Analytical Report on a Selection of Finger-Rings from Late Iron Age Context in Bohemia

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ABSTRACT
The paper presents results of technological analyses executed on selected finger-rings prevalently from the Stradonice oppidum. Analysed were the elementary composition of the metal parts of the finger rings; the technology employed for the manufacturing of the metal parts and for the setting of the gems in the bezels; as well as the material of the inlays.

KEYWORDS
Finger ring; Roman; gem; XRF; SEM/EDS; bronze alloy; brass; amber.

MATERIAL AND OBJECTIVES

The study included 28 metal finger-rings, the majority from the site of Stradonice and nowadays kept in the collection of the National Museum in Prague (**Tab. 1**). The work focused on ascertaining the state of preservation of the single pieces and on the determination of the elementary composition of both their metallic parts and the inlays with the objective of defining the production technology and making more precise some points concerning the provenance of the rings. Moreover, imprints of the images depicted on the gems have been made in order to facilitate their iconographic and stylistic analysis.

The rings featured various degrees of deterioration. All of them were affected by corrosion ranging from superficial to structurally destructive and concerning both the metallic parts and the inlays. Some of the rings were broken; some of these were reconsolidated in the past with excessive quantities of cement which disfigured their original shape. The inlays of many rings are not preserved. We took advantage of the fragmentary state of the rings using the points of fracture for measuring the elementary composition of the metal alloys not only on the surface but also in the objects' cores. Thanks to the absence of several inlays we could study the technology of their attachment to the bezel and in some cases the materials placed beneath them. In what follows we refer to the single pieces by the catalogue numbers used in the archaeological part of the study (Kysela 2016).

THE ANALYTICAL METHODS

XRF SPECTROMETRY

This method is based on measuring the characteristic secondary X-ray radiation emitted by the sample. It enables the ascertainment of the elements present in the sample and also – by means of intensity analysis – of their mutual quantitative proportion (Novotná – Karhan – Pechová 2001; Hložek *et al*. 2005).

Cat. n°	inv. n° (NM-H1)	metal	inlay	analytic method
K1	–	Ag /Cu/Sn	Glass	XRF, SEM/ EDX
S1	80264	Brass	–	XRF
S2	80265	Brass	–	XRF
S8	81575	Brass	–	XRF
S9	81576	Brass	Glass	XRF
S10	81577	Brass	Glass	XRF, SEM/ EDX
S11	81578	Brass	Glass	XRF
S12	81580	Brass	Glass	XRF
S13	81581	Brass	–	XRF, SEM/ EDX
S14	81582	Brass	Glass	XRF
S15	81583	Brass	–	XRF
S16	81599	Brass	Stone	XRF
S17	81601	Fe	–	XRF
S18	81602	Fe	Stone/ Glass?	XRF
S19	81603	Fe	Glass	XRF
S20	81604	Fe	Glass	XRF
S21	81605	Fe	–	XRF
S22	81606	Fe	Amber	XRF, IR
S23	81607	Fe	Glass	XRF
S24	81608	Fe	–	XRF
S25	81609	Fe	Amber?	XRF, IR
S26	105608	Brass	Glass	XRF, SEM/ EDX
S27	105628	Brass?	Glass	XRF, SEM/ EDX
S?2	26422	Fe	Stone	XRF
Sx1	81579	Mixed	–	XRF
Sx2	81600	Gilded Ag	Glass	XRF
Sx3	105609	Bronze	–	XRF
Sx4	212676	Mixed	Amber	XRF

Tab. 1: The analysed pieces and the analyses executed on them.

The elementary composition of the metallic parts of the finger-rings was analysed primarily by a portable XRF spectrometer Delta Professional (produced by BAS Rudice), in the mode "analytic plus" in the case of the metallic parts and in the mode "geochem" in the case of the inlays. The measurements were taken with the use of a 3 mm ray collimator in two subsequent steps: in the case of the metallic parts 20 kV/20 sec > 40 kV/20 sec, and in the case of inlays, requiring a longer measuring time due to the presence of light elements, 20 kV/30 sec > 20 kV/ 90 sec the measurements were taken on the objects' surfaces and the results may therefore be biased due to locally present corrosive products. For this reason, the quantitative measurements were taken only after cleaning the objects' surfaces and the presented results are only average values of several measurements. In the case of the non-metallic parts, the presented results must be considered only roughly indicative due to the high proportion of light elements which are difficult to measure by portable analysers.

SCANNING ELECTRON MICROSCOPY WITH ENERGY-DISPERSIVE DETECTOR (SEM/EDS)

Selected rings (cat. nos. K1, S8, S11, S17, S20, S26, S27) were further analysed by electron microscopy with elementary composition measured by means of an EDX detector. The electron microscope JEOL JSM-6490LV used for our analysis was fitted with the EDX detector Oxford Instruments INCA X-ACT. The accelerating potential was set at 15 kV. The measurements were taken on miniature samples. Sampling the artefacts was indispensable for the successful implementation of the analysis which requires the application of an irremovable conductive layer, hardly imaginable on the fragile and complexly shaped rings. The samples were placed in the device in such a way as to allow the study of both the uncorroded core and of the surface.

The measurements were made in cooperation with I. Macek in the Department of Mineralogy and Petrography of the Natural History Museum, the National Museum in Prague.

IR SPECTROMETRY

The inlays of two of the studied rings (S22 and S25) seemed – according to macroscopic observation – to be made of amber. Miniature samples were taken from crevices in the inlays in order to be analysed by means of IR spectrometry, which would not only permit one to determine if the material is actually amber, but also to ascertain its probable origin with more precision.

As is well known, the geographic origin of amber can be determined by means of molecular spectroscopy. For example Baltic amber can be distinguished in the IR spectra by its specific spectral characteristic, the so-called "Baltic shoulder" due to the presence of the succinic acid and its esters (Giuliano 2007; Shashouna 2002).

