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Archaeometric Investigation of a Hunnic-Period Sacrificial Assemblage from Nyergesújfalu, Hungary

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A B S T R A C T

Near Nyergesújfalu (Komárom-Esztergom County, Hungary), objects of a Hunnic-period sacrificial assemblage were found in 2021. The Hunnic period assemblage contains fifteen items altogether: four gold lunular mounts, six cellwork-decorated gold oval mounts, two cellwork-decorated gold suspension rings, two gold buckles and fragments of a scale-patterned gilded silver plate. The present study aims to determine the elemental composition of the metal alloy of the Hunnic-period objects and characterise the decoration techniques (gilding and garnet inlays) by using optical microscopy, handheld X-ray fluorescence spectrometry (hXRF) and scanning electron microscopy with energy-dispersive X-ray spectrometry (SEM-EDX). The gold objects, including their small parts such as the rivets of buckles and lunular mounts, sockets and filigree, were manufactured from a relatively good-quality gold alloy (>80 wt% Au). The fragments of the scale-patterned silver plate were manufactured from a high-quality silver alloy (>94 wt% Ag), similar to late Roman silver alloys characterised by high Ag content, and was decorated with fire (mercury) gilding. The garnets used for inlays are almandine and intermediate pyrope-almandine garnets. Based on their chemistry, the garnets belong to Group X and probably originate from the placer deposits of Sri Lanka.

1. Introduction: the archaeological background and the analysed artefacts

At the end of July 2021, volunteers of the Hungarian National Museum's (HNM) Community Archaeology Programme and the HNM Balassa Bálint Museum organised a trip into the Gerecse Mountains to discover new sites in the area. The choice was not random: based on reports of earlier findings, the forest-covered mountains have been a preferred hunting ground of metal detector-equipped treasure hunters for decades. Near Nyergesújfalu (Komárom-Esztergom County, Hungary), positioned on a forest-covered northern high plateau with a 10% slope, the first objects of a Hunnic-period sacrificial assemblage were found (Figure 1) (Schilling, 2022). The Hunnic-period finds were situated at five separate spots, a few metres away from the others. The first objects were found at a shallow depth, probably moved there by the roots of an oak tree.

The Hunnic-period assemblage contains fifteen items altogether: gold lunular mounts, cellwork-decorated gold oval mounts, cellwork-decorated gold suspension rings, gold buckles and fragments of a scale-patterned gilded silver plate (Figure 2) (Schilling, 2022). The scale-patterned gilded silver plate is about 0.25 mm thick (Figure 2C); based on available analogies, it could be a part of the decorative cover of a dagger (Bóna, 1991; 1993), a scabbard (*e.g.*, Pannonhalma–Szélsőhalom; Tomka, 1986a; 1986b, recently interpreted as a saddle, Piros *et al.*, 2022), or a saddle (*e.g.*, Telki–Anna-lak; Szenthe *et al.,* 2019; Göd–Bócsaújtelep; Mráv *et al.,* 2021; Nyíregyháza–Oros; Piros *et al.,* 2021; Debrecen–Agrár park; Piros *et al.,* 2023). The plate had been detached from whatever object it decorated and had been folded before it was hidden.

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Figure 1. The location of the site in the Carpathian Basin.

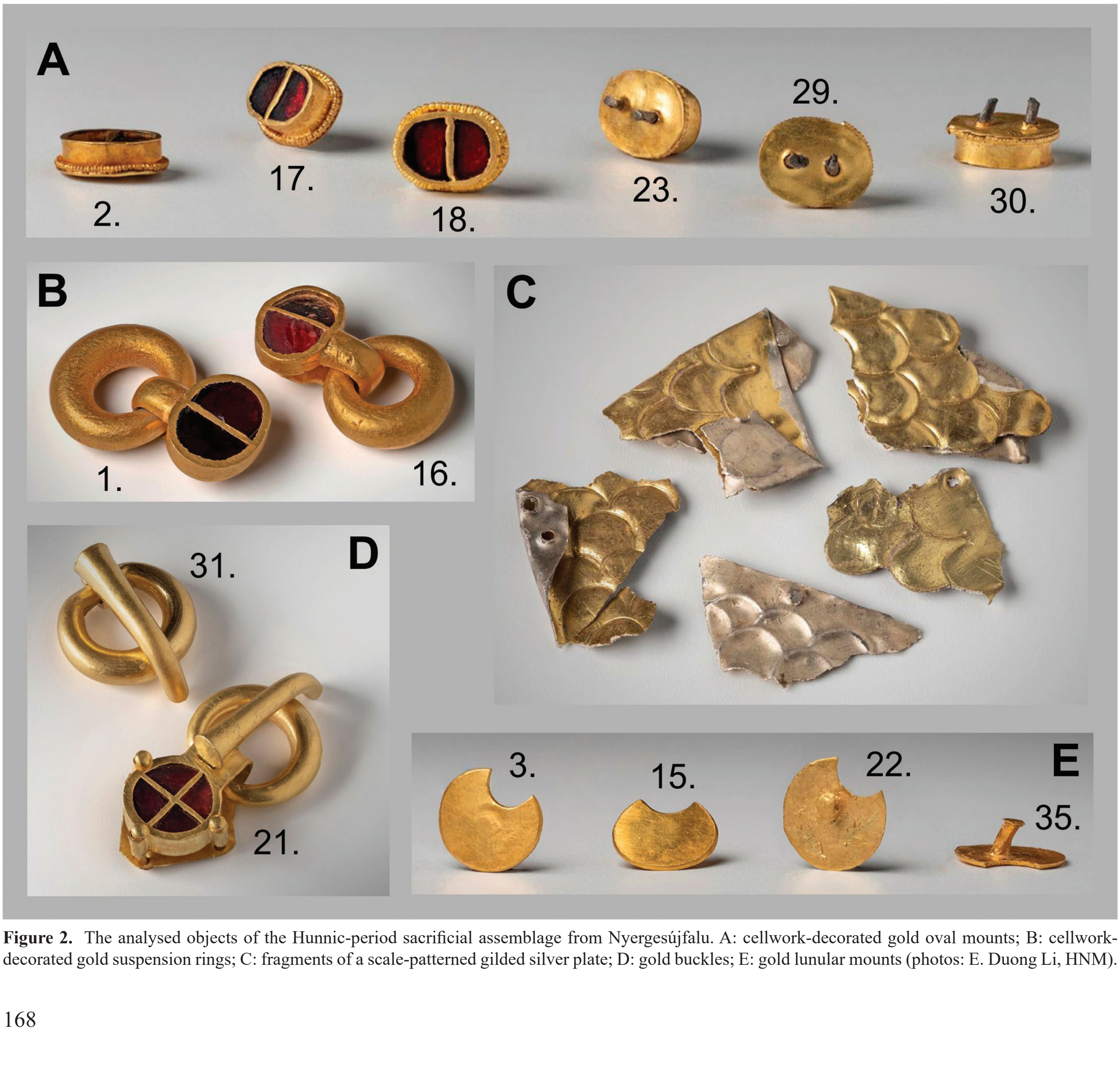

Figure 2. The analysed objects of the Hunnic-period sacrificial assemblage from Nyergesújfalu. A: cellwork-decorated gold oval mounts; B: cellwork-decorated gold suspension rings; C: fragments of a scale-patterned gilded silver plate; D: gold buckles; E: gold lunular mounts (photos: E. Duong Li, HNM).

The four lunular gold mounts (Figure 2E) are especially important: of that type, only gilded silver (*e.g.*, Telki–Annalak; Szenthe *et al.,* 2019), silver (*e.g.*, Lengyeltóti; Bakay, 1978), and bronze (*e.g.*, Solva/Esztergom–Bánomi-dűlő; Kelemen, 2008) specimens were known. These mounts probably decorated belts or straps of unknown function.

The six oval gold mounts were decorated with two facing semi-circular translucent red gemstone (garnet) inlays in an oval cellwork case engirded by notched gold wire (Figure 2A). Originally, they had been fastened by a pair of silver rivets on a backplate and probably decorated artefacts or articles of clothing made of organic material.

The two gold suspension rings (Figure 2B) with cellwork decoration belong to a type that, in a simpler version (Bóna, 1991; 1993), had already appeared during the late Roman Period. These pieces were probably accessories to a leather belt, and their exact function determined their positions: they could have belonged to a side-strap slung over the shoulder or were perhaps used to suspend an object, maybe a dagger or a sword, from a belt.

The material, size, and elaboration of the gold buckle's loop and tongue are akin to the other buckle in the assemblage (Figure 2D). Originally, this piece probably also had a cellwork-decorated mount plate that had perhaps already broken off and became lost in Hunnic times or was intentionally not interred with the rest of the items for some reason that is unknown to us. It probably fastened a belt or strap of undetermined function. The other gold buckle in the assemblage, a piece with a mount plate decorated with translucent red gemstone (garnet) inlays in a gold cellwork case, also probably once fastened a belt or strap of unknown function. This item is of particular interest as its precise analogy, the so-called "Marcelháza buckle" (Bóna, 1991; 1993), was bought by the HNM in 1889 and taken into the inventory of its collection as a find with "site unknown". The two buckles are exceptionally similar in both elaboration and design, but determining their exact relation requires further analysis, just as is the case with the artefacts with identical cellwork structures from Bátaszék–Iskola (Bóna, 1991; 1993) and Fürst (Bavaria, Germany; Fehr, 2003).

The present study aims to determine the elemental composition of the metal alloy of the Hunnic-period objects and characterise the decoration techniques (gilding of the silver plate and garnet inlays of the gold objects).

2. Methodology

The objects were at first thoroughly observed with optical microscopy to characterise the manufacturing techniques and garnet inclusions. The chemical composition of the metal alloy and the gilding was analysed by using handheld X-ray fluorescence spectrometry (hXRF). No surface cleaning was performed prior to the measurements.

