Archaeologia Historica Polona
vol. 32, 2024–2025, pp. 283–298, ISSN 1425–3534, DOI: 10.12775/AHP.2024-2025.011

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Metallurgical analyses in studies on the origin of forged coins from the 11th century in Pomerania (Poland)

Abstract. Counterfeit coins in circulation during the early Middle Ages are considered to be products made primarily of copper alloys, often silver-plated or silver-washed. To describe it accurately, it is important that the selected measuring technique accounts for the complexity of such a structure. The application of the right method is of key importance given that the coins in circulation are made using an alloy with an intentionally reduced silver content, which are referred to as imitative coins or coins issued based on original coin stamps. Based on macroscopic and microscopic observations to which a group of 49 coins unearthed at the early medieval site of Pawłówek was subjected to (23 of which showed characteristics of forgeries), four were subjected to a detailed SEM/EDX analysis to identify differences in the chemical composition of the surface of these objects, and then they were tested by XRF fluorescence spectroscopy Based on the findings, it can be concluded that in all these cases, we are dealing with counterfeit coins. On their heavily corroded surface, a top layer of silver was present zonally, with a bronze or brass core underneath.

Keywords: Pomerania, hillfort in Pawłówek, early Middle Ages, metallographic analyses, coins, counterfeiting.

Introduction

In reference to the early Middle Ages, the *designatum* that corresponds to the notion of a "counterfeit coin" is understood and defined rather unequivocally by numismatists and archaeologists who deal with Central European coinage. A counterfeit coin is a coin imitated in an illegal manner, made principally from a metal other than silver (usually copper with an addition of zinc or lead), often plated with silver to conceal its true nature. Such coins have been long known in western Slavdom, though they are not always obvious in identification (Paszkiewicz 2012; Wiechmann 2013; Bogucki, Magiera 2015). They are frequently mentioned in the context of imitative coins, that is, specimens made in silver, not necessarily high grade, typically characterised by reliefs significantly effaced compared to the original (Suchodolski, 1998; Bogucki 2008; Szczurek 2020). In practice, many early medieval coin counterfeits can be identified as imitative coins, although not all imitative coins are examples of forgery in the strict sense, obviously. In essence, the issue of identifying these coins is even more complex once we take into consideration the intentional reduction of silver content in officially issued coins minted using original stamps (e.g., Bolesław the Bold's issues).

Until recently, in numismatic analyses of both these categories of coins from Pomerania (northern Poland), the evaluation of the metal alloy used for manufacturing them was based solely on a subjective description of their colour. Owing to this, it was possible to distinguish and categorise in terms of territory coins dated back to the second half of the 11th century or the first two decades of the 12th century, made in the so-called yellow metal characteristic of East Pomerania (Gdańsk, Nakło) and a red metal that occurs in West Pomerania (Paszkiewicz 2012; Bogucki, Magiera 2015, p. 20, Fig. 8). Obviously, the colour variation of the coins stemmed from the applied alloy and the content of its main component, that is, copper. Intuitive observations cannot replace objective analyses concerned with materials science, which at present must constitute the basis in studies on this type of coins. For several decades now, they have been successfully conducted in Western Europe (La Niece 1990; 1993; Zwicker, Gale 1991; Anheuser 1996) and in Poland (Bogucki 2008; Chabrzyk, Młodecka 2013; Pańczyk *et al.* 2015; Kędzierski 2021). In the case of counterfeit coins potentially made up of various components of varying alloy composition, it is important that the chosen measurement technique accounts for the complexity of such a structure and the state of its preservation (Miśta-Jakubowska *et al.* 2019). It should be noted that these coins were made using different technologies and different fluxes were applied in the production process, affecting the structure and chemical composition of the coins. Hence, it is often neither clear nor obvious as to how one should interpret archaeometric survey results, mainly the proportion of silver and copper in individual coin lots, particularly given the natural processes of copper loss in the near-surface layers

of coins reported in the literature. This is related to copper leaching and diffusion in the course of corrosion occurring during long-term deposition of an artefact in an environment characterised by high humidity and contamination (Pańczyk *et al.* 2015).