The samples were analysed by means of IR-spectroscopy by ATR in the FTIR spectrometer Nicolet 6700 (Thermo-Nicolet, USA) with the following measurement parameters: spectral range 4000–650 cm^{-1}, resolution 4 cm^{-1}, number of spectral accumulations 128, apodisation Happ-Genzel. The resulting IR spectrum was processed by the Omnic program and interpreted using the new methodical report for archaeological ambers (Tisucká – Ohlídalová 2013). The measurements were taken by M. Ohlídalová, National Museum in Prague.

GEM IMPRINTS AND OPTICAL MICROSCOPY

The majority of the preserved inlays bears a negative image. In order to facilitate their stylistic and iconographic analysis (cf. Kysela 2016) their positive casts were executed. The positive relief allows one to make details out more clearly and the white colour of the imprints supresses the visually disturbing chromatic effects, reflections and superficial corrosion of the originals. The imprints were taken from cleaned inlays before the cleaning of the metallic parts and after separation by a layer of cyclododecane which prevented the casting substance from leaking deep into the body of the inlay. As the casting substance we used the synthetic rubber Lukopren N1522 (produced by Lučební závody, a.s. Kolín). The gems and their casts were studied and photographed through the stereomicroscope Olympus.

The material of the inlays was determined by P. Burdová in the Department of Mineralogy and Petrography of the Natural History Museum, the National Museum in Prague by means of polarized gemologic microscope GIAGEM Instruments with Leica optics.

ANALYSES OF THE INDIVIDUAL PIECES

K1 The inlay is made of glass. The metallic part is made of an alloy of silver (ca. 63 %), tin (ca. 31 %) and copper (ca. 5 %). The surface XRF measurements have detected relatively high proportions of gold and also traces of iron, mercury and lead. None of these elements was, however, confirmed by the EDX analysis. Most probably, the finger-ring was originally gold-plated; the EDX measurements were probably taken in spots, where the surface deterioration removed all the remains of the gilding. The blackened surface is caused by oxidation as indicated by higher proportions of oxide. Given the absence of sulphur in the surface layer, the darkening was not caused by the typical reaction with sulphuric pollutants but with oxide and humidity reacting with copper probably producing the corrosive interlayer too (**Fig. 1**).

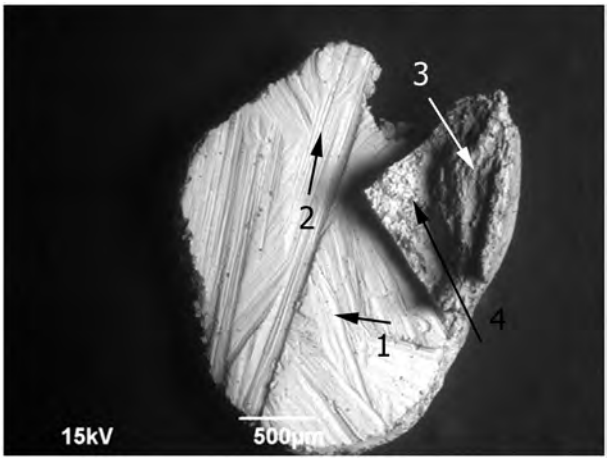

Fig. 1: K1 – the SEM photograph of the analysed sample. The arrows indicate the different points where measurements were taken (photo by the author).

S8 The gem of this ring is not preserved. The gem setting, nevertheless, features a very well preserved underlying layer meant to enhance though its reflexion the luminosity of the gem itself (**Pl. 4/1:S6a**). This ground layer, into which the gem had been set, was preserved thanks to conservation through varnishing shortly after the ring was unearthed. Unfortunately, due to its general fragility, this intervention could not be removed and the exact nature of the ground layer could not be analytically investigated. The ground matter was examined under optic and electron microscope (**Fig. 2**) and can be determined as a two-layer metal leaf without an organic support. The ground layer is made of silver, probably of partially melted silver filings covered by a layer of gilding (**Pl. 4/1:S6b**, **Fig. 2 right**). Apart from these two metals, sulphur and carbon have been detected, most probably as the result of melting.

The metallic part of the ring is made of a brass alloy consisting of 90 % copper and 10 % zinc (excluding the elements resulting from surface corrosion, such as Al and Si). No surface treatment of the metal has been detected.

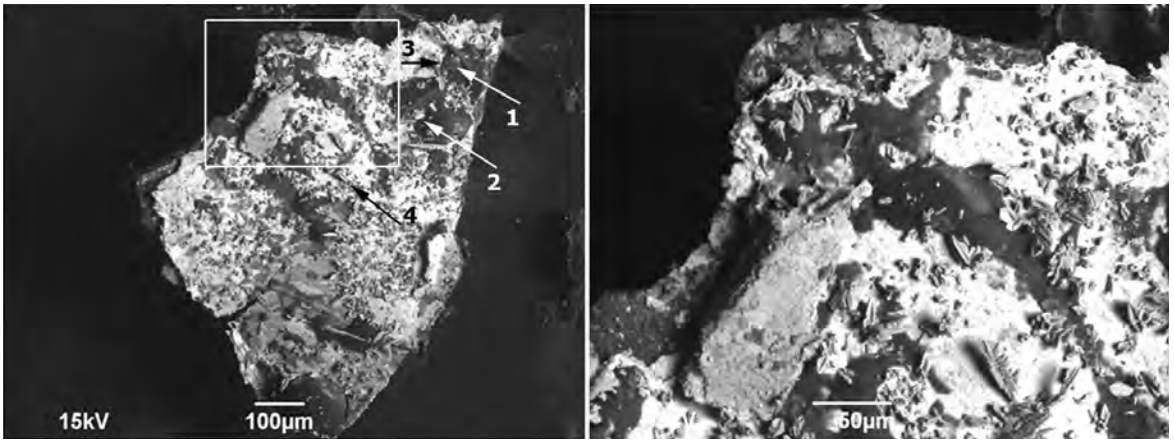

Fig. 2: S8 – Left: the SEM photograph of the analysed sample. The arrows indicate the different points where measurements were taken. Right: detail of the insufficiently melted silver filings (photo by the author).