Table 1. Chemical composition of different certified silver and gold standards. The averages are calculated based on 5–5 measurements of each standard.

	Description	Ag	Cu	Au	Pb	Bi	Zn	Pd
Silver standards								
AGQ1 C	certified value	(bal)	2.532	0.251	0.245			
	average±st.dev.	97.16±0.02	2.33±0.07	0.22±0.01	0.21±0.01			
AGQ2 C	certified value	(bal)	5.808	0.978	0.469			
	average±st.dev.	92.89±0.1	5.68±0.09	0.94±0.01	0.48±0.01			
AGQ3 C	certified value	(bal)	9.612	1.975	0.921			
	average±st.dev.	86.99±0.09	10.04±0.06	1.94±0.02	1.01±0.02			
AGA2 A	certified value	(bal)	10	0.507	1.02	0.113	0.502	
	average±st.dev.	87.68±0.04	10.19±0.05	0.48±0.02	1.03±0.01	0.12±0.003	0.50±0.01	
Gold standards								
0720-16	certified value			99.99				
	average±st.dev.			100.00				
0738-16	certified value	19.8	21.1	58.58			0.52	
	average±st.dev.	19.65±0.06	21.22±0.06	58.58±0.04			0.53±0.01	
0732-16	certified value	57.1	9.44	33.46				
	average±st.dev.	57.68±0.06	9.01±0.01	33.08±0.05			0.23±0.005	
0734-16a	certified value	7.09	48.82	33.41			10.68	
	average±st.dev.	6.66±0.10	49.19±0.13	32.81±0.68			11.08±0.22	
0704-16d	certified value	2.99	9.19	75.22				12.6
	average±st.dev.	2.61±0.14	9.48±0.05	75.45±0.14				12.22±0.30

Scanning electron microscopy with energy-dispersive X-ray spectrometry (SEM-EDX) was used to determine the chemical composition of the garnet inlays. As garnets are non-conductive materials, a special sample preparation was applied earlier (Bendő *et al.,* 2013; Mozgai *et al.*, 2021a). However, using the low vacuum mode during SEM-EDX measurements, garnets could be analysed without any special sample preparation. Only the surface of the garnets was cleaned by ethanol. Two small fragments of the gilded silver plate were embedded in resin in cross section and polished in order to study the chemical composition and microtexture of the gilding in detail by using SEM-EDX.

2.1 Optical microscopy (OM)

A Dino-Lite AM4113T–FVW digital UV/VIS LED USB microscope and a ZEISS STEMI 2000-C stereomicroscope with polarised light (illumination: ZEISS KL 1500 LCD) were used to observe the metal applique and gilding of the objects and the mineral inclusions of the garnet inlays. A SONY Nex 5 TL camera was used to capture the images.

2.2 Handheld X-ray fluorescence spectrometry (hXRF)

A SPECTRO xSORT Combi handheld X-ray fluorescence spectrometer was used. Analytical conditions: 15–50 kV, 30–120 µA, Rh anode, Peltier cooling SDD detector, 'Alloy Plus including Light Elements' built-in calibration, 3 mm measurement area, 60 seconds acquisition time. In the case of gilding, the built-in calibration does not calculate the mercury content; therefore, the presence of mercury can only be determined qualitatively based on the hXRF spectra. The accuracy of the measurements was tested by measuring certified silver (MBH Analytical Ltd.) and gold (Fluxana GmbH) standards (Table 1).

2.3 Scanning electron microscopy with energy-dispersive X-ray spectrometry (SEM-EDX)

A JEOL JSM-IT700HR scanning electron microscope equipped with Oxford Instruments Aztec X-ACT Premium SDD energy-dispersive X-ray spectrometer (EDS) was used in low vacuum mode (50 Pa pressure). Analytical conditions: 20 kV accelerating voltage, 90 seconds (point analyses) and 30 min (mapping) acquisition time. The results were normalised to 100 wt%. During quantitative analysis, built-in factory standards were used. Each garnet was analysed by at least three (in the case of non-ideal surfaces more than three) point (spots 1 µm in diameter) measurements and one area measurement (200 µm × 200 µm). The accuracy of the garnet analyses was determined after Locock (2008). Only the "Superior", "Excellent" and "Good" results were used for interpretation. The average of the "Fair" and/or "Poor" results were used only in the case of one garnet where no better quality data were acquired.

3. Results and discussion

3.1 Gold objects

The gold objects were manufactured from a relatively good-quality gold alloy based on the hXRF measurements (Table 2; Figures 3 and 4). The buckles, suspension rings and lunular mounts show a rather homogeneous composition (Au: 83.2–85.7 wt%; Ag: 14.1–15.7 wt%; Cu: 0.2–0.5 wt%) in contrast to the more scattered composition of the oval mounts (Au: 80.9–89.3 wt%; Ag: 8.6–14.9 wt%; Cu: 0.7–4.9 wt%) (Figure 4).

The small-sized components of each of the objects (rivets, filigree, sockets, *etc.*) were analysed separately

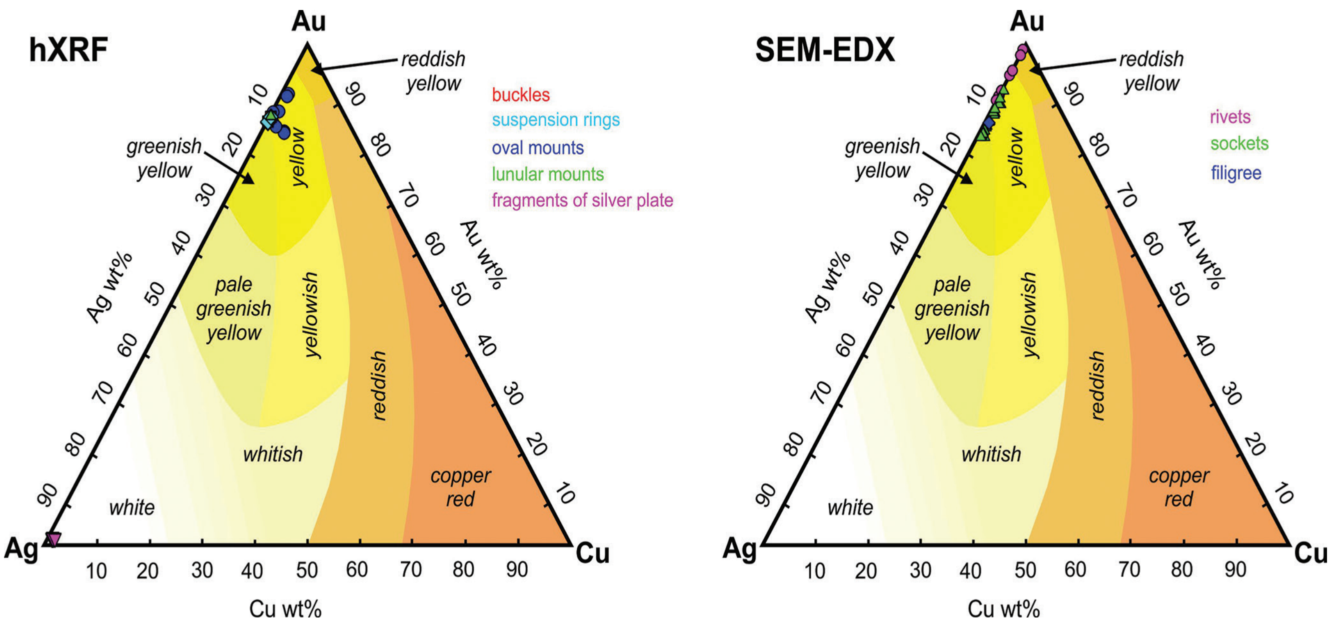

Figure 3. Composition of the gold and silver objects based on the hXRF and SEM-EDX measurements depicted on the gold–silver–copper ternary diagram (after Leuser, 1949).

