds reflecting the Early Roman period (Bliujienė 2013, Fig. 191); whereas burials in the vicinity of the former Ėgliškiai barrows began only in

Figure 8. Radiographs showing iron clasp needles embedded in pin heads: 1. dress pins with wheel-shaped heads with traces of an iron clasp needle (LNM); 2. heads of dress pins with a spool-shaped head and traces of an iron clasp needle inside from Paalksniai barrow cemetery, barrow 9, grave 1 (LNM GRD 68594); 3, 4. heads of dress pins with a spool-shaped head and traces of an iron clasp needle inside from Jagminiškė (LNM AR 16:17,15) barrow cemetery. From the J. Obst collection, find circumstances unclear (photographs by A. Bliujienė, radiographs by Rapolas Vedrickas).

the Late Roman period, in Egliškiai-Anduliai cemetery, which is located almost one kilometre southeast of the former barrows.

Earliest Iron Age sites have been found on the right bank of the River Nemunas in central Lithuania, but they do not form important concentrations there (Merkevičius 1994; 2014) (Figs. 1 and 12). However, it is clear that the sites are located along an important transport route, which was to carry people, raw materials and other necessities. In this paper, the region is represented by the Earliest Iron Age burial grounds of Naudvaris and Raudonėnai, where spiral temple ornaments made of leaded bronze and bronze were found (Table 1; Fig. 3.1–4; Appendix). Partly due to contacts with Bogaczewo and Sambian-Natangian cultures, more sites from the Early Roman period appear in the region of the lower and middle reaches of the Nemunas (Bertašius 2002, pp. 22–23, Fig. 1; Grižas and Bitner-Wróblewska 2007; Bliujienė 2016). Burial sites then begin to concentrate at the confluences of the rivers Nemunas and Neris, the Nemunas and the Dubysa, and the Nemunas and the Jūra. The area around the confluence of the Nemunas and the Neris, with Sargėnai, Kulautuva, Veršvai, Paštuva and Marvelė cemeteries, and some habitation sites, became a particularly important centre during the Early Roman period (Figs. 1 and 12).

During the Earliest Iron Age, one of the sites of non-ferrous metal production may have been in the former settlement of Paalksniai in the Samogitian highlands. Burials in the barrow in the area of the settlement began