S11 The glass inlay is preserved firmly set in the bezel though in comparison with other rings it protrudes markedly over the level of the relatively low bezel frame (whose present height corresponds to the original shape of the object and is not due to loss of material caused by corrosion). The gem's circumference was clearly cut in order to fit the narrow frame (**Fig. 3c**).

The XRF surface measurements determined the alloy as brass with (apart from Cu and Zn) the presence of Fe, P and Pb, and traces of Ag and Hg. The SEM/EDX analyses found that the metallic core was plated with a surface layer on another alloy (**Fig. 3a–b**). The core is made of

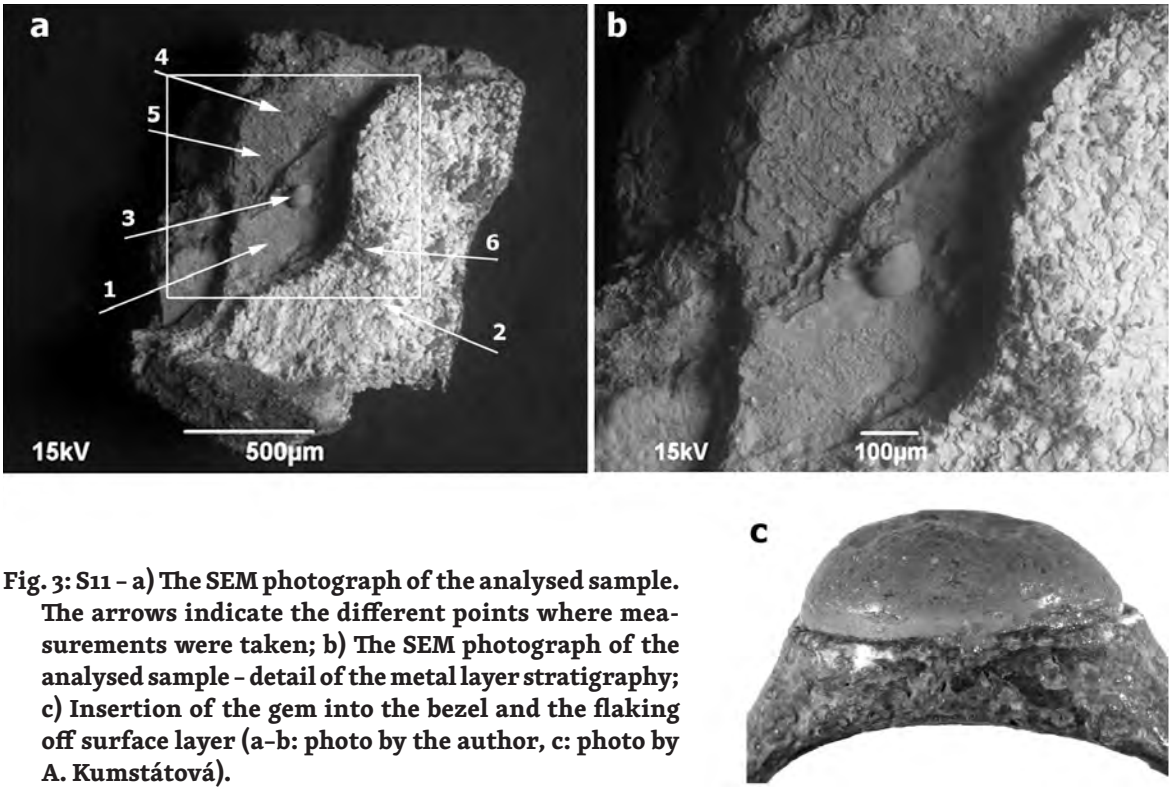

Fig. 3: S11 – a) The SEM photograph of the analysed sample. The arrows indicate the different points where measurements were taken; b) The SEM photograph of the analysed sample – detail of the metal layer stratigraphy; c) Insertion of the gem into the bezel and the flaking off surface layer (a–b: photo by the author, c: photo by A. Kumstátová).

an alloy of Cu, Zn and a small amount of Sn (in the ratio 12:5:1) and the measured points also produced a fair representation of the elements resulting from corrosion, such as Si, P, Ca and S. Silver was not detected by this method. The surface layer (also heavily corroded) is made of a different brass without the presence of tin, unlike the core with the presence of Sn and a higher amount of Cl^- ions (3.15 wt.%). In the interlayer between the core and the surface layer elements related to corrosion damage were detected. The corrosion products of copper expand and lead to the flaking of the surface layers. Apart from these features, the surface consists only of oxidised copper, which is caused by its higher reactivity and efflorescence formation.

S17 Thanks to the absence of a gem, its setting in the bezel of the iron ring could be studied in detail. In the central part of the bezel, heavy corrosion is macroscopically observable, including soft corrosive products of iron and organic remains, perhaps of an adhesive by means of which the gem was glued inside the bezel (**Pl. 4/1:S17a–b**). The substance was not identified. Around the bezel's circumference were detected the remains of a shiny greyish metallic layer, partly flaking off, originally lining the entire interior of the cavity (**Pl. 4/1:S17a, c**). The layer was identified as silver by means of the SEM/EDX analysis (**Fig. 4**). The other identified elements (Fe, Si, Ca and P) result from corrosive processes. Sulphur, present in the form of tiny needles, was probably employed as an admixture in the silver lining while the higher proportions of carbon in the smooth parts probably resulted from melting. The body of the ring is made of iron without admixtures and without any identifiable surface treatment.