Material and research methods

The subject of this analysis is a group of coins unique in Poland, unearthed at an early medieval hillfort in Pawłówek on the Kuyavia-Pomerania border, northern Poland, dated back to the second half of the 11th century – the first quarter of the 12th century, examined in the years 2008–2012 (Fig. 1). It comprises 50 specimens, 24 of which showed traits of coin forgery. As yet, counterfeit coins have been known in western Slavdom only in the form of single finds and hoards, the sole assemblage comparable in terms of the numerosity of counterfeits being the series unearthed in Parchim, Mecklenburg (Wiechmann 2013). The majority of the counterfeit coins from Pawłówek were identified in the course of preliminary SEM/EDX analyses carried out at the Institute of Physics of the Polish Academy of Sciences, Warsaw (Czechowski *et al.* 2012). The findings that they yielded proved insufficient though, since for each coin, specific readings were taken for the surface layer, the colour of which is most uniform. They reflected the composition of the alloy only in one area measuring ca. 50 by 50 microns. Particular attention should be paid to a group of 18 coins with high copper content exceeding 80% of the mass in the alloy, as concluded at that time. Some of them were characterised by a small content of silver, zinc, tin, and lead, whereas individual specimens were based on copper and tin only. However, the structural diversity of the coins called for a more detailed materials analysis, which was not conducted until a decade later.

The studies were carried out in a double-track manner. A SEM/EDX analysis was applied, performed at the Faculty of Chemistry, Nicolaus Copernicus University (NCU). In this case, scanning electron microscopy (SEM) with EDS (Energy Dispersive Spectroscopy) was performed by means of the ZEISS LEO 1430VP system under variable pressure (20Pa), at the accelerating voltage of 28kV by means of a back-scattered electron (BSE) detector. In turn, the elements were investigated using the energy dispersive X-ray (EDX) spectrometer Quantax 200 with the XFlash 4010 detector, Bruker AXS, with the concentration limits of 0.1–100% by mass. Another method applied was X-ray fluorescence spectroscopy (XRF) carried out at the Institute of Historic Monument Conservation and Heritage Science, Faculty of Fine Arts, NCU, using X–MET8000.

In the group of coins determined as counterfeits, based on the analysis of shape and minting methods, two fundamental categories were distinguished. Group one comprised as many as 21 flat, relatively thin plates made of copper alloys, irregular