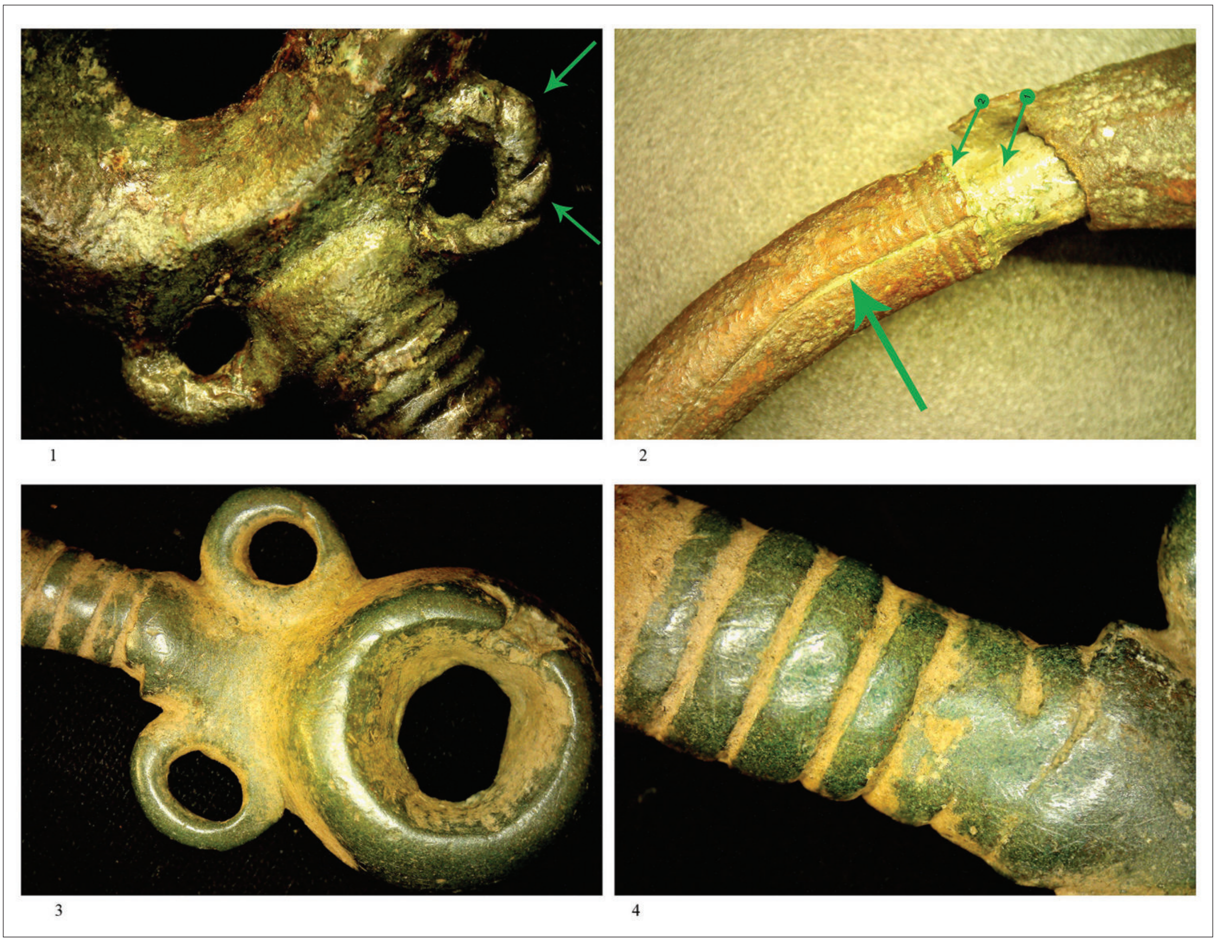

Figure 9. Dress pins with a wheel-shaped head from Ėgliškiai barrow cemetery, barrow 2, grave 1 (LNM AR 636:2); 2. a fragment of a neck-ring bow with hollow trumpet-shaped terminals from Glaušiai cemetery, find circumstances unclear (KMM 830); 3, 4. a dress pin with a wheel-shaped head from Vilūnai site, stray find (LNM). Enlarged 50× (photographs by E. Babenskas).

to take place as early as the second half of the 1st century AD (Michelbertas 2011, pp. 79–80). In the Early Roman period, several barrow cemeteries appeared within the boundaries of the district of Kelmė, and, to a certain extent, of Šilalė, which would indicate that there were some places where non-ferrous metal was worked (Figs. 1 and 12). On the other hand, the picture can be a bit deceptive, as there are many excavated barrow cemeteries in the region. However, production is also partly attested to by the discovery of a hoard of eight copper ingots at the village of Miežaičiai. All 8 ingots were analysed by XRF method. The results show that the ingots were cast from copper alloy with a very high percentage of copper (Cu is 90–96%). The zinc and lead in this alloy make up only a small percentage (Zn 1.3–3.1%, Pb 1.4–3.9%), while Sn was not found. The ingots weighed 247 to 371 grams, one ingot weighing even 611 grams. The elemental composition of the raw material does not contradict that of finds from the Roman and Migration periods.