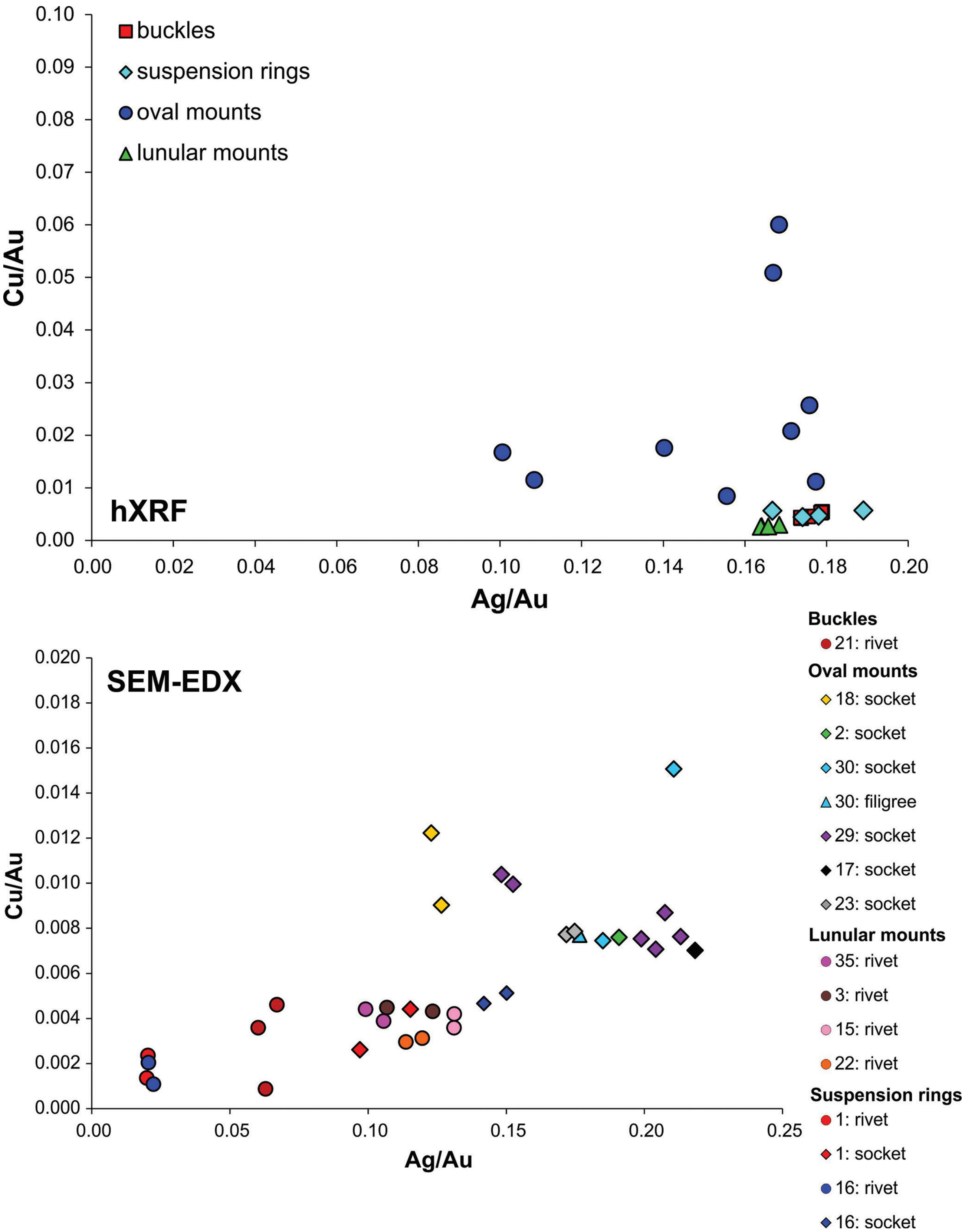

Figure 4. Composition of the gold objects based on the hXRF and their small components based on the SEM-EDX measurements plotted on the Cu/Au vs. Ag/Au diagram.

using SEM-EDX. The oval mounts were fastened to their holder with silver rivets, which were completely converted into silver chloride and silver sulphide during corrosion processes. The other small parts of the objects (rivets of the buckles and lunular mounts, sockets and filigree of the oval mounts and suspension rings) were all manufactured from relatively good-quality gold alloy (Table 3; Figures 3 and 4). Generally, the rivets were manufactured from a gold alloy with a lower silver and copper content (Au: 88.1–97.9 wt%; Ag: 1.9–11.6 wt%; Cu: 0.1–0.4 wt%) than the sockets and filigree (Au: 81.6–90.9 wt%; Ag: 8.8–17.8 wt%; Cu: 0.2–1.2 wt%) (Figures 3 and 4).

Table 2. Elemental composition of the studied gold and gilded silver objects based on the hXRF measurements. The results are given in wt%. LOD: limit of detection. The presence of mercury in the gilded areas is not calculated, only qualitatively determined (+: mercury is present) (see Figure 6). In some cases, iron was also detected, but it was interpreted as surface contamination and was not taken into consideration during interpretation.

Object No.	Description	Au	Ag	Cu	Pb	Bi	Hg
Gold buckles							
21.	loop	84.9	14.8	0.36	<LOD	<LOD	
	tongue	84.7	14.9	0.38	<LOD	<LOD	
	plate	84.2	15.1	0.46	<LOD	<LOD	
31.	tongue	84.8	14.7	0.37	<LOD	<LOD	
	loop	84.2	15.0	0.44	<LOD	<LOD	
Gold suspension rings							
1.	loop	84.7	14.1	0.48	<LOD	<LOD	
	socket	83.2	15.7	0.47	<LOD	<LOD	
16.	loop	84.5	15.0	0.39	<LOD	<LOD	
	socket	84.8	14.8	0.37	<LOD	<LOD	
Gold oval mounts							
18.	socket	85.9	8.6	1.4	<LOD	<LOD	
	back plate	89.3	9.7	1.0	<LOD	<LOD	
2.	socket	82.0	13.7	4.2	<LOD	<LOD	
	back plate	83.8	14.9	0.93	<LOD	<LOD	
30.	socket	80.9	13.6	4.9	<LOD	<LOD	
23.	socket	83.8	14.4	1.7	<LOD	<LOD	
17.	socket	83.2	14.6	2.1	<LOD	<LOD	
29.	socket	86.4	12.1	1.5	<LOD	<LOD	
	back plate	85.7	13.3	0.72	<LOD	<LOD	
Gold lunular mounts							
22.	metal	85.7	14.1	0.23	<LOD	<LOD	
3.	metal	85.7	14.1	0.22	<LOD	<LOD	
35.	metal	85.4	14.4	0.25	<LOD	<LOD	
15.	metal	85.6	14.2	0.22	<LOD	<LOD	
Scale-patterned gilded silver plate							
fragment 1	metal	1.5	96.8	0.8	0.13	0.03	
fragment 2	metal	1.3	96.3	0.9	0.09	0.02	
fragment 3	metal	1.5	97.0	0.8	0.09	0.02	
fragment 4	metal	1.4	95.9	0.9	0.09	0.02	
fragment 5	metal	1.3	96.9	1.0	0.09	0.02	
fragment 6	metal	1.3	96.0	1.1	0.09	0.02	
fragment 7	metal	1.4	97.0	0.8	0.09	0.02	
fragment 8	metal	1.4	96.8	1.0	0.09	0.02	
fragment 9	metal	1.4	94.2	1.3	0.09	0.02	
fragment 10	metal	1.4	96.9	0.9	0.09	0.02	
fragment 11	metal	1.6	96.8	0.9	0.09	0.02	
fragment 12	metal	1.4	96.8	0.9	0.09	0.02	
fragment 13	metal	1.3	96.3	1.4	0.09	0.02	
fragment 1	gilding	80.6	12.3	<LOD	<LOD	<LOD	+
fragment 2	gilding	93.5	4.8	<LOD	<LOD	<LOD	+

Table 2. Elemental composition of the studied gold and gilded silver objects based on the hXRF measurements. The results are given in wt%. LOD: limit of detection. The presence of mercury in the gilded areas is not calculated, only qualitatively determined (+: mercury is present) (see Figure 6). In some cases, iron was also detected, but it was interpreted as surface contamination and was not taken into consideration during interpretation. (*Continuation*)

Object No.	Description	Au	Ag	Cu	Pb	Bi	Hg
fragment 3	gilding	77.2	20.6	<LOD	<LOD	<LOD	+
fragment 4	gilding	90.1	8.2	<LOD	<LOD	<LOD	+
fragment 5	gilding	80.4	19.1	<LOD	<LOD	<LOD	+
fragment 6	gilding	95.4	3.1	<LOD	<LOD	<LOD	+
fragment 7	gilding	95.1	4.2	<LOD	<LOD	<LOD	+
fragment 8	gilding	82.5	16.8	<LOD	<LOD	<LOD	+
fragment 9	gilding	93.3	6.2	<LOD	<LOD	<LOD	+
fragment 10	gilding	87.6	11.4	<LOD	<LOD	<LOD	+
fragment 11	gilding	91.8	6.1	<LOD	<LOD	<LOD	+
fragment 12	gilding	88.4	9.6	<LOD	<LOD	<LOD	+
fragment 13	gilding	82.0	17.5	<LOD	<LOD	<LOD	+

Table 3. Elemental composition of the small components of the studied gold objects based on the SEM-EDX measurements. The results are given in wt% and normalised to 100%.

Object No.	Description	Au	Ag	Cu
Gold buckles				
21.	rivet 1	93.3	6.2	0.43
	rivet 2	94.0	5.7	0.34
	rivet 3	94.0	5.9	0.08
Gold suspension rings				
1.	rivet	97.9	1.9	0.13
		97.8	2.0	0.23
	socket	90.9	8.8	0.24
		89.3	10.3	0.39
16.	rivet	97.8	2.0	0.20
		97.7	2.2	0.11
	socket	86.6	13.0	0.44
		87.2	12.4	0.41
Gold oval mounts				
18.	socket	88.1	10.8	1.08
		88.1	11.1	0.79
2.	socket	83.4	15.9	0.63
30.	socket	83.9	15.5	0.62
		81.6	17.2	1.23
	filigree	84.4	14.9	0.65
23.	socket	84.8	14.6	0.65
		84.6	14.8	0.66
17.	socket	81.6	17.8	0.57
29.	socket	86.3	12.8	0.90
		86.0	13.1	0.86
		81.9	17.5	0.63
		82.9	16.5	0.62
		82.6	16.8	0.58
		82.2	17.1	0.71
Gold lunular mounts				
22.	rivet	89.6	10.2	0.26
		89.1	10.6	0.28
3.	rivet	90.0	9.6	0.40
		88.7	10.9	0.38
35.	rivet	90.1	9.5	0.35
		90.6	9.0	0.40
15.	rivet	88.1	11.6	0.32
		88.1	11.6	0.37

It is generally thought that gold objects from the Migration Period with a relatively high gold content were most probably produced by re-melting late Roman gold coins (*solidi*) (Kent, 1972; Arrhenius, 1977; Hawkes, 1984; Oddy and Meyer, 1986; La Niece and Cowell, 2008). However, systematic scientific analyses of gold coins and gold objects have yet to prove it. In the Carpathian Basin, the highest amount of high purity gold was probably available in the form of *solidi* received as Roman tribute (Kiss, 1986; Hardt, 2004; Baumeister, 2004). The analysed objects exhibit lower gold contents; therefore, if Roman coins were used to manufacture the objects, they were then alloyed with silver in order to increase the hardness and durability of the alloy, or the gold was debased for economic reasons. Alternatively, objects with a higher silver content than *solidi* were re-melted and reused, or primary gold-silver ores (*e.g.*, electrum) were used to manufacture the objects. The gold content of the analysed objects is lower than the gold content of previously studied Hunnic-period gold objects from the Carpathian Basin, which are generally characterised with a gold content higher than 90 wt%, sometimes higher than 97 wt% (Horváth, 2013; Szenthe *et al.,* 2019; Horváth *et al.,* 2019; 2022).