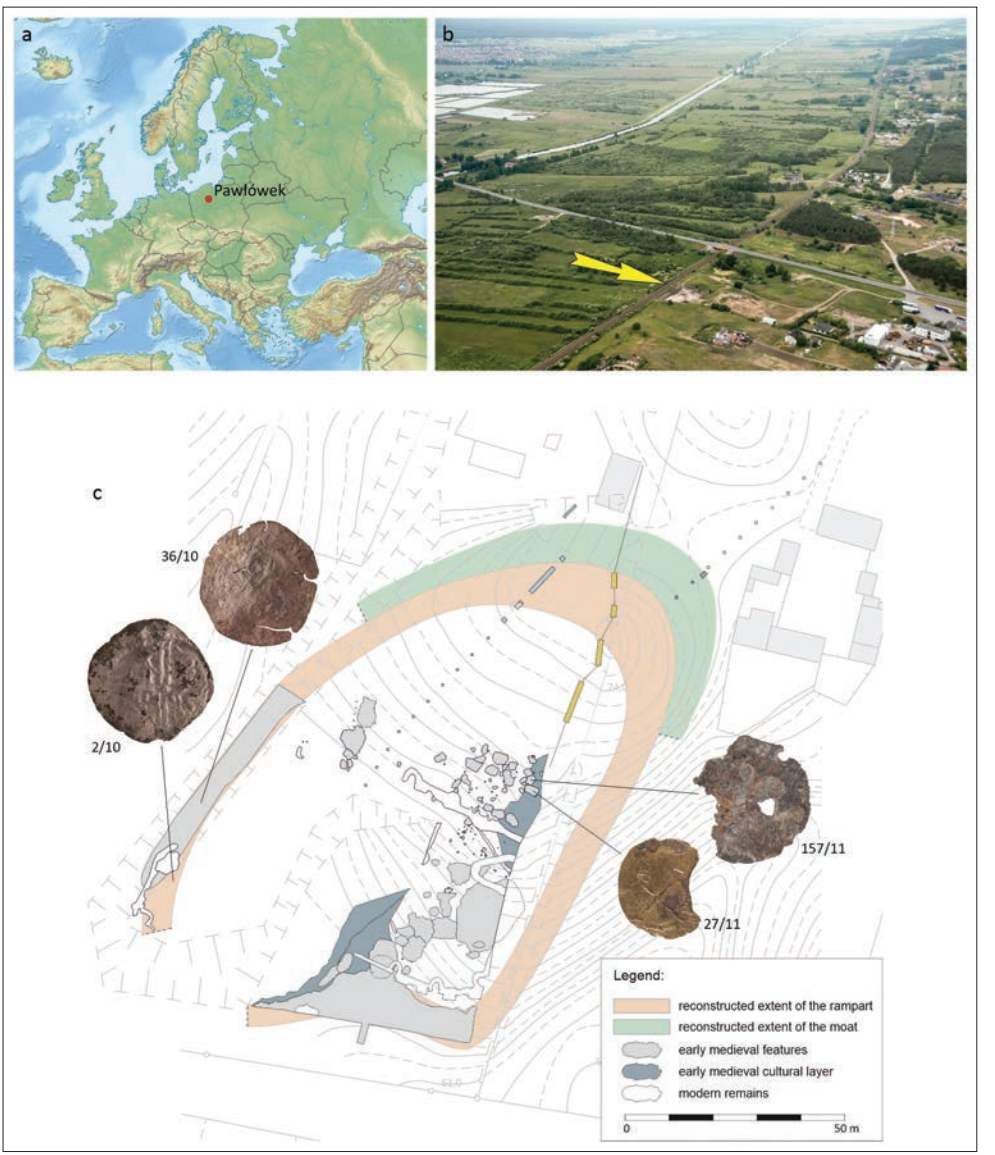


Fig. 1. Pawłówek, Kuyavia-Pomerania Voivodeship: a – contour map of Europe with marked location of the site; b – aerial photography of the site; c – planigraphy of the unearthed relics with the location of the discussed coins (photo by W. Stępień; developed by W. Ochotny)

and often polygonal in shape, either with poorly preserved reliefs or without any. In terms of typology, the items classified to this category included one imitation of a Helmet-type denarius (1003–1009) of King Aethelred II (978–1016), England, two cross denarii of type V, five cross denarii of type VI, and a type-VII denarius (Musiałowski 2022). The other 12 specimens were not classified despite five of them bearing traces of stamps, albeit not that characteristic. The other group involved three regularly circular coins (?), classified as cross denarii of type V with raised edges and clear traces of bilateral reliefs. Most of these specimens were severely effaced, perhaps as early as when circulating in the early Middle Ages. All the coins were bearing on their surfaces numerous corrosion products containing, among others, oxides, sulphides and chlorides of silver and copper. Additionally, in some cases, traces of firing were recorded, most likely related to the depositional process.

The execution of the fundamental research task was preceded by maintenance procedures that the source material was submitted to, entailing preparation of particular specimens for the planned analyses. These involved, primarily, reducing corrosion products until the metallic surface of the coins was revealed (Hamilton 1999, pp. 300–301; Miazga 2017, p. 54), a process carried out by means of repeated bathing in a 5% disodium versenate solution, whereby the frequency and duration were dictated by the thickness of the corrosion layers.

For the detailed metallographic studies, a larger group was selected, involving solely flat and usually irregular specimens. In this group, 15 coins were subjected to a SEM/EDX analysis deployed in material science research for observation, analysis and characterisation of material surfaces, mainly morphology and elemental composition. This allowed us to determine the amounts of specific elements by means of a semiquantitative non-model method using maps showing the distribution of specific elements in the examined microarea of the sample. Aside from basic values typical of the metals that the structure of the coins was made of, specific results showed also the percentage of gasses and elements stemming from post-depositional processes, such as silicon, carbon, phosphorous, and sulphur. The study also covered aluminium, the presence of which was related to the applied research method.