Although there is little information on Late Bronze Age and Earliest Iron Age finds from southern Lithuania, finds from 2020 suggest that there may also have been centres for the production of particular artefacts, as well as places of regional exchange. One such centre may have been in the vicinity of Vilūnai (Figs. 1 and 10). In addition to the pin found at Vilūnai, two pieces of very poorly preserved leaded bronze alloy bracelets, probably belonging to the Earliest Iron Age, were also found. It is likely that an Earliest Iron Age burial site was located in this area, but due to years of intensive farming activities and infrastructure works around the area, the site may have been completely destroyed. More prehistoric sites were revealed and investigated during further rescue excavations in the construction area of the international gas pipeline at the village of Vilūnai. One such object was the Vilūnai 4 site, where two AMS ^{14}C dates were obtained from a feature resembling the Early and Late Bronze Age in its eastern part. The dates pointed to 1108–919 cal BC (2842±29; FTMC-YY40-5) and 1625–1502 cal BC (3284±28; FTMC-YY40-6) (Rimkus 2021). However, the dates do not fall into the relative age of the pin fragment, as in the east Baltic its type is ascribed by most authors to the Earliest

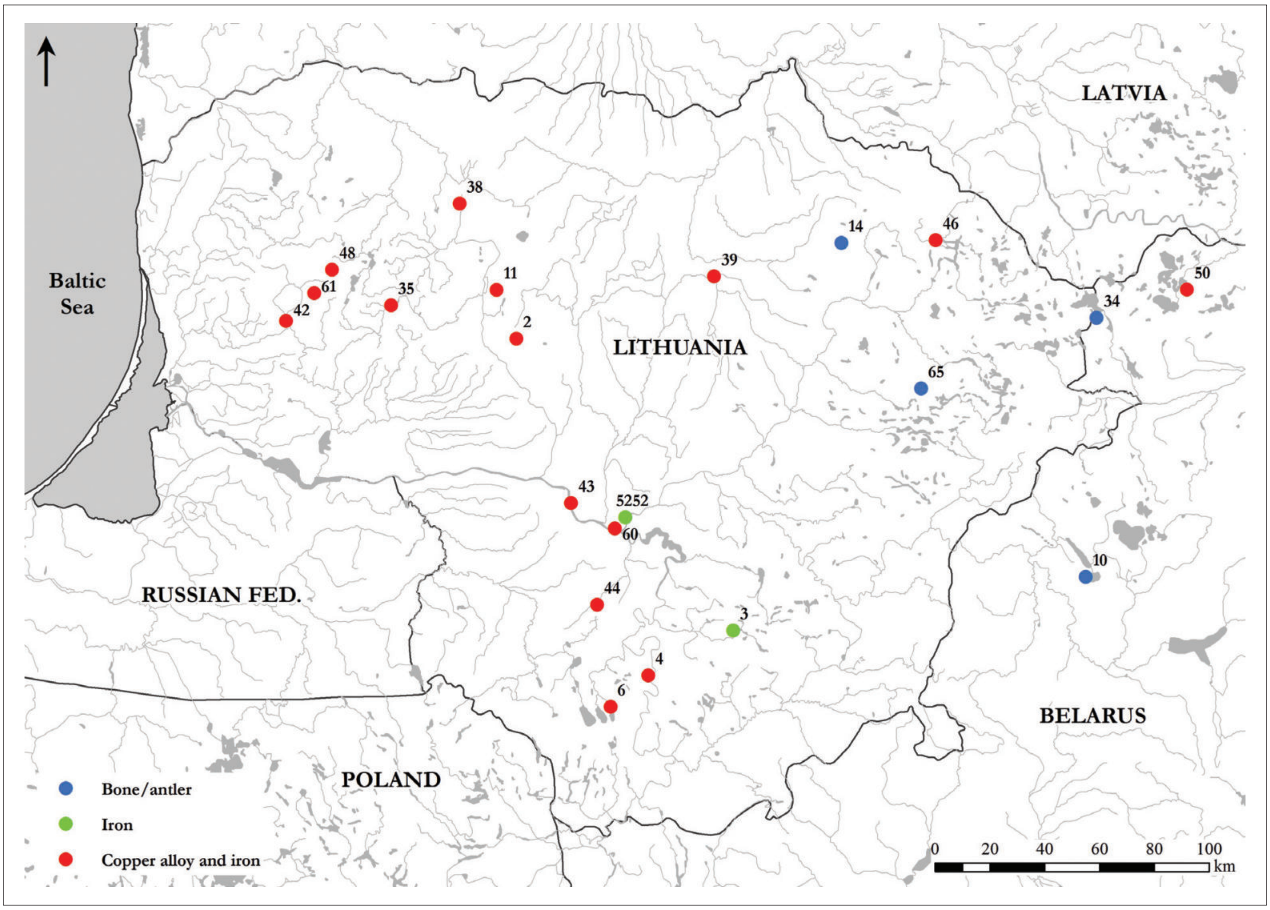

Figure 10. The distribution of spool-head dress pins with pin material marked (according to Tautavičius 1978, Map 41; with new additions by the article authors). For the site numbers on the map, see Appendix (drawing by G.Petrauskas).

Iron Age (Grigalavičienė 1995, p. 185; Merkevičius 2011, pp. 32–33; Girininkas 2013, p. 226). This indicates that the Vilūnai area was inhabited during the Late Bronze Age and Earliest Iron Age, and although the available absolute dates do not coincide with the relative chronology of the pin (see Fig. 3.12), it does not exclude the possibility that there was continuity of occupation in these areas during the