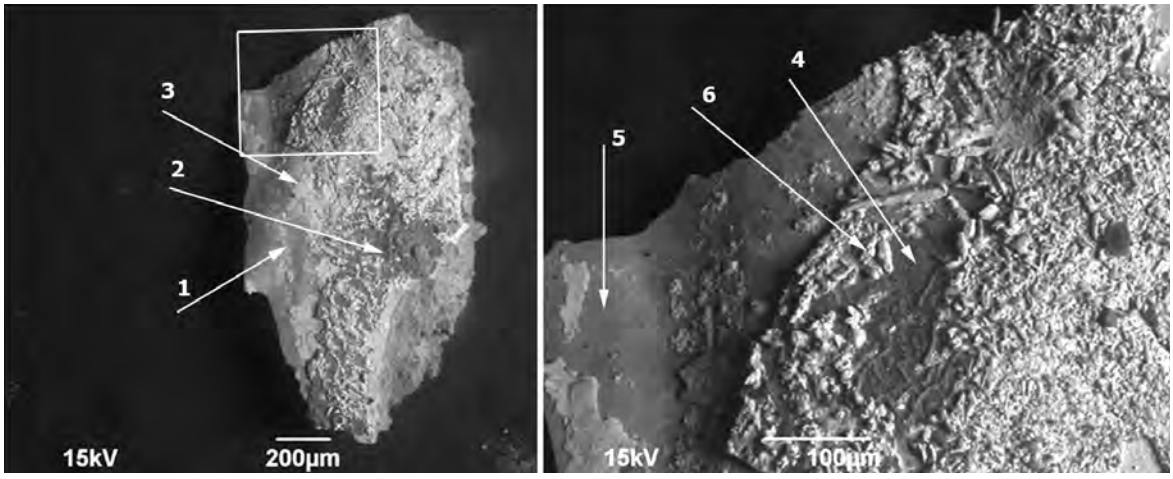

Fig. 4: S17 The SEM photograph of the analysed sample (left) and a detail thereof. The arrows indicate the different points where measurements were taken (photo by the author).

S20 The gem of this ring is preserved firmly attached inside its setting. The entire ring including the gem is heavily corroded. Both the XRF measurement on the gem's surface and the character of its corrosion (iridising layers, secondary precipitates) prove its soda nature. Considering the condition of the artefact, there was no point in executing any further analyses.

The body of the ring is made of iron and the SEM/EDX analysis (**Fig. 5**) excluded the presence of a surface layer. No chloride ions were present. The white precipitates were determined as calcareous.

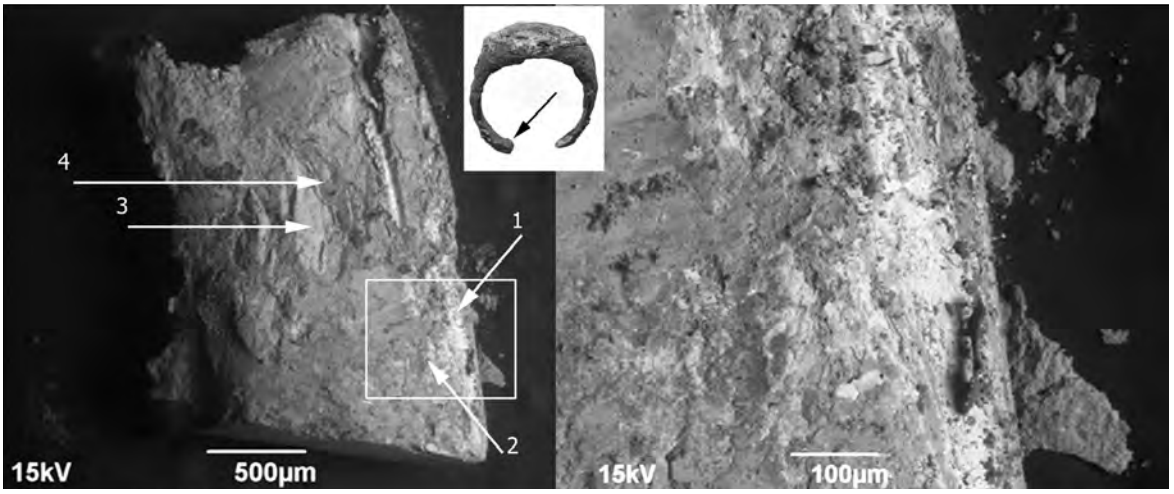

Fig. 5: S20 – The SEM photograph of the analysed sample and a detail thereof. The arrows indicate the different points where measurements were taken (photo by the author).

S22 Only the amber inlay was analysed in this ring. **Fig. 6 right** presents the ATR-IR spectra of the amber sample with indicated peaks of the absorptions relevant for the study of the material's origin. **Fig. 6 left** presents a detail of the spectral area 750–1950 cm^{-1} of the analysed spectrum in comparison with the standards of Baltic amber (Ukraine, 24384) and of rumanite (Ploesti, 24372). A hint of the Baltic shoulder is present in the analysed spectrum at the point of 1203 cm^{-1}, but unequivocal identification of the amber as Baltic is hindered by the absence of absorption at 885 cm^{-1}. For this reason, the origin of the studied amber cannot be determined unambiguously.

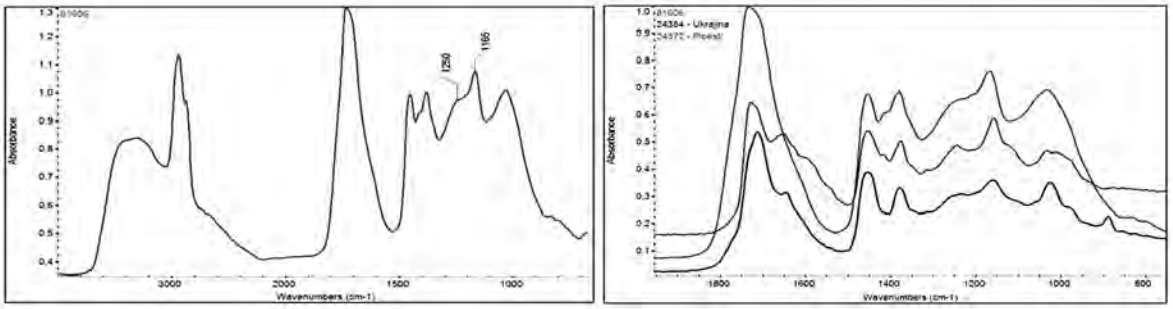

Fig. 6: ATR-IR spectrum of the analysed amber sample (left) and the ATR-IR spectrum of the analysed sample in comparison with the standards of Baltic amber (Ukraine, 24384) and of rumanite (Ploesti, 24372) in the spectral zone of 750–1950 cm^{-1} (right).