Due to the relatively high silver content demonstrated in the macroscopic and microscopic observations after the removal of the corrosion products, four coins were subjected to a detailed analysis using a BSE detector that registers the differences in the chemical composition of surfaces. These differences were visible in photographs taken in various shades of grey (inv. no. 2/10, 36/10, 27/11, 157/11). The areas that show occurrences of elements with higher mass numbers are brighter (e.g., silver), whereas those with lower mass numbers are darker (e.g., copper). On this basis, for each object, two or three measurement areas were determined. The next step in the analytical study, which sought to provide conclusive results

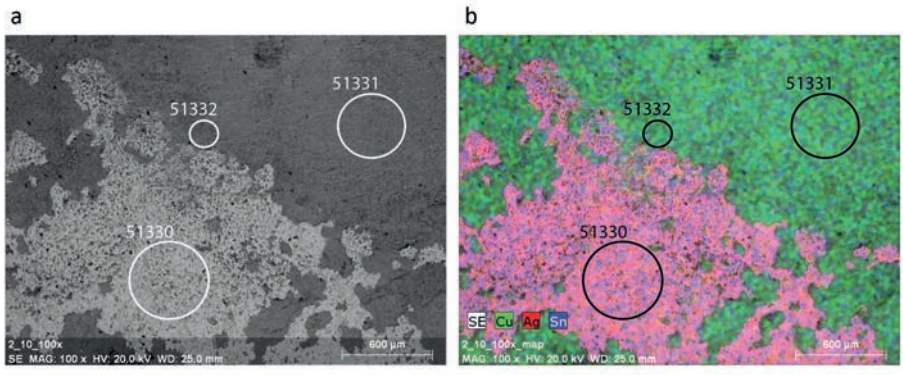
concerning the quantitative content of elements in particular specimens, was the method of mapping the surface of the investigated objects, which turned out to be of key importance for interpreting the results (Figs. 2–5). In a bigger research area, their composition was verified using the X-ray fluorescence (XRF) spectroscopy, whereby the excitation of a spectrum characteristic of a given material is obtained by means of exposing it to high-energy X-rays.

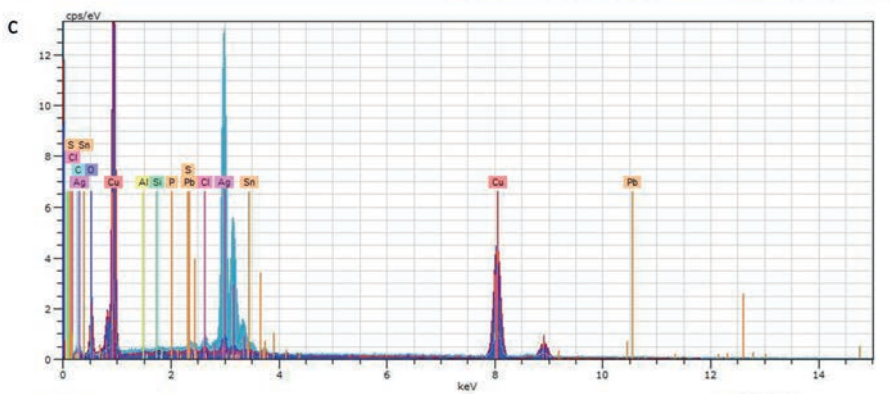
Results

As for the specimen (inv. no. 2/10) identified as an imitation of a denarius of Aethelred II (Fig. 2: d, Fig. 6), in the course of studies implemented in 2011–2012, a very high content of silver (91.48%) and a low content of copper (5.65%) were recorded, suggesting that we could be dealing here with a coin made of high-grade silver (Czechowski *et al*. 2012). Different results for this specimen were obtained in the course of a re-examination performed in 2022. Considering the image obtained by using the BSE detector, three measurement points were determined at that time (Fig. 2: a, b). In two of them (no. 51331, no. 51332), high copper content was detected, reaching about 93.33–95.11% with some content of silver 3.16–5.27% and of tin 1.40–1.73%. The results obtained for the third point (no. 51330) were significantly different. The dominant element was silver 77.13% with relatively low content of copper 15.91% and lead 6.96%. The content of these specific elements reflects the coin structure obtained by means of mapping with a visible copper alloy core enclosed (no. 51331, no. 51332), as well as locally preserved areas with high content of silver that constitute the surface layer of the artefact (no. 51330; Fig. 2: a–e).