Earliest Iron Age. In addition, finds from the Aukštadvaris hillfort and settlement fit the major centres of southeast Lithuania. Based on the settlements of Late Brushed Pottery culture, the Vilūnai and Aukštadvaris centres were still functioning in the Early Roman period (Daugudis 1998) (Figs. 1 and 12).

At Prienlaukis in the Trans-Nemunas region, under unclear circumstances, in the probably disturbed barrow from the Earliest Iron Age, round open-work pendants and pendants of other shapes were found (Grigalavichene 1980, p. 78, Table XXV). Published data from two pendants tested by OES method shows that they are made of brass (Miarkiavichius 1980, Table) (Figs. 1 and 12). This centre seems to extend further, as a Late Roman period spacer ring with red enamel inlay was found in the centre (Michelbertas 2016, p. 80). On the other hand, in the nearby Pažarstis barrows, a massive bracelet with 'knobs', an eye fibula and other finds confirm the existence of the centre in the Early Roman period (Michelbertas 1986, Fig. 60.2; Grižas and Bitner-Wróblewska 2007, p. 263, Figs. 2–6).

In recent years, Late Bronze Age and Earliest Iron Age hillforts in northeast and east Lithuania have yielded both technical ceramics and finds, mostly jewellery (Figs. 1 and 12). However, the question of who produced them remains open, as no concentrated artefact production places have yet been found. Therefore, we must assume that jewellery made of copper alloys was produced locally (Krzywicki 1914; 1917; Luchtanas 1981; 1992; Grigalavičienė 1986b; 1992; Čivilytė 2014; Podėnas et al. 2016; Banytė-Rowell 2017; Luchtanas et al. 2019). The contradiction between the large number of technical ceramic and non-located jewellery workshops discovered can be solved by claiming that production places were short-lived, without the need for specialised equipment. On the other hand, it is likely that the artefacts were made by highly skilled travelling jewellers (Čivilytė 2014; Podėnas and Čivilytė 2019).