3.2 Silver objects

The fragments of the scale-patterned silver plate were manufactured from a high-quality silver alloy (Ag: 94.2–97.0 wt%; Cu: 0.80–1.4 wt%; Au: 1.3–1.6 wt%; Pb: 0.09–0.13 wt%; Bi: 200–300 ppm) (Table 2; Figure 3). This composition corresponds well with the general trend that the beginning of the 5th century AD is characterised with high-quality silver alloys with low Au, Pb, Zn and varying Bi content similar to late Roman silver alloys (Hughes and Hall, 1979; Lang *et al.,* 1984; Cowell and Hook, 2010; Doračić *et al.,* 2015; Lang and Hughes, 2016; Greiff, 2017; Vulić *et al.,* 2017; Mozgai *et al.,* 2020; 2021b; Troalen and Lang, 2022). However, a gradual debasement of silver alloys occurred towards the end of the 5th century (Horváth *et al.,* 2019;

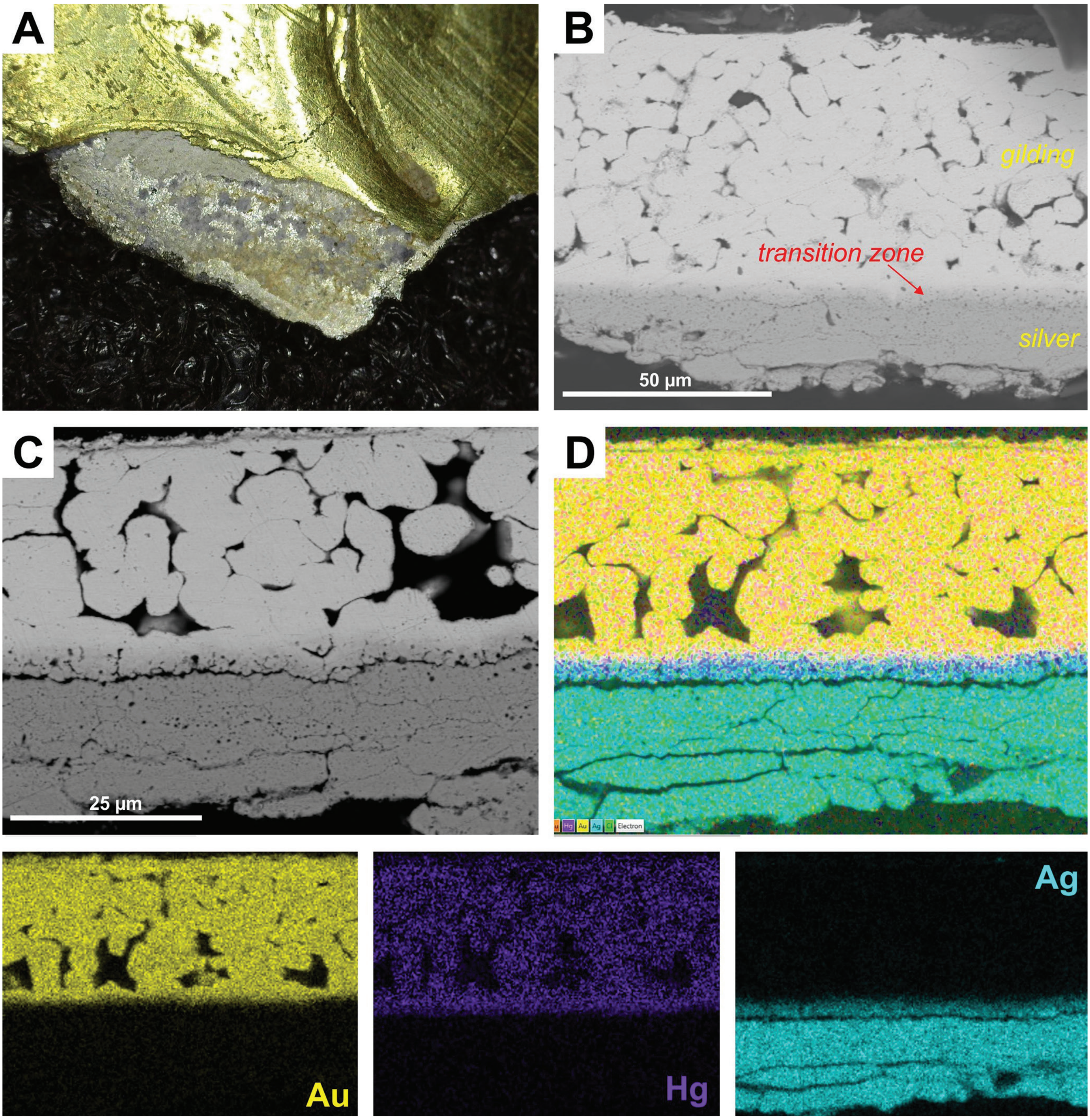

Figure 5. The gilding of the scale-patterned silver plate. A: optical microscopic image of the gilding; B–C: backscattered electron images of the gilding in cross section; D: element distribution maps of the gilded area.

Mozgai *et al.,* 2019; 2021a). Comparing our results to gilded silver plates from other Hunnic-period sacrificial deposits, the silver plate from Nyergesújfalu has a similar silver and copper content to the silver plates from Telki–Anna-lak (Ag: 93.4–97.6 wt%; Cu: 0.9–2.2 wt%) (Szenthe *et al.,* 2019). However, the silver plates from Debrecen–Agrár park and Göd–Bócsaújtelep exhibit a higher copper content (Ag: 90.6–95.0 wt%; Cu: 2.4–4.4 wt%) (Mráv *et al.,* 2021; Piros *et al.,* 2023). The silver plates from Nyíregyháza–Oros corroded completely into silver sulphide, chloride and bromide during burial, and therefore its original chemical composition could not be determined (Piros *et al.,* 2021).

3.3 Gilding

The scale-patterned silver plate was decorated with gilding (Figure 5A). The gold content of the gilded areas is generally above 80 wt%, based on the hXRF measurements, indicating a rather thick gilding (Table 2). The gilding shows a porous microtexture in the BSE images, its thickness reaching to 50–60 micrometres (Figure 5B–C). Mercury was detected in the gilded areas by hXRF and SEM-EDX measurements as well, indicating the use of fire gilding (Figure 6). Previous studies on the objects from the 5th century AD have also proved the use of fire (or mercury) gilding (Craddock *et al.,* 2010; Horváth, 2013; Szenthe *et al.*, 2019; Mozgai *et al.*, 2021a). Fire gilding was most probably invented in China in the 4th century BC, and it then became the standard method of gilding in the 3rd century AD and continued in use throughout the Migration Period and medieval Europe until the invention of electroplating in the mid-19th century (Lechtman, 1971; Lins and Oddy, 1975; Oddy, 1981; 1988; 1991; 1993; 2000).

A few micrometres thick transition zone is present between the gilding and the silver substrate, in which only mercury and silver was detected (silver amalgam) (Figure 5B–D). This special microtexture of the gilding helps to determine the type of fire gilding used. Several types of fire gilding can be distinguished based on recipes and previous analyses on gilded objects (Anheuser, 1997; Oddy, 2000; Giumlia-Mair, 2020; Török and Giumlia-Mair, 2022). In one of the methods, gold was dissolved in hot mercury and the resulting gold amalgam was rubbed on to the cleaned metal surface. Then the object was heated for a few minutes at 250–300 °C (below the boiling point of mercury, 375 °C), until it turned from grey to yellow. It was important to avoid any overheating of the object: if silver is overheated, the gold will discolour or even disappear into the substrate. A firmly bonded, but porous, matte gilded layer will form, which then needs to be burnished. A few micrometres thick mercury enrichment zone can be observed at the gold/silver interface when a paste of gold amalgam is applied, which has a maximum mercury content of less than 25% (Anheuser, 1997). Another method of fire gilding is to apply a layer of mercury to the metal surface to be gilded and then lay pieces of gold leaf on top. The gold leaf dissolves in mercury creating a gold amalgam *in situ*, after which the object is heated and burnished. In this case, the initial coating of the silver substrate with mercury can be inferred from the presence of a 10–15 µm thick layer of silver amalgam with 25–50% mercury underneath the gilding. Mercury is absorbed into the silver as soon as it is applied because of the very high solid solubility of mercury in silver (Anheuser, 1997). When more than one layer of gold leaf is applied, the different layers blend into one and become indistinguishable in cross section (Anheuser, 1997). The spreading of pure mercury before the application of gold leaf can sometimes be observed in those places where the entire area originally coated with mercury was afterward not entirely covered with