S25 Only the amber inlay was analysed in this ring. **Fig. 7 left** presents the ATR-IR spectrum in comparison with the spectra of bentonite and of Baltic amber (Ukraine, 24384). **Fig. 7 right** presents a detail of the spectral area 750–1950 cm^{-1} of the analysed spectrum in comparison with the standards of Baltic amber (Ukraine, 24384) and of rumanite (Ploesti, 24372). The analysed spectrum features significant absorptions of inorganic alumino-silicate phase with crystalline water which significantly overlap the intensions belonging to the organic phase of the sample. Based on the absorption bands corresponding to the vibrations n (C-H) and d (C = O) it can only be said that the sample is a natural resin without any specifications.

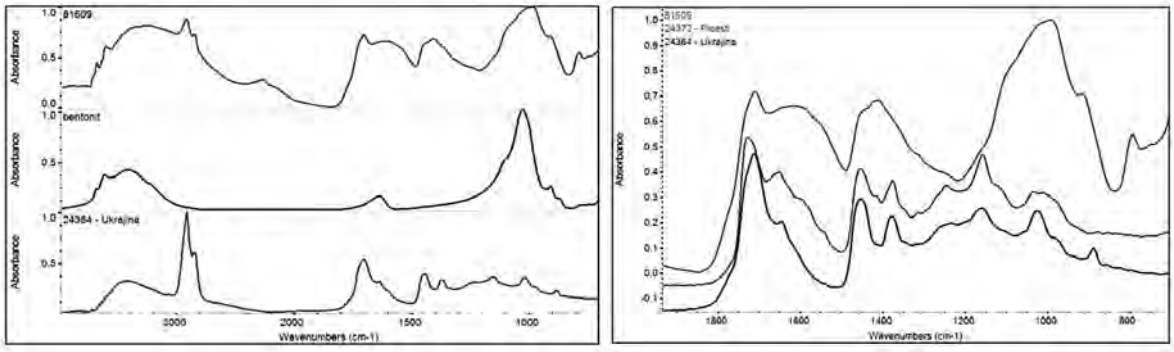

Fig. 7: ATR-IR spectrum of the analysed amber sample (left) and the ATR-IR spectrum of the analysed sample in comparison with the standards of Baltic amber (Ukraine, 24384) and of rumanite (Ploesti, 24372) in the spectral zone of 750–1950 cm^{-1} (right).

S26 The gem is preserved in this ring, firmly set in the bezel. Though it is set more deeply than in S11, it is likewise cut in order to fit the narrow bezel ring (**Fig. 8c**).

Repeated surface measurements identified the alloy as brass while the punctual SEM/EDX analyses (**Fig. 8a–c**) failed to detect any traces of Zn. This may be caused by an insufficient homogeneity of the alloy or by the use of various alloys for the ring and bezel respectively. The measurements were taken in the transverse cut through the ring and on a flake of the surface layer from the same spot. Both samples contained Cu, numerous elements connected to corrosive processes (S, Si, Ca, Mg and a high amount of P and K), and also small proportions of Sn, thus excluding the possibility of an intentionally applied surface layer. The surface is thus covered by a mere corrosion crust underlaid by high amount of chlorides.

The composition of the gem, measured by the XRF analyser in the 'non-metallic mode', was approximately determined as Si – Al – Ca – Mn, with trace presence of K, P, S, Sr, Rb, Fe a Ti, indicative of (most probably soda) glass.

S27 The gem of this finger-ring is preserved though no more within the bezel from which it had fallen off. The lining of the bezel beneath the gems (**Pl. 4/1:S27a**) is well preserved including – in its entire extent – a greyish metallic layer with localised remains of gold and in its central part macroscopically visible remains of an organic substance, most probably natural glue. The nature of this substance was not identified.

The metal lining was analysed by means of SEM/EDX which confirmed its assumed identification as surface gilded silver leaf. Its dark lower level (**Fig. 9**) contained significant proportions of Cu and Zn while the presence of Pb, identified by XRF was not confirmed.

The alloy of the finger-ring body was identified as brass by the XRF, while SEM/EDX detected Zn only in the bottom of the bezel beneath the lining but not in the sample from the ring body; Sn was identified in one measured point. Just like in the case of S26, this may be caused by an insufficient homogeneity of the alloy or by two different copper alloys. Unlike S26, however, no elements characteristic of corrosion have been detected.

The microscopy of the gem executed in the Department of Petrography of the National Museum identified the material clearly as glass. The approximate measurements of the elementary composition by the XRF suggest that it can be classified as soda glass.