A different situation was determined in the case of a coin (inv. no. 36/10) identified as cross denarius type VI minted about 1015–1025 (Fig. 3: d; 6). The measurements obtained in the years 2011–2012 showed that we are dealing here with a specimen made of a copper alloy with low silver content (5.16%) and very high copper content (91.57%) (Czechowski *et al.* 2012). In the course of the 2022 research, in three examined points (no. 49982, no. 49983, no. 49984) a similar silver content was obtained, that is, 47.65% and 62.88%, respectively, with lower copper content 33.10–45.04% and a relatively high proportion of zinc 4.02–7.31%. Only the analysis of microscopic images provided by the BSE detector and the mapping process indicate local occurrence of the surface layer of the silver, which is best readable in measurement no. 49982. Surface imaging also indicates that the brass core of the coin is visible in specific points (Fig. 3: a–e).

The situation was different for the coin (inv. no. 157/11) described as an unreadable cross denarius (Fig. 4: d, Fig. 6). During the measurement procedure carried out in 2011–2012, high silver content was recorded (40.76%) along with a somewhat similar value for copper (37.40%), as well as zinc (5.5%), and lead (1.07%)





Mass percent (%)

Spectrum	C	O	Al	Si	P	S	Cl	Cu	Ag	Sn	Pb
51330	1.64	11.37	0.12	-	-	-	-	13.57	67.34	-	5.95
51331	4.33	17.06	0.44	0.24	0.10	0.44	0.51	74.31	1.20	1.37	-
51332	4.88	15.79	0.20	0.08	0.02	-	0.36	73.74	3.79	1.15	-
Mean value:	3.62	14.74	0.25	0.10	0.04	0.15	0.29	53.87	24.11	0.84	1.98
Sigma:	1.73	2.98	0.17	0.12	0.06	0.26	0.26	34.90	37.46	0.73	3.43
Sigma mean:	1.00	1.72	0.10	0.07	0.03	0.15	0.15	20.15	21.63	0.42	1.98