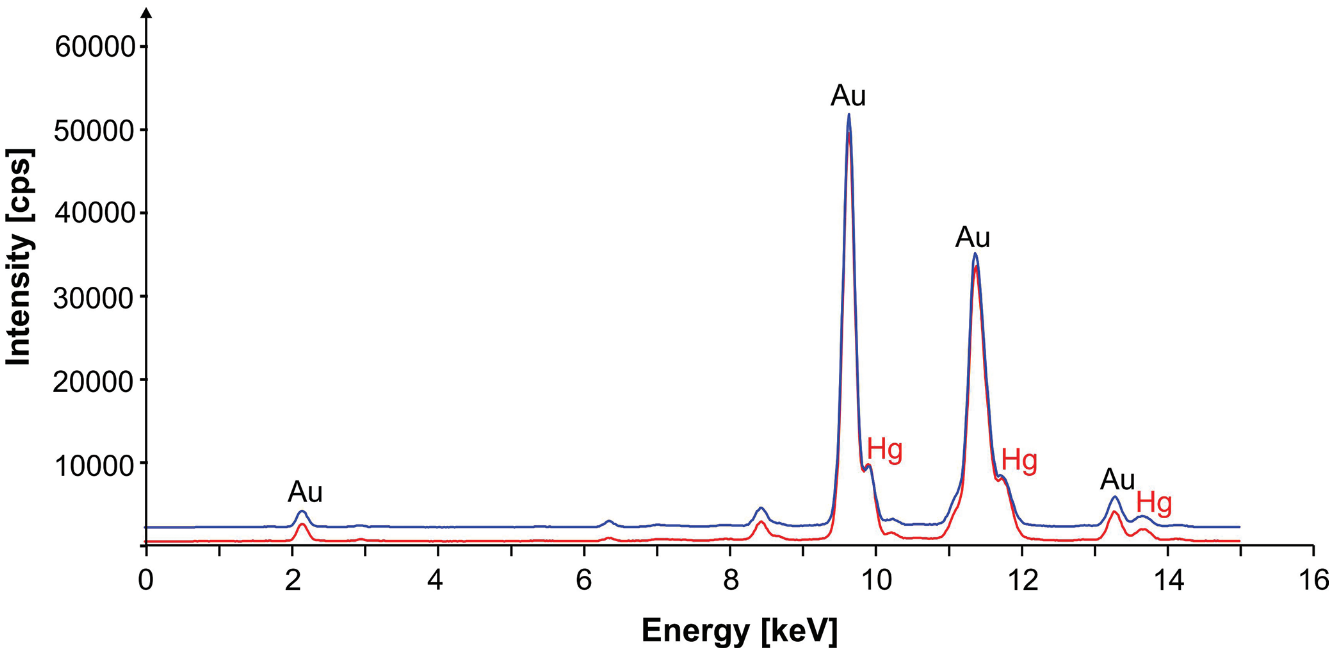

Figure 6. Typical XRF spectra of the gilded areas of the scale-patterned silver plate.

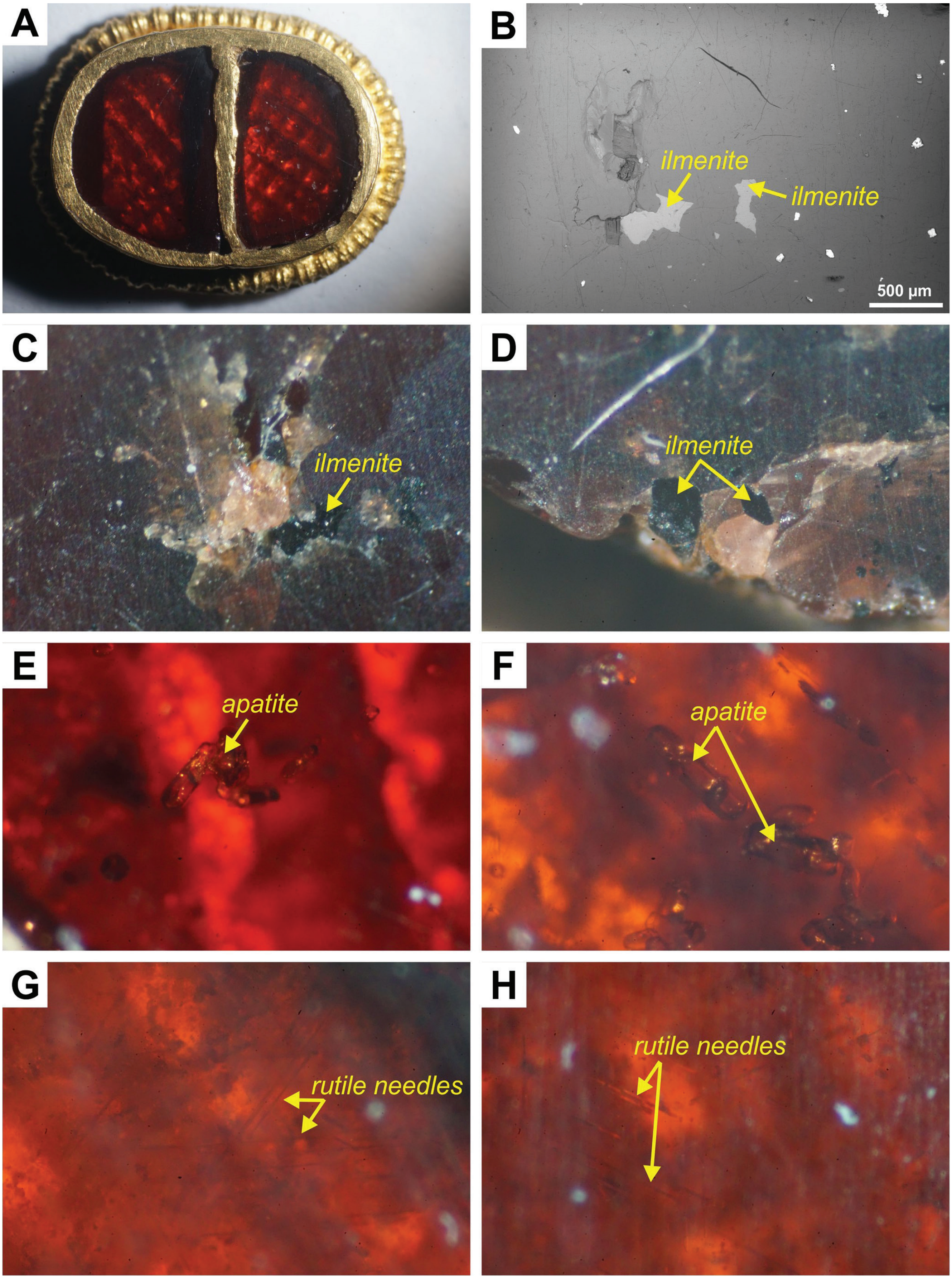

Figure 7. A: cross-hatched backing foils between the garnet slabs and the backing paste; B–H: typical mineral inclusions in the garnets of the studied objects.

Table 4. Chemical composition of the garnet inlays based on the SEM-EDX measurements. The results are given in wt%. The accuracy of the garnet analyses was determined after Locock (2008). Only the "Superior", "Excellent" and "Good" results were used and their averages were calculated. "Fair" and/or "Poor" results were used in those cases where no better-quality data were received (in the case of one garnet, indicated with *). No.: number of analyses used to calculate the average values after Locock (2008).

Description		No. of analyses	SiO_2	Al_2O_3	MgO	FeO	MnO	CaO
Gold buckle								
21.	grt 1	1	39.8	23.2	10.8	20.9	1.14	4.3
	grt 2	12	39.9	23.0	13.0	19.5	0.79	3.8
	grt 3	9	40.1	23.1	12.7	17.9	0.95	5.2
	grt 4	8	39.9	22.9	12.3	19.3	0.54	5.0
Gold suspension rings								
1.	grt 1	5	40.1	23.4	13.1	17.5	0.87	5.0
	grt 2	7	38.5	22.1	6.7	27.9	0.46	4.3
16.	grt 1	1	40.3	23.3	12.3	19.0	0.85	4.2
	grt 2	4	37.9	21.6	6.3	29.6	0.71	3.7
Gold oval mounts								
18.	grt 1	5	39.8	23.2	11.3	19.1	0.99	5.5
	grt 2	4	40.0	23.5	12.7	19.2	0.82	3.7
2.	grt 1	4	40.0	23.1	11.5	19.0	0.97	5.4
	grt 2*	15	41.0	24.0	12.3	17.7	0.72	4.2
30.	grt 1	5	39.4	22.8	9.4	20.8	1.16	6.3
	grt 2	4	40.1	23.1	11.4	19.2	1.00	5.2
23.	grt 1	6	40.2	23.3	12.4	17.6	0.51	5.8
	grt 2	7	39.9	23.2	12.7	18.1	0.79	5.2
17.	grt 1	4	39.7	22.8	13.6	19.0	0.86	3.8
	grt 2	4	39.3	22.6	10.8	20.7	0.96	5.6
29.	grt 1	4	39.7	23.1	11.2	20.0	0.76	5.2
	grt 2	5	40.2	23.2	13.0	18.8	0.74	4.0

gold. In this case, silver amalgam remains on the surface adjacent to the gilded areas (Anheuser, 1997).

As the mercury enriched transition zone is only few micrometres thick, most probably the first type of fire gilding was used to decorate the silver plate from Nyergesújfalu. The silver plates from Telki–Anna-lak and Debrecen–Agrár park were also decorated with fire gilding (Szenthe *et al.,* 2019; Piros *et al.,* 2023), in contrast to the silver plates from Nyíregyháza–Oros and Göd–Bócsaújtelep, where no mercury was detected in the gilded areas (Mráv *et al.*, 2021; Piros *et al.*, 2021). In these latter cases, the use of another type of gilding, namely diffusion bonding is supposed, but further measurements are needed to prove this.

3.4 Garnet inlays

Metalwork objects with red gemstones, identified mostly as garnets, were widespread during the Hellenistic, Roman and Early Medieval times (Arrhenius, 1985; Adams, 2011). Gold objects decorated with gemstones, most often with red garnets, are typical elements of Hunnic-period ritual deposits (Horváth, 2013; Szenthe *et al.,* 2019). Among the analysed objects, the gold buckle was decorated with four garnet inlays, while the suspension rings and the oval mounts were decorated with two garnets each, respectively (Figure 2). The garnets are flat-cut slabs, with carefully polished surfaces. In order to enhance their optical effect, plain or cross-hatched backing foils were placed between them and the backing paste (Figure 7A).