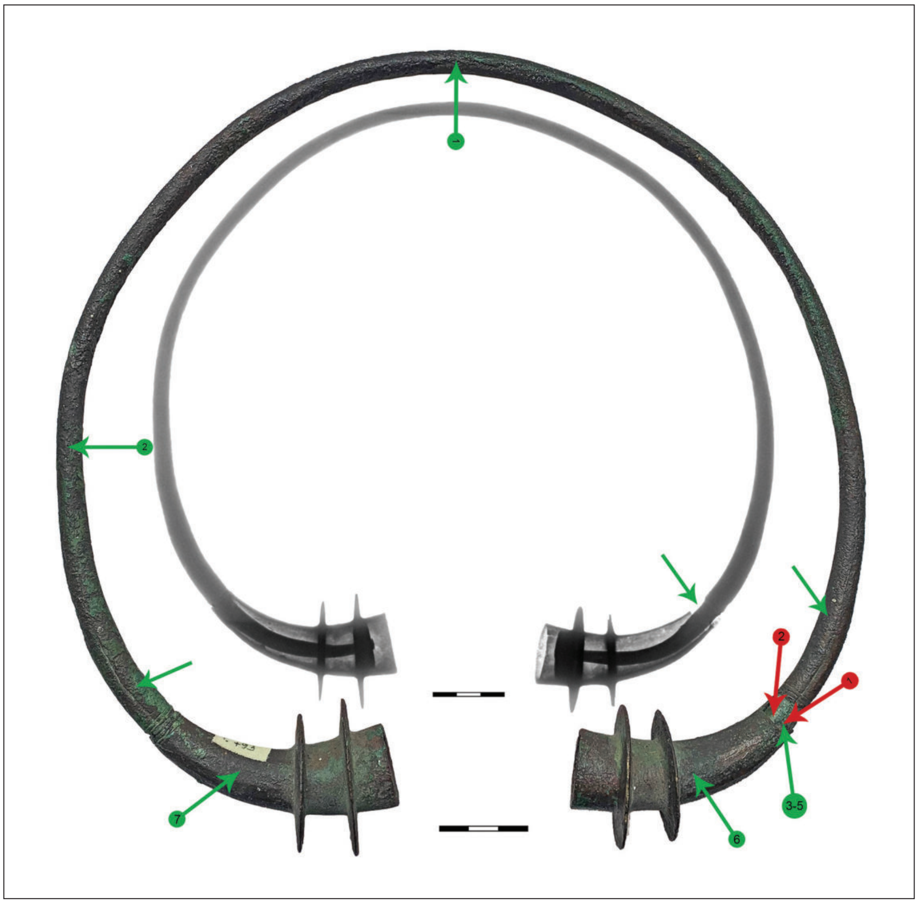

Figure 11. Photograph and radiograph of the neck-ring with hollow trumpet-shaped terminals from Glaušiai (KMM 830) cemetery. Spots investigated by XRF method marked with green arrows; spots of investigated solder are marked with red arrows (photograph by A. Bliujienė, radiograph by R. Vedrickas).

In the Early Roman period, this major centre of hillforts and settlements continued, and probably disintegrated into smaller units, and the leadership of Kernavė, with a number of surrounding sites, in east Lithuania prevailed (Figs. 1 and 12).

Conclusions

Based on the results of X-ray fluorescence (XRF) spectrometry studies on Lithuanian archaeological material, it was found that artefacts from the Late Bronze Age to the Earliest Iron Age were made of bronze and leaded bronze. However, there is no essential difference in the composition of the copper alloys used between east and west Lithuania. Nevertheless, there was a slight difference in the composition of copper alloys used in east and west Lithuania during this period. The alloys from the western part are more homogeneous. Towards the end of the Earliest Iron Age, brass-like alloys appeared among the copper alloys used. At the end of the Earliest Iron Age, in addition to casting, the number of artefacts produced from hammered wire and thin tin sheets increased. Technically, malleable brass was most suitable for the production of artefacts by forging. Thus, the change in the elemental composition of copper alloy may have been due to the greater variety of artefacts produced in the east Baltic region at the end of the Earliest Iron Age. The change in alloy, on the other hand, was a European trend that reached north-east Europe fairly quickly. However, the main change in the composition of copper alloys took place during the transition from the Earliest Iron Age to the Early Roman period.

Alloys and/or scrap metal used to reach present-day Lithuania through a long and complex chain of exchange, using different exchange equivalents. The elemental composition of copper alloys in artefacts dated to the Late Bronze and the Earliest Iron Ages, and the Early Roman period followed the same tendencies as in other European regions.