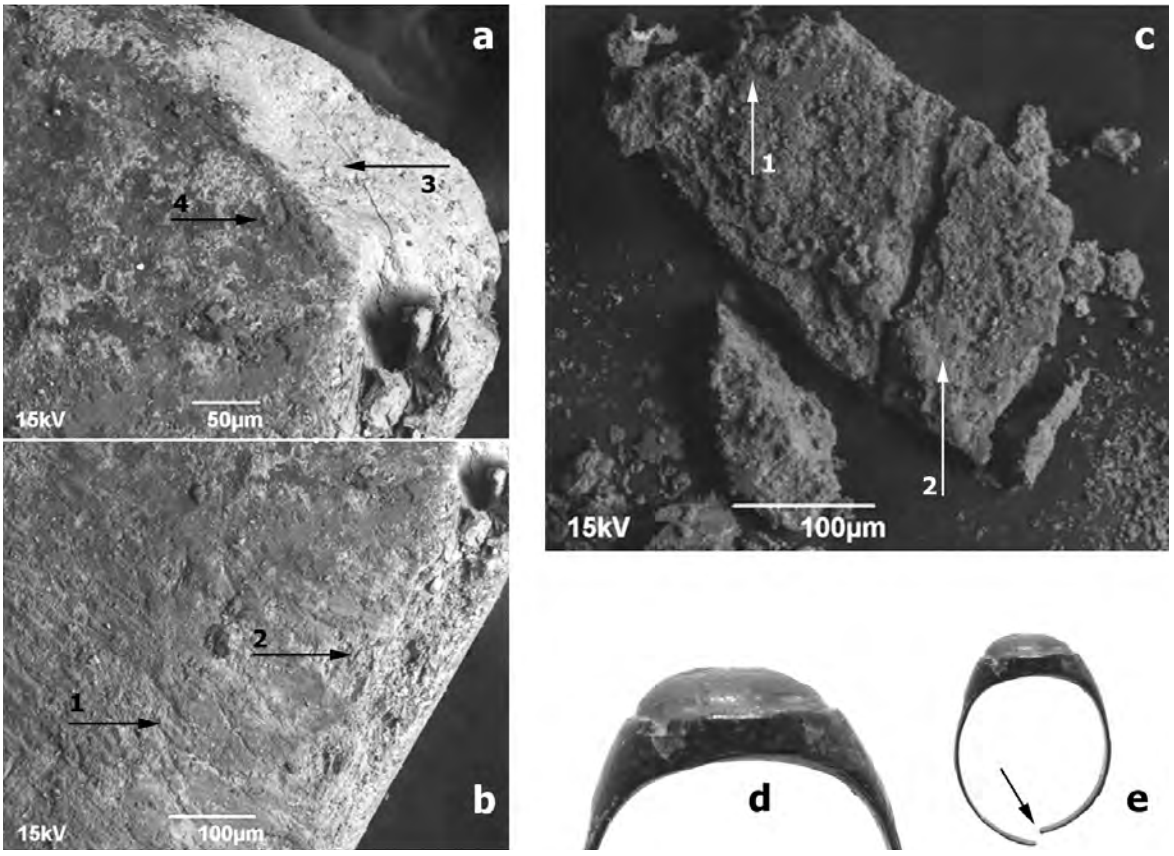

Fig. 8: S26 – a) The SEM photograph of the analysed sample. The arrows indicate the different points where measurements were taken; b) The SEM photograph of the analysed sample – detail of the marginal part of the sample with the darker part more affected by corrosion while in the lighter part the metal was recently cleaned; c) Insertion of the gem into the bezel; d) Point where the sample was taken (a–b: photo by the author, c–d: photo by A. Kumstátová).

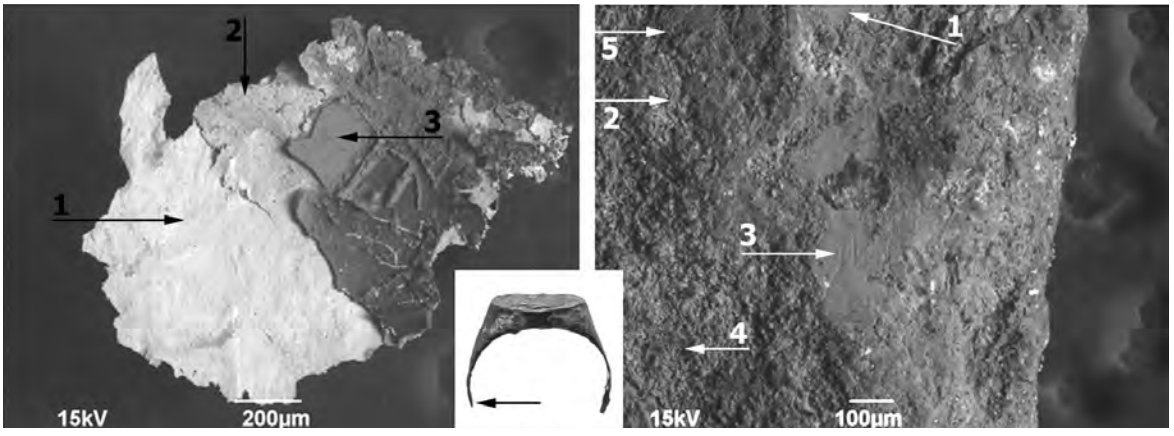

Fig. 9: S27 The SEM photographs of the analysed sample. The arrows indicate the different points where measurements were taken. Left: Sample including the entire stratification. Right: Detail of the base metal (photos by the author). Centre: the point of sampling (photo A. Kumstátová).

COMPOSITION OF THE MATERIALS – A SYNTHESIS

METALS

The study of the elementary composition of the rings metals enabled us to outline three major groups within them (**Tab. 2** and **3**): iron rings; brass rings with varying proportions of the basic components; and rings of other copper (or silver) alloys.

Iron rings are represented by eleven objects; these are bigger than the rings of copper alloys; due to their size they seem to be rather more male than female. They were produced by hammering. The gems were inserted into box bezels whose rims were filed thinner in order to prevent the inlay from cracking during the insertion. The inlays are as a rule less pronounced than in the brass rings and are also made of more varied materials, including glass paste, stone, and amber.

The iron rings are all affected by corrosive processes, in some cases the object has been almost completely destroyed (S25). The metal employed for the production of the iron rings is very homogenous in the entire assemblage. The XRF analysis detected only low proportions (hundredths to tenths of a %) of Cu and Zn, which was, however, not confirmed by the SEM/EDX. The surface layers of the iron rings contain high proportions of Si and Al, and furthermore also small amounts of P and S. These elements can be linked to the corrosive processes or – in the case of S and Si which were also detected by the SEM/EDX in the metallic core – with an insufficient purity of the raw material.

Brass rings are represented by 13 objects very similar to each other. They are generally smaller than the iron rings, produced by casting and set with glass inlays (with the exception of S16). The way in which the inlays are set inside the bezels is the same as for the iron rings. While some pieces are very well preserved (S9, S10), in others the ring got broken (S11, S26), in yet others it is almost completely absent (S14, S15). The surface layer often flakes off, in many cases it is affected by pitting corrosion. Visually these rings give the impression of a separately applied surface layer over the metallic core which was nevertheless ascertained only in a single case (S11); in other cases the SEM/EDX analysis proved it to be only a corrosive layer.