Based on the chemistry, the garnets used for inlays are from the pyralspite (pyrope–almandine–spessartine) series, namely almandine and an intermediate composition of pyrope-almandine garnets with elevated Ca content (Table 4; Figure 8). No ugrandite (uvarovite–grossular–andradite) series garnet was identified. The detected inclusions have been identified based on their morphology and optical features. Rutile needles, large, clear apatite and black opaque ilmenite crystals were observed (Figure 7B–H). These are mainly accessory minerals that are not indicators for the source of the rocks.

The chemical composition of the garnet slabs was compared to the chemical composition of the garnets from

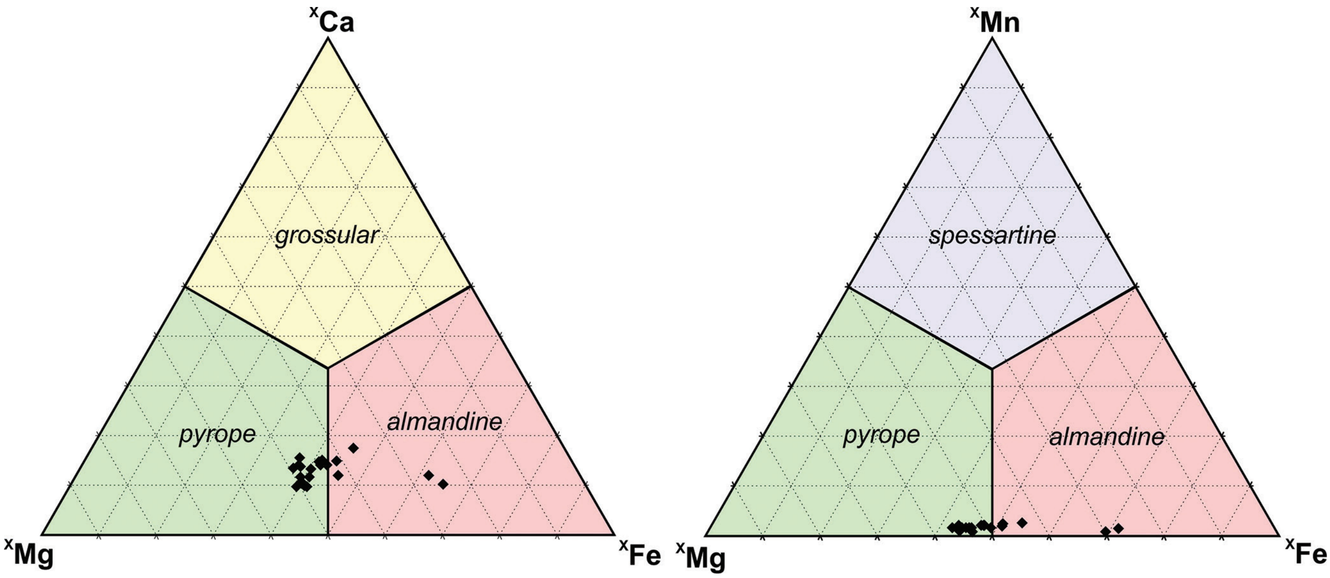

Figure 8. Ternary plots showing the composition of the garnets of the objects based on the cation occupancy of the X site in the garnet structure calculated from the SEM-EDX data (after Grew *et al.*, 2013).

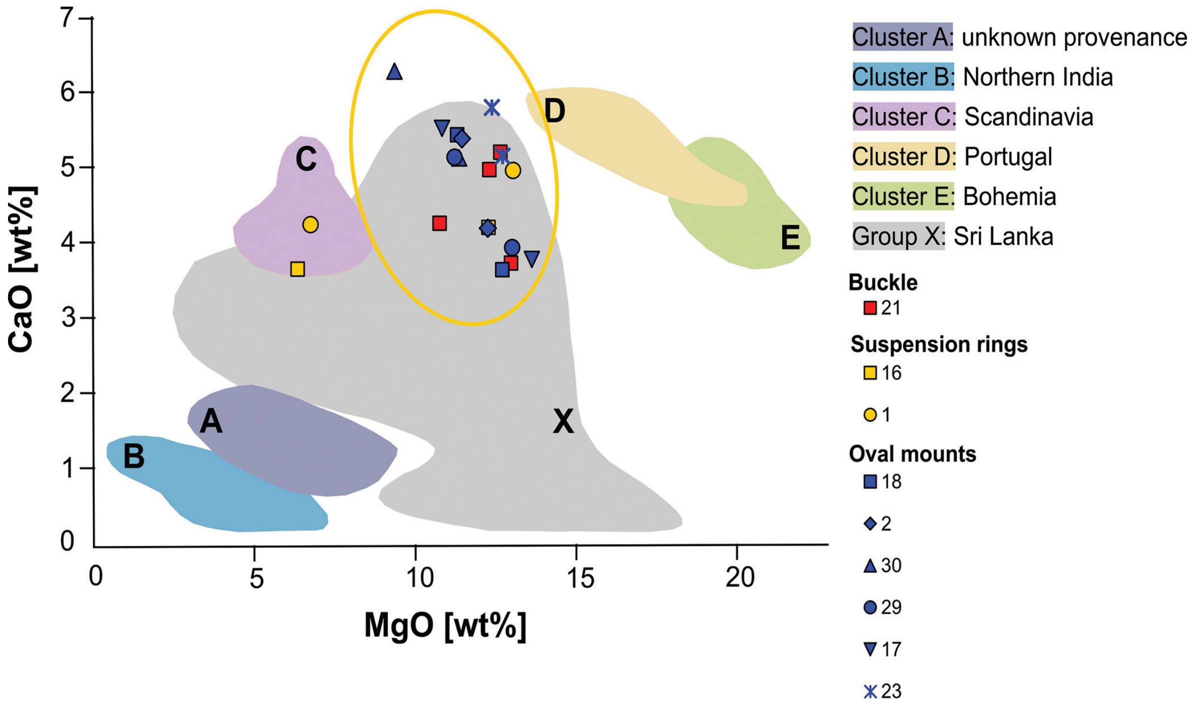

Figure 9. CaO–MgO plot showing the composition of the garnets based on the SEM-EDX measurements. The classification of possible provenances is based on Greiff, 1998; Quast and Schüssler, 2000; Mannerstrand and Lundqvist, 2003; Calligaro *et al.,* 2008; Gilg *et al.,* 2010; 2018. The grey area represents garnets with variable chemical and gemmological characteristics that derive from various, unknown deposits and cover possible new clusters (Then-Obłuska *et al.,* 2021; Nasdala *et al.,* 2023). Yellow circle: Sri Lanka (Anuradhapura or Elahera?) (Calligaro and Périn, 2019; Nasdala *et al.,* 2023).

those deposits, which were certainly known and used in the Migration Period, as attested by the analyses of other contemporaneous objects. The chemical composition and the characteristic inclusion assemblages revealed that European deposits (Portugal and Bohemia) can be excluded as possible sources, as they are characterised with higher Mg and Ca contents (Figure 9). Garnets from Scandinavia (Cluster C) can also be excluded, as they were only of local interest and have different types of mineral inclusions (Gilg and Hyršl, 2014; Then-Obłuska *et al.*, 2021). Based on the results, the analysed garnets belong to Group X (Figure 9). Group X garnets, almandines with an elevated Mg content, were predominant all over Europe during the 5th century AD (Greiff, 1998; Calligaro *et al.,* 2008; Périn and Calligaro, 2016; Gilg *et al.,* 2010; 2018; 2019; Calligaro and Périn, 2019; Then-Obłuska *et al.,* 2021; Nasdala *et al.,* 2023).

Group X garnets were originally thought to derive from the placer deposits of Sri Lanka, known as *Taprobane* in the written sources, but recent studies describe them as garnets with variable compositions and inclusion characteristics that derive from various, unknown deposits but may contain new minor clusters (Greiff, 1998; Calligaro *et al.,* 2008; Gilg *et al.,* 2010; 2018; Then-Obłuska *et al.,* 2021; Nasdala *et al.,* 2023). Recent studies have further classified Group X based on the chemical composition and mineral inclusions of the garnets (Périn and Calligaro, 2016; Calligaro and Périn, 2019; Gilg *et al.*, 2019; Nasdala *et al.,* 2023). Based on their elevated Ca content, the garnets probably originate from Cluster H, the placer deposits of Anuradhapura or Elahera, Sri Lanka (Calligaro and Périn, 2019; Pion *et al.* 2020; Nasdala *et al.,* 2023) (Figure 9). Garnets from Sri Lanka were most likely transported via long-distance maritime trade routes (Roth, 1980; Kessler, 2001; Schmetzer *et al.,* 2017).

4. Conclusion

The gold objects, including their small parts such as rivets of the buckles and lunular mounts, sockets and filigree, were manufactured from a relatively good-quality gold alloy. The rivets, except for the fully corroded silver rivets on the oval mounts, were generally manufactured from a gold alloy with a higher gold content than the sockets and the filigree. If the analysed gold objects were manufactured from Roman gold coins (*solidi*), the gold was alloyed with silver in order to increase the hardness and durability of the alloy or debased due to economic reasons. Re-melted objects with a higher silver content than the coins or primary silver-gold ores could also have been used to manufacture the objects.

The fragments of the scale-patterned silver plate were manufactured from a high-quality silver alloy, similar to late Roman silver alloys characterised with high Ag content. The compositions are similar to the silver plates from Telki–Anna-lak. The scale-patterned silver plate was decorated with fire (mercury) gilding. The type of fire gilding was determined: a gold-amalgam layer was applied to the surface to be gilded, and then it was heated and burnished.

The garnets used for inlays are almandine and intermediate pyrope-almandine garnets. Based on their chemistry, the garnets belong to Group X, the predominant garnet type all over Europe during the 5th century AD, and probably originated from the placer deposits of Cluster H (Anuradhapura or Elahera, Sri Lanka), from where they were most likely transported via long-distance maritime trade routes.