The process of change in the elemental composition of copper alloys in the Early Roman period was accompanied by the rapid development of high-production technologies, with the emergence of finds produced by highly sophisticated manufacturing and processing techniques that could only be mastered by jewellers who were able to use multiplex technologies. The technologies of the Earliest Iron Age and the Early Roman period have been characterised by means of radiographic and micro-chemical

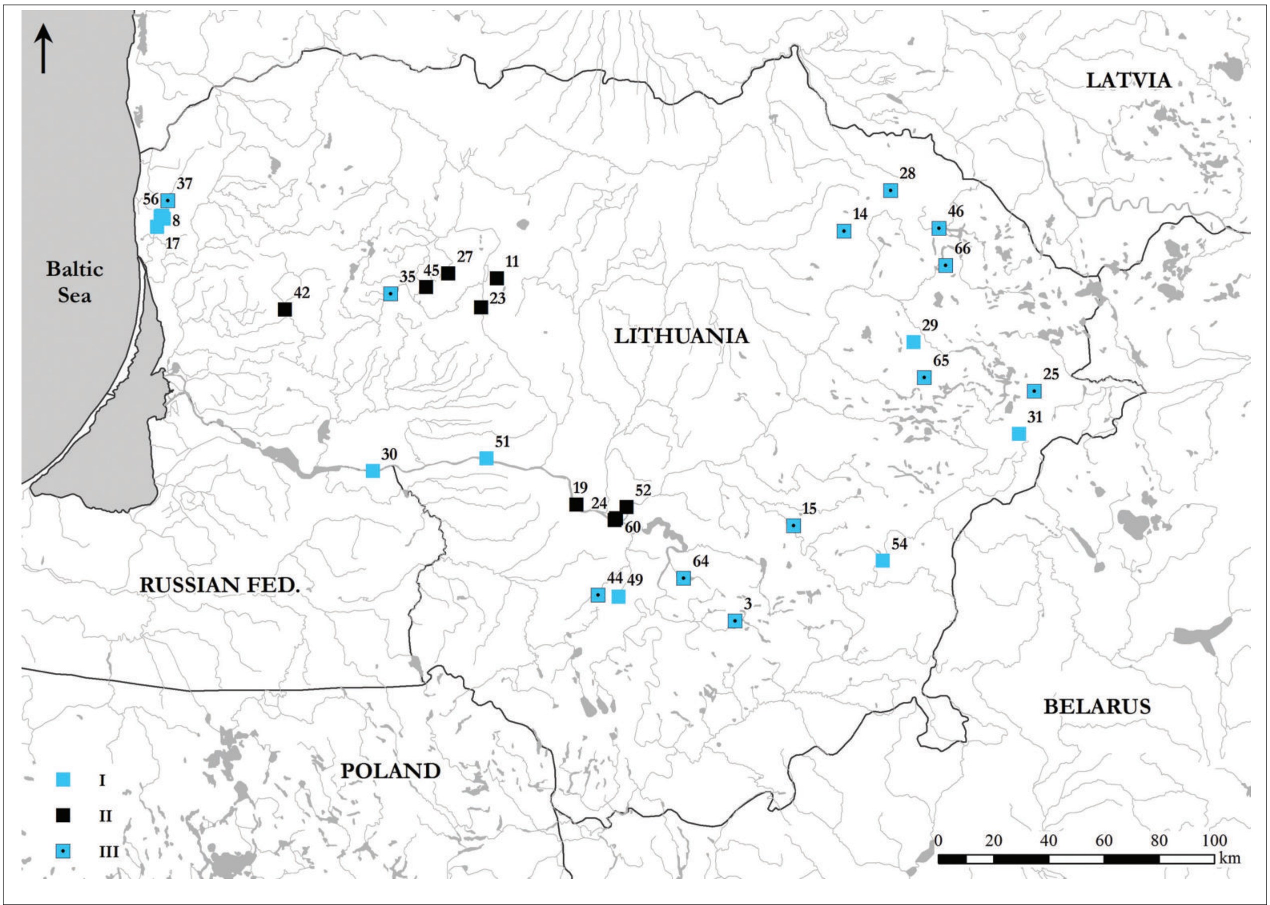

Figure 12. Possible major sites:
I. In the Bronze and Earliest Iron Ages; II. In the Early Roman Period; III. In the Earliest Iron Age and the Early Roman Period. For the site numbers on the map, see Appendix (drawing by G. Petrauskas).

qualitative analysis, and by means of magnification studies of the finds. It is therefore likely that this role was played by itinerant jewellers, based on contemporaneous monuments and the distribution of artefacts in distinct major centres. The sudden jump in the settlement structure has allowed for the identification of new production techniques, jewellery-making skills, production sites, and to some extent, changes in the direction of exchange.

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Appendix

Sites mentioned in the text (see Fig. 1). The site numbers correspond to the numbers on all maps in the article.

1. Adakavas (Tauragė district).
2. Akmenė (Sandrausiškė) (Raseiniai district).
3. Aukštadvaris (Trakai district).
4. Bakšiai (Alytus city).
5. Batakiai (Tauragė district).
6. Cigoniškiai (Alytus district).
7. Dauglaukis (Tauragė district).
8. Ėgliškiai (Kretinga district).
9. Glaušiai (Kėdainiai district).
10. Gorani (Smarhon district, Belarus).
11. Jagminiškė (Kelmė district)
12. Jonelaičiai (Šiauliai district).
13. Kegai (Telšiai district).
14. Kereliai (Kupiškis district).
15. Kernavė (Širvintos district).