The composition of the copper alloys is relatively constant: 70–90 % of Cu and ca. 10 % of Zn. The XFR measurements on the surface regularly detected small amounts of Pb (0.1–0.6 % with the exception of S9 with 2.4 % of Pb) and Fe (0.2–1.7 %), in some cases of Sn (the highest percentage – 1.7 % – in the case of S10). The comparison of the XRF and SEM/EDX results show that the alloys were very heterogeneous with numerous impurities. The SEM/EDX analysis suggests that some of the rings were manufactured from two different copper alloys. The poor condition of the metal and the limited sampling do not permit the confirmation of soldering of the two parts.

The inlays in the brass rings were all made of transparent yellowish glass, most probably soda based.

Rings made of bronze and other alloys include nine artefacts. Several alloys were identified including bronze (Cu-Sn), lead bronze (Cu-Sn-Pb), silver and other non-classifiable copper alloys. A single object of this group corresponds by its form to the previously studied iron and brass objects, the ring K1 made of an alloy of silver, copper and tin. This ring was most probably gold plated.

Cat. n°	N° of measurements	Fe	Cu	Zn	Sn	Al	Si	P	S	Ti	Mn	Co	Ag	Hg	Pb	Au
S17 side	3	78.59	–	0.05	0.01	4.06	12.13	3.28	1.09	0.18	0.09	0.49	–	–	–	–
S17 bezel	2	91.12	0.16	0.02	0.04	1.48	0.85	1.63	2.53	0.00	0.02	0.28	1.62	0.15	–	–
S18	3	56.94	0.15	0.09	–	10.93	25.91	2.86	0.60	1.18	0.58	0.51	–	–	–	–
S19	3	79.56	0.16	0.39	–	3.75	11.27	2.79	1.38	0.18	0.06	0.43	–	–	–	–
S20	2	95.58	0.28	0.11	–	–	2.70	–	–	0.31	0.67	0.26	–	–	–	–
S21	6	79.31	0.03	0.09	0.08	4.40	12.94	1.80	0.97	0.11	0.03	0.22	–	–	–	–
S22	3	83.89	0.28	0.34	0.09	1.80	11.00	1.34	0.09	0.55	0.35	–	–	–	0.10	–
S23	2	80.88	–	–	–	–	13.82	3.15	1.27	0.47	0.42	–	–	–	–	–
S24	2	64.59	–	0.06	–	9.41	21.76	1.75	0.67	0.51	0.58	0.58	–	–	–	–
S25	2	81.52	1.42	0.03	–	0.95	11.89	0.27	1.49	0.50	0.40	0.51	–	–	0.93	–
S?2	2	88.68	0.29	0.16	–	1.57	7.06	0.56	1.13	0.11	0.08	0.36	–	–	–	–

Cat. n°	N° of measurements	Fe	Cu	Zn	Sn	Al	Si	P	S	Ti	Mn	Co	Ag	Hg	Pb	Au
S1	3	0.70	84.77	4.45	–	2.72	6.00	0.83	–	–	0.01	–	–	–	0.47	–
S2	2–side	1.75	58.55	22.95	–	4.32	10.87	–	–	0.34	0.05	–	–	–	1.06	–
S2 bezel	3	1.53	59.66	6.52	–	9.54	19.97	1.30	–	0.26	0.05	–	0.48	–	0.64	0.04
S8 bezel	7	0.19	70.22	9.80	–	0.53	1.77	1.07	–	–	–	–	14.33	0.05	0.21	1.79
S8 side	5	0.30	82.50	3.19	–	4.77	8.24	0.73	–	–	–	–	0.02	0.04	0.14	–
S9 surface	2	1.49	61.15	7.71	–	3.60	17.48	6.54	–	–	0.12	–	0.29	0.03	1.50	–
S9 under the crust	3	1.50	75.48	11.89	–	–	8.60	–	–	0.02	0.02	–	–	–	2.40	–
S10	4	1.33	63.72	8.42	1.34	3.92	17.75	2.57	–	0.11	–	–	0.07	–	0.67	–
S11	2	0.87	75.64	9.63	0.34	1.94	9.99	0.75	0.35	–	0.01	–	0.03	0.07	0.35	–
S12 surface lining	2	0.34	77.63	4.90	–	4.42	10.35	2.17	–	–	–	–	0.04	–	0.14	–
S12 under the crust	2	0.26	88.01	5.70	–	1.82	2.86	1.20	–	–	–	–	–	–	0.14	–

S13	2	0.55	84.37	8.14	0.36	0.85	1.98	2.45	–	–	–	–	0.50	–	0.64	0.11
S14	3	0.78	83.67	5.76	0.06	0.69	6.50	0.30	1.43	–	0.06	–	–	0.02	0.62	–
S15 side	2	0.13	92.16	3.49	–	0.74	2.07	0.84	0.42	–	–	–	–	–	0.13	–
S15 bezel	1	0.39	82.26	4.11	–	3.94	6.98	1.92	–	–	–	–	0.08	–	0.29	–
S16	2	0.36	85.42	9.05	–	–	1.70	0.45	2.67	–	–	–	–	–	0.26	–
S26 surface	3	1.09	81.38	7.10	0.52	–	9.05	–	–	0.07	–	–	–	0.15	0.58	–
S26 under the crust	2	0.33	81.77	5.51	0.37	2.94	5.51	3.28	–	–	–	–	–	–	0.27	–
S27 side	2	0.52	85.38	3.36	–	3.28	5.53	1.44	–	–	–	–	0.10	–	0.38	–
S27 bezel	2	1.30	68.78	12.35	–	2.15	4.86	2.16	–	–	–	–	1.50	–	6.46	0.37

Cat. n°	**N° of measurements**	**Fe**	**Cu**	**Zn**	**Sn**	**Al**	**Si**	**P**	**S**	**Ti**	**Mn**	**Co**	**Ag**	**Hg**	**Pb**	**Au**
K1 surface	3	0.71	10.15	0.16	53.12	–	–	–	–	–	0.14	–	33.10	0.05	0.66	1.90
K1 break	2	0.38	6.66	–	44.08	–	–	–	–	–	–	–	46.66	–	0.88	1.35
Sx1	4	3.61	63.97	11.89	14.24	0.00	1.30	–	–	0.05	0.01	–	–	–	4.13	–
Sx2	2	2.02	1.57	0.42	–	–	–	–	–	0.30	–	–	93.96	0.03	1.01	0.66
Sx3	2	1.02	76.80	–	19.91	–	1.98	–	–	–	–	–	–	–	0.17	–
Sx4	2	2.21	55.27	5.94	16.89	–	–	–	–	–	–	–	–	–	19.71	–

Table 2: XRF analysis (in wt%).