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References

ADAMS, N., 2011. The Garnet Millennium: The Role of Seal Stones in Garnet Studies. In: C. Entwistle, and N. Adams, eds. *"Gems of Heaven:" Recent Research on Engraved Gemstones in Late Antiquity c. AD 200–600.* British Museum Research Publication, 177. London: Trustees of the British Museum, pp. 10–24.

ANHEUSER, K., 1997. The Practice and Characterization of Historic Fire Gilding Techniques. *The Journal of The Minerals, Metals & Materials Society*, 49, 58–62.

ARRHENIUS, B., 1977. Metallanalysen von Goldbrakteaten. Vorbericht über ein laufendes Forschungsprojekt. *Frühmittelalterliche Studien,* 11, 74–84.

ARRHENIUS, B., 1985. *Merovingian Garnet Jewellery. Emergence and social implications*. Stockholm: Almqvist & Wiksell.

BAKAY, K., 1978. Bestattung eines vornehmen Kriegers vom 5. Jahrhundert in Lengyeltóti (Komitat Somogy, Kreis Marcali). *Acta Archaeologica Academiae Scientiarum Hungaricae*, 30, 149–172.

BAUMEISTER, M., 2004. *Metallrecycling in der Frühgeschichte. Untersuchungen zur technischen, wirtschaftlichen und gesellschaftlichen Rolle sekundär Metallverwertung im 1. Jahrtausend n. Chr*. Rahden: VML Verlag Marie Leidorf.

BENDŐ, Z., OLÁH, I., PÉTERDI, B., SZAKMÁNY, G., HORVÁTH, E., 2013. Csiszolt kőeszközök és ékkövek roncsolásmentes SEM-EDX vizsgálata: lehetőségek és korlátok / Non-destructive SEM-EDX analytical method for polished stone tools and gems: opportunities and limitations. *Archeometriai Műhely*, 10(1), 51–61.

BÓNA, I., 1991. *Das Hunnenreich*. Budapest: Corvina Kiadó.

BÓNA, I., 1993. *A hunok és nagykirályaik*. Budapest: Corvina Kiadó.

CALLIGARO, T., and PÉRIN, P., 2019. Le commerce des grenats à l'époque mérovingienne. *Archéopages,* 5, 109–120.

CALLIGARO, T., PÉRIN, P., VALLET, F., and POIROT, J.-P., 2008. Contribution à l'étude des grenats mérovingiens (Basilique de Saint-Denis et autres collections du musée d'Archéologie nationale, diverses collections publiques et objets fouilles récentes). *Antiquités Nationales*, 38, 111–144.

COWELL, M., and HOOK, D., 2010. The analysis of the metal artefacts. In: C. Johns, ed. *The Hoxne Late Roman Silver Treasure: gold jewellery and silver plate.* London: British Museum Press, pp. 175–183.

CRADDOCK, P., COWELL, M., HOOK, D., HUGHES, M., LA NIECE, S., and MEEKS, N., 2010. Change and stasis: the technology of Dark Age metalwork from the Carpathian Basin. *The British Museum Technical Research Bulletin*, 4, 55–65.

DORAČIĆ, D., LANG, J., and FLETCHER, P., 2015. Late Roman silver hoard from Vinkovci, Croatia – a preliminary technological overview. *Historical Metallurgy*, 49(2), 87–95.

FEHR, H., 2003. Bemerkungen zum völkerwanderungszeitlichen Grabfund von Fürst. *Bericht der Bayerischen Bodendenkmalpflege*, 43/44, 209–228.

GILG, H.A., GAST, N., and CALLIGARO, T., 2010. Vom Karfunkelstein. In: L. Wamser, ed. *Karfunkelstein und Seide. Neue Schätze aus Bayerns Frühzeit.* Ausstellungskataloge der Archäologischen Staatssammlung, 37. München: F. Pustet, pp. 87–100.

GILG, H.A., and HYRŠL, J., 2014. Garnet mines in Europe. In: J. Toussaint, ed., *Rouges et noirs, rubis, grenat, onyx, obsidienne et autres minéraux rouges et noirs dans l'art et l'archéologie*. Namur: Société archéologique de Namur, pp. 145–173.

GILG, H.A., SCHMETZER, K., and SCHÜSSLER, U., 2018. An Early Byzantine Engraved Almandine from The Garibpet Deposit, Telangana State, India: Evidence for Garnet Trade Along the Ancient Maritime Silk Road. *Gems & Gemology*, 54(2), 149–165.

GILG, H.A., SCHÜSSLER, U., KRAUSE. J., and SCHULZ, B., 2019. The use of phosphate inclusions in origin determination of ancient and medieval garnets. In: *36th International Gemmological Conference – Book of Abstracts*, Nantes: IGC, pp. 41–43.

GIUMLIA-MAIR, A., 2020. Plating and Surface Treatments on Ancient Metalwork. *Advances in Archaeomaterials*, 1, 1–26.

GREIFF, S., 1998. Naturwissenschaftliche Untersuchungen zur Frage der Rohstein-quellen für frühmittelalterlichen Almandingranatschmuck rheinfränkischer Provenienz. *Jahrbuch des Römisch-Germanisches*

Zentralmuseums, 45(2), 599–646.

GREIFF, S., 2017. Chemisch-analytische Untersuchungen der Trierer Silberkanne. In: A. Kaufmann-Heinimann, and M. Martin, eds. *Die Apostelkanne und das Tafelsilber im Hortfund von 1628. Trierer Silberschätze des 5. Jahrhunderts.* Trier: Rheinisches Landesmuseum, pp. 158–170.

GREW, E.S., LOCOCK, A.J., MILLS, S.J., GALUSKINA, I.O., GALUSKIN, E.V., and HÅLENIUS, U., 2013. IMA Report: Nomenclature of the garnet supergroup. *American Mineralogist*, 98, 785–811.

HARDT, M., 2004. *Gold und Herrschaft. Die Schätze europäischer Könige und Fürsten im ersten Jahrtausend*. Berlin: Akademieverlag.

HAWKES, S.C., 1984. The Amherst Brooch. *Archaeologia Cantiana*, 101, 129–151.

HORVÁTH, E., 2013. Gemstone and glass inlaid fine metalwork from the Carpathian Basin: the Hunnic and Early Merovingian Periods. *Dissertationes Archaeologicae ex Instituto Archaeologico Universitatis de Rolando Eötvös nominatae*, 3(1), 275–302.

HORVÁTH, E., MOZGAI, V., MAY, Z., and BAJNÓCZI, B., 2022. Hun kori örökség – a nagyváradi polikróm aranycsüngő / Inherited from the Hunnic Period – the polychrome gold pendant from Nagyvárad (Oradea). *Archeometriai Műhely*, 19(2), 155–174.

HORVÁTH, E., MOZGAI, V., TOPA, B., SZABÓ, M., and BAJNÓCZI, B., 2019. Fine metalwork between two periods: tracing changes in goldsmithing tradition and craft organisation in the mid-to-late 5th-century Carpathian Basin by the investigation of polychrome goldsmiths' works. In: *5th International Conference Archaeometallurgy in Europe 2019 – Book of Abstracts*. Miskolc: University of Miskolc, p. 23.

HUGHES, M.J., and HALL, J.A., 1979. X-ray fluorescence analysis of Late Roman and Sassanian silver plate. *Journal of Archaeological Science*, 6, 321–344.

KELEMEN, M., 2008. *Solva. Esztergom későrómai temetői / Solva. Die spätrömischen Gräberfelder von Esztergom*. Libelli Archaeologici Seria Nova, 3. Budapest: Hungarian National Museum.

KENT, J.P.C., 1972. Gold standards of the Merovingian coinage, A.D. 580–700. In: E. Hall, and D.M. Metcalf, eds. *Methods of chemical and metallurgical investigation of ancient coinage*. Royal Numismatic Society Special Publication, 8. London: Royal Numismatic Society, pp. 69–74.

KESSLER, O., 2001. Der spätantik-frühmittelalterliche Handel zwischen Europa und Asien und die Bedeutung des Almandins als Fernhandelsgut. In: E. Pohl, U. Recker, and C. Theune, eds. *Archäologisches Zellwerk: Beiträge zur Kulturgeschichte in Europa und Asien. Festschrift für Helmut Roth zum 60. Geburtstag*. Internationale Archäologie, Studia honoraria, 16. Rahden: VML Verlag Marie Leidorf, pp. 113–128.

KISS, A., 1986. Die Goldfunde des Karpatenbeckens von 5–10. Jh. (Angaben zu den Vergleichsmöglichkeiten der schriftlichen und archäologischen Quellen). *Acta Archaeologica Academiae Scientiarum Hungaricae,* 38, 105–145.

LANG, J., and HUGHES, M., 2016. The Mildenhall Treasure: Technical Aspects of Construction and Decoration. In: R. Hobbs, ed. *The Mildenhall Treasure: Late Roman Silver Plate from East Anglia*. London: British Museum Press, pp. 240–249.

LANG, J. HUGHES, M.J., and ODDY, W.A., 1984. Report on the Scientific Examination of the Sea City Dish 62, the Achilles Dish 63 and some other Items. In: H.A. Cahn, and A. Kaufmann-Heinimann, eds. *Der spätrömische Silberschatz von Kaiseraugst*. Derendingen: Basler Beiträge zur Ur- und Frühgeschichte, 19, pp. 375–381.

LA NIECE, S., and COWELL, M., 2008. Crimean Metalwork. Analysis and Technical Examination. In: D. Kidd, and B. Ager, eds. *The Berthier-Delagarde Collection of Crimean Jewellery in the British Museum and Related Material*. British Museum Research Publication, 166. Oxford: British Museum Press, pp. 151–160.

LECHTMAN, H.N., 1971. Ancient Methods of Gilding Silver: Examples from the Old and the New Worlds. In: R.H. Brill, ed. *Science and Archaeology*, Cambridge: Cambridge University Press, pp. 2–30.