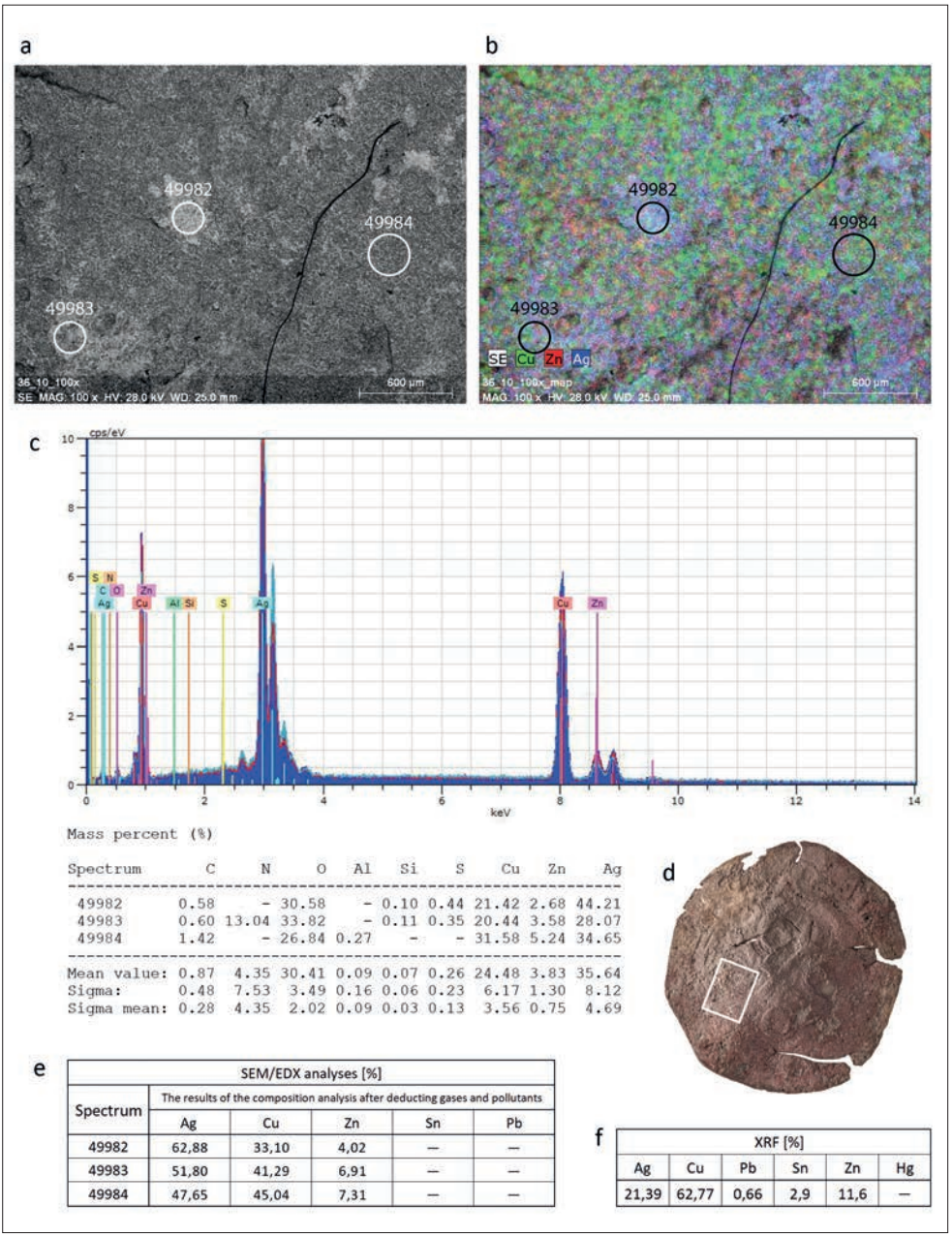
e

SEM/EDX analyses [%]					
Spectrum	The results of the composition analysis after deducting gases and pollutants				
	Ag	Cu	Zn	Sn	Pb
51330	77,13	15,91	—	—	6,96
51331	3,16	95,11	—	1,73	—
51332	5,27	93,33	—	1,40	—

f

XRF [%]					
Ag	Cu	Pb	Sn	Zn	Hg
14,38	80,18	1,9	1,77	1,41	—

Fig. 2. Pawłówek, Kuyavia-Pomerania Voivodeship, site 11. Coin, layer humus (inv. no. 2/10). Analysis of the coin surface identification of elements (SEM/EDX): a – BSE image; b – map of the distribution of the elements in the analysed coin surface; c – spectrum diagram and table showing the semi-quantitative contribution of each element in the analysed coin surface; d – coin with the area of research marked using (developed by W. Ochotny)



Mass percent (%)

Spectrum	C	N	O	Al	Si	S	Cu	Zn	Ag
49982	0.58	-	30.58	-	0.10	0.44	21.42	2.68	44.21
49983	0.60	13.04	33.82	-	0.11	0.35	20.44	3.58	28.07
49984	1.42	-	26.84	0.27	-	-	31.58	5.24	34.65
Mean value:	0.87	4.35	30.41	0.09	0.07	0.26	24.48	3.83	35.64
Sigma:	0.48	7.53	3.49	0.16	0.06	0.23	6.17	1.30	8.12
Sigma mean:	0.28	4.35	2.02	0.09	0.03	0.13	3.56	0.75	4.69

e

Spectrum	SEM/EDX analyses [%]				
	The results of the composition analysis after deducting gases and pollutants				
	Ag	Cu	Zn	Sn	Pb
49982	62,88	33,10	4,02	—	—
49983	51,80	41,29	6,91	—	—
49984	47,65	45,04	7,31	—	—

f

XRF [%]					
Ag	Cu	Pb	Sn	Zn	Hg
21,39	62,77	0,66	2,9	11,6	—

Fig. 3. Pawłówek, Kuyavia-Pomerania Voivodeship, site 11. Coin, layer 2 (inv. no. 36/10). Analysis of the coin surface identification of elements (SEM/EDX): a – BSE image; b – map of the distribution of the elements in the analysed coin surface; c – spectrum and table showing the semi-quantitative contribution of each element in the analysed coin surface; d – coin with the area of research marked using the method SEM/EDX; e – SEM/EDX analyses [%], after purification; f – XRF analyses [%] (developed by W. Ochotny)