16. Kybartiškė (Šiauliai district).
17. Kretingalė (Klaipėda district).
18. Kukiai (Petreliai) (Mažeikiai district).
19. Kulautuva (Kaunas district).
20. Kurmaičiai (Kretinga district).
21. Linksmėnai (Kurmaičiai) (Joniškis district).
22. Linkuva (Pakruojis district).
23. Maironiai (Saudininkai) (Kelmė district).
24. Marvelė (Kaunas city).
25. Mažulonys (Ignalina district).
26. Medvėgalis (Karūžiškė) (Šilalė district).
27. Miežaičiai (Kelmė district).
28. Moškėnai (Laukupėnai) (Rokiškis district).
29. Narkūnai (Utena district).
30. Naudvaris (Jurbarkas district).
31. Nevieriškė (Švenčionys district).
32. Nikėlai (Šilutė district).
33. Noliškiai (Šiauliai district).
34. Nurviany (Braslav district, Belarus).
35. Paalksniai (Kelmė district).
36. Pabaliai (Joniškis district).
37. Padvariai (Kretinga district).
38. Padvarninkai (Šiauliai district).
39. Pajuostis (Panevėžys district).
40. Pajūralis (Skerdynai) (Šilalė district).
41. Papilys (Skomantai) (Klaipėda district).
42. Paragaudis (Šilalė district).
43. Paštuva (Kaunas district).
44. Pažarstis (Prienai district).
45. Perkūniškė (Kelmė district).
46. Petrešiūnai (Rokiškis district).
47. Pilviškės (Vilnius district).
48. Pribitka (Rietavas municipality).
49. Prienlaukys (Prienai district).
50. Ratiunki (Braslav district, Belarus).
51. Raudonėnai (Jurbarkas district).
52. Sargėnai (Kaunas city).
53. Sokiškiai (Ignalina district).
54. Staviškės (Vilnius city).
55. Strazdai (Ječiškės) (Pagėgiai municipality).
56. Šlažiai (Kretinga district).
57. Šlikiai (Klaipėda district).
58. Telšiai (Telšiai district).
59. Velikuškės (Zarasai district).
60. Veršvai (Kaunas city).
61. Vienragiai (Rietavas municipality).
62. Vilkija (Kaunas district).
63. Vilkų Kampas (Šilutė district).
64. Vilūnai (Kaišiadorys district).
65. Vorėnai (Molėtai district).
66. Vosgėliai (Zarasai district).
67. Zastaučiai (Mažeikiai district).

Abbreviations

Lietuvos arch. – Lietuvos archeologija

Archaeol. Balt. – Archaeologija Baltica

Arch. Lituana – Archaeologia Lituana

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ESMINIAI VARIO LYDINIŲ SUDĖTIES POKYČIAI, ATSKLEIDŽIANTYS TECHNOLOGINIUS SKIRTUMUS, PEREINANT IŠ ANKSTYVOJO GELEŽIES AMŽIAUS Į ANKSTYVĄJĮ ROMĖNIŠKĄJĮ LAIKOTARPĮ LIETUVOJE

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Santrauka

Remiantis Lietuvos archeologinės medžiagos rentgeno fluorescencijos (XRF) spektrometrijos tyrimų rezultatais, nustatyta, kad nuo vėlyvojo bronzos amžiaus iki ankstyvojo geležies amžiaus dirbiniai buvo gaminti iš bronzos ir švino bronzos (2; 3; 5 pav.; 1 lent.). Ankstyvajame geležies amžiuje nėra esminio skirtumo tarp vario lydinių naudotų Rytų ir Vakarų Lietuvoje, elementinės sudėties. Tačiau vis dėlto vakarinėje dalyje naudotų lydinių elementinė sudėtis homogeniškesnė už naudotų rytinėje Lietuvoje dalyje. Ankstyvojo geležies amžiaus pabaigoje tarp naudojamų vario lydinių atsiranda į žalvarį panašių lydinių (5:13, 14; 4 pav. 2, 3 lent.). Tačiau pagrindinis vario lydinių sudėties pokytis įvyko virsmo iš ankstyvojo geležies amžiaus į ankstyvąjį romėniškąjį laikotarpį metu. Ankstyvojo geležies amžiaus pabaigoje, be liejimo, pagausėja dirbinių iš kaltos vielos ir plonų skardos lakštų. Technologiškai žalvaris buvo tinkamiausias dirbinių gamybai kalimo būdu. Taigi, vario lydinių elementinės sudėties pasikeitimas galėjo atsirasti dėl didesnės Rytų Baltijos regiono dirbinių įvairovės ankstyvojo geležies amžiaus pabaigoje. Kita vertus, elementinės sudėties lydinių kaita iš bronzos tipo lydinių į žalvarį buvo europinė tendencija, gana greitai pasiekusi Šiaurės rytų Europą. Lydiniai ar / ir metalo laužas dabartinę Lietuvos teritoriją pasiekdavo sudėtinga ir ilga mainų grandine, naudojant skirtingus mainų ekvivalentus. Vario lydinių elementinė sudėtis ankstyvuoju metalų laikotarpiu ir ankstyvuoju romėniškuoju laikotarpiu kito tuo pačiu ritmu, kokiu ji kito Europoje, įsisavinant naujus rūdynus ir metalo laužą naujiems dirbiniams gaminti. Lietuvoje vario lydinių elementinės sudėties kaitos į žalvarį procesas ankstyvuoju romėniškuoju laikotarpiu buvo lydimas staigios aukštų gamybos technologijų plėtros. Atsirado dirbinių, gamintų naudojant itin sudėtingas gamybos ir apdirbimo technologijas (6; 7; 8:2–5; 9:2; 10; 11 pav.; 2, 3 lent.), todėl tikėtina, kad jie gaminti keliaujančių juvelyrų. Staigus apgyvendinimo struktūros šuolis, naujoviškai pagamintų dirbinių atsiradimas ir paplitimas leidžia nustatyti atsiradusius gamybos centrus ir iš dalies pasikeitusias mainų kryptis (11 pav.).