LEUSER, J., 1949. Über die Besonderheiten der Edelmetalllegierungen im Schmuckgewerbe. *Metall,* 3, 105–110.

LINS, P.A., and ODDY, W.A., 1975. The Origins of Mercury Gilding. *Journal of Archaeological Science,* 2, 365–373.

LOCOCK, A.J., 2008. An Excel spreadsheet to recast analyses of garnet into end-member components, and a synopsis of the crystal chemistry of natural silicate garnets. *Computers & Geosciences*, 34, 1769–1780.

MANNERSTRAND, M., and LUNDQVIST, L., 2013. Garnet chemistry from the Slöinge Excavation, Halland and additional Swedish and Danish excavations – comparisons with Garnet Occurring in a Rock Context. *Journal of Archaeological Sciences,* 30(2), 169–183.

MOZGAI, V., BAJNÓCZI, B., MAY, Z., and MRÁV, ZS., 2020. A hordozható XRF alkalmazási lehetőségei és korlátai római ezüsttálak archeometriai vizsgálatában / Possibilities and limitations of the use of handheld XRF in the archaeometric study of Roman silver platters. *Archeometriai Műhely*, 17(3), 253–270.

MOZGAI, V., BAJNÓCZI, B., MAY, Z., and MRÁV, ZS., 2021b. Non-destructive handheld XRF study of archaeological composite silver objects – the case study of the late Roman Seuso Treasure. *Archaeological and Anthropological Sciences*, 13(5), 83.

MOZGAI, V., HORVÁTH, E., and BAJNÓCZI, B., 2021a. Possibilities and limitations of non-invasive analytical methods in the examination of garnet- and niello-inlaid precious metal objects – case study of three polychrome animal-style silver buckles from the 5th-century Carpathian Basin. *Interdisciplinaria Archaeologica – Natural Sciences in Archaeology,* 12(1), 45–67.

MOZGAI, V., HORVÁTH, E., MIHÁCZI-PÁLFI, A., HAJNAL, ZS., and BAJNÓCZI, B., 2019. Metal composition and decoration techniques of polychrome gold and gilded silver brooches from the 5th-century AD Carpathian Basin. In: *YRA 2019.* Paris: Maison Archéologie–Ethnologie (MAE, Nanterre), p. 1.

MRÁV, ZS., MOZGAI, V., and BÁRÁNY, A., 2021. Fragments of silver-gilt saddle plates and horse bones buried in a Late Roman ditch at Göd (Pest County, Hungary). Contributions to the funerary sacrifice deposits and „horse skin" rituals of the Hun period. In: Zs. Rácz, and G. Szenthe, eds. *Attila's Europe? Structural transformation and strategies of success in the European Hun period*. Budapest: Hungarian National Museum, Eötvös Loránd University, pp. 449–475.

NASDALA, L., LAMERS, T., GILG, H.A., CHANMUANG N., C., GRIESSER, M., KIRCHWEGER, F., ERLACHER, A., BÖHMLER, M., and GIESTER, G., 2023. The Imperial Crown of the Holy Roman Empire, Part I: Photoluminescence and Raman Spectroscopic Study of the Gemstones. *The Journal of Gemmology*, 38(5), 448–473.

ODDY, A., 1981. Gilding Through the Ages – An Outline History of the Process in the Old World. *Gold Bulletin*, 14(2), 75–79.

ODDY, W.A., 1988. The gilding of Roman silver plate. In: F. Baratte, and N. Duval, eds. *Argenterie romaine et byzantine: actes de la table ronde, Paris 11–13 octobre 1983. Archéologie de l'antiquité tardive*. Paris: De Boccard, pp. 9–21.

ODDY W.A., 1991. Gilding: an outline of the technological history of the plating of gold on to silver or copper in the Old World. *Endeavour, New Series*, 15(1), 29–33.

ODDY, A., 1993. Gilding of metals in the Old World. In: S. La Niece, and P. Craddock, eds. *Metal Plating and Patination – Cultural, Technical and Historical Developments*. Oxford: Butterworth-Heinemann Ltd., pp. 171–181.

ODDY, A., 2000. A History of Gilding with Particular Reference to Statuary. In: T. Drayman-Weisser, ed. *Gilded Metals – History, Technology and Conservation*. London: Archetype Publications, pp. 1–19.

ODDY, W.A., and MEYER, V.E.G., 1986. The analysis of the gold finds from Helgö and their relationships to other Early Medieval gold. In: A. Lundström, and H. Clarke, eds. *Excavations at Helgö X. Coins, Iron and Gold. Kungl*. Stockholm: Vitterhets Historie och Antikvitets akademien, pp. 153–178.

PÉRIN, P., and CALLIGARO, T., 2016. Note sur l'origine des grenats utilisés par les orfèvres du haut Moyen Âge occidental européen. In: A. Bollók, G. Csíky, and T. Vida, eds. *Between Byzantium and the steppe: archaeological and historical studies in honour of Csanád Bálint on the occasion of his 70th birthday*. Budapest: Institute of Archaeology, Research Centre for the Humanities, Hungarian Academy of Sciences, pp. 75–86.

PION, C., GRATUZE, B., PÉRIN, P., and CALLIGARO, T. 2020. Chapter 36. Bead and garnet trade between the Merovingian, Mediterranean, and Indian Worlds. In: B. Effros, and I. Moreira, eds. *The Oxford Handbook of the Merovingian World*. New York: Oxford University Press, pp. 819–859.

PIROS, R.Á., MOZGAI, V., and BAJNÓCZI, B., 2021. New results on horse trappings from the Hunnic-period Carpathian Basin based on non-destructive archaeometric analyses. *Archaeologia Baltica*, 28, 25–38.

PIROS, R.Á., MOZGAI, V., and BAJNÓCZI, B., 2022. Hun kori lószerszámveretek új régészeti és archeometriai eredményei Árpás, Pannonhalma, Zugló és Szederkény lelőhelyekről / New archaeological and archaeometric results of Hunnic-period horse tacks from Árpás, Pannonhalma, Zugló and Szederkény. *Archeometriai Műhely,* 19(2), 137–154.

PIROS, R.Á., MOZGAI, V., BAJNÓCZI, B., NAGY, E.GY., and WIESZNER, B., 2023. A Debrecen–Agrár parki lószerszámzatok archeometriai vizsgálatának előzetes eredményei / Archaeometric study of the horse tacks from Debrecen–Agrár park: preliminary results. In: A. Türk, B. Jancsik, and B. Sudár, eds. *HADAK ÚTJÁN. A népvándorláskor kutatóinak XXIX. konferenciája. Budapest, 2019. november 15–16. 29th Conference of scholars on the Migration Period. November 15–16, 2019, Budapest: 2. kötet*. Budapest: Bölcsészettudományi Kutatóközpont Magyar Őstörténeti Kutatócsoport, Pázmány Péter Katolikus Egyetem, BTK Régészettudományi Intézet, Martin Opitz Kiadó, pp. 201–215.

QUAST, D., and SCHÜSSLER, U., 2000. Mineralogische Untersuchungen zur Herkunft der Granate merovingzeitlicher Cloisonnéarbeiten. *Germania,* 78, 75–96.

ROTH, H., 1980. Almandinhandel und -verarbeitung im Bereich des Mittelmeeres. Zum archäologischen Befund und der schriftlichen Überlieferung in der Spätantike und in frühen Mittelaltern. *Beiträge zur allgemeinen und vergleichenden Archäologie*, 2, 309–335.

SCHILLING, L., 2022. Among the oak tree's roots, under the pocket watch. Hunnic-period assemblage from the outskirts of Nyergesújfalu. *Hungarian Archaeology E-Journal*, spring 2022, 36–42.

SCHMETZER, K., GILG, H. A., SCHÜSSLER, U., PANJIKAR, J., CALLIGARO, T., and PÉRIN, P., 2017. The linkage between garnets found in India at the Arikamedu historical site and their source at the Garibpet deposit. *The Journal of Gemmology*, 35(7), 589–627.

SZENTHE, G., MOZGAI, V., HORVÁTH, E., and BAJNÓCZI, B., 2019. Ritual deposit from the Hun period from Telki (Central Hungary) – A preliminary report. *Hungarian Archaeology E-Journal*, spring 2019, 9–19.

THEN-OBŁUSKA, J., GILG, H.A., SCHÜSSLER, U., and WAGNER, B., 2021. Western connections of Northeast Africa. The garnet evidence from late antique Nubia, Sudan. *Archaeometry*, 63(2), 227–246.

TOMKA, P., 1986a. A sztyeppei temetkezési szokások sajátos változata. A hun halotti áldozat. / Die eigenartige Variante der Begrabungsgewohnheiten von den Steppen. Das hunnische Totenopfer. *Arrabona*, 22–23, 35–55.

TOMKA, P., 1986b. Der hunnische Fürstenfund von Pannonhalma. *Acta Archaeologica Academiae Scientiarum Hungaricae*, 38, 423–488.

TÖRÖK, B., and GIUMLIA-MAIR, A., 2022. Examination of Metal Finds from the 10th Century Cemetery of Kiskunfélegyháza (Hungary). *Interdisciplinaria Archaeologica – Natural Sciences in Archaeology*, 13(2), 163–177.

TROALEN, L., and LANG, J., 2022. The technology of the Traprain Treasure. In: F. Hunter, A. Kaufmann-Heinimann, and K. Painter, eds. *The Late Roman Silver Treasure from Traprain Law*. Edinburgh: NMSE-Publishing Ltd., pp. 315–328.

VULIĆ, H., DORAČIĆ, D., HOBBS, R., and LANG, J., 2017. The Vinkovci treasure of Late Roman silver plate: preliminary report. *Journal of Roman Archaeology*, 30, 127–150.