THE BEZEL LININGS

Underlying ring inlays with metal leaves in order to enhance their chromatic and reflective properties is a technique widely used until today. The underlying materials preserved in our corpus were identified as gilded silver (cf. S6, S17, S27, **Pl. 4/1**). The analysis identified technological faults in melting which proves to the complexity of their manufacturing. The macroscopically observable fine silver fillings and irregular gilding prove that neither metal was thoroughly melted. It cannot be demonstratively attested whether the melting took place directly in the bezel or if the underlying metal leaves were manufactured separately and then inserted into the bezel (it would be difficult to maintain the temperature of the base layer without melting down the ring itself). The shaping of the rims as well as the heterogeneity of the underlying layers and of the bezels hint rather at the use of prefabricated leaves or at the use of silver leaves gilded in the bezel.

Cat. N°	Measurement point	Fe	Sn	Cu	Zn	Pb	Ag	Au
K1	1		24.9	4.01			58.99	
	2		23.92	4.38			58.8	
	3 (surface)		37.44	2.96			43.03	
	4 (surface)		28.89	13.49			40.45	
S8	1 (leaf)						52.53	26.71
S8	2 (grain in the leaf)						86.83	
S8	3 (leaf, dark)						2.88	
S8	4 (leaf)			2.41			97.59	
S8	5 (leaf) not in a figure			1.82			39.45	58.73
S11	1 (center)	0.93		62.64	10.24			
S11	2 (top)			78.67				
S11	3 (center)			40.12	30.27			
S11	4 (bottom)	2.59	3.06	38.42	16.05			
S11	5 (bottom)	1.74	2.32	34.8	18.71			
S11	6 (top crust)			40.95	30.23			
S17	1	72.42					23.02	
S17	2	49.94					11.57	
S17	3	2.92					35.51	
S17	4 (dark)	40.07					16.91	
S17	5 (smooth)	54.95					18.11	
S17	6 (grain)	5.18					64.03	
S20	1	97.26						
S20	2	93.92						
S20	3	97.32						
S20	4	97.8						
S26	1 (metal)	1.41	1.64	62.51				
S26	2 (metal)			78.14				
S26	3 (metal)			78.81				
S26	4 (metal, dark part)	2.42		28.12				
S26	1 (crust, top)	3.2		22.2				
S26	2 (crust, top)	2.03		6				
S26	3 (crust, detail)	2.63	3.04	49.82				
S27	1 (leaf, ligth)						73.03	13.52
S27	3 (leaf, dark)			32.52	25.32		4.07	
S27	2 (leaf, light grey)						85.05	
S27	1 (metal)			5.78				
S27	2 (metal)			56.56				
S27	3 (metal)			5.77				
S27	4 (metal)		11.41	40.49				
S27	5 (metal)			73.08				
	Measurement point	**Fe**	**Sn**	**Cu**	**Zn**	**Pb**	**Ag**	**Au**

Table 3: SEM/EDX analysis (in wt%).

Na	O	P	S	Si	Ca	C	Cl	Al	K	Mg	Ti
	12.1										
	12.44			0.46							
	15.38			1.18							
	15.78			1.4							
	15.31		5.45								
			13.17								
1.2	36.88		0.44			58.59					
	22.61			3.57							
	20.62			0.71							
	23.95			5.66							
	28.3	1.94	1.14	7.47	1.02						
	29.35	0.81	1.29	10.16	0.81						
	21.71	0.63	0.57	1.66	1.11		3.15				
			3.7	0.86							
	27.15	2.47	2.08	4.02	2.78						
	44.36		3.79	0.34		13.07					
	28.8	3.99	3.24	4.41	2.58						
	22.78		2.7	1.45							
	20.41		8.28	1.28	0.81						
				1.64	0.73			0.37			
		1.11		2.84	1.7			0.43			
				1.8	0.88						
				1.5	0.71						
	25.92	5.52		1.36	1.63						
	20.98		0.87								
	20.56			0.63							
	31.88	2.16	1.46	9.58	7.48		9.34	5.36	2.18		
	37.09	11.7		5.8	14.92			2.18	2.07	0.84	
	44.05	1.1		21.18	1.88			14.44	7.35	0.98	0.99
	30.57	11.02		1.43	1.48						
			13.45								
	27.59	6.19		4.31							
			14.95								
	57.01		36.78	0.43							
	31.63		11.01	0.8							
			93.42	0.8							
	32.9	2.17	8.93	1.98				0.73			
	23.51		3.41								
Na	**O**	**P**	**S**	**Si**	**Ca**	**C**	**Cl**	**Al**	**K**	**Mg**	**Ti**

THE INLAYS

Two matters employed for inlay production were investigated: Transparent yellowish badly melted glass, most probably soda based (the XRF method does not register Na, though it does K and Pb – neither of these elements was detected in the analysed samples in values sufficient for using as flux). This substance was employed exclusively in the brass finger-rings. The sample S22 was analytically identified as amber though the material origin could not be specified. The sample S25 could only be identified as mineralized pitch; an unambiguous determination of its precise nature was not possible by means of the employed analytical method (it could be amber though heavily degraded).

CONCLUSION

The detailed technological analysis of the assemblage of rings has produced valuable data shedding new light on a very specific sector of ancient metallurgy and jewellery. The most important was the study of the metal leaf linings of the bezels. Such analyses cannot be executed on intact objects; in fragmentary rings on the other hand, the fragile linings rarely survive.

Most rings made of iron or brass are produced from alloys of a relatively constant composition. The objects whose composition differed from these are mostly suspect of being more recent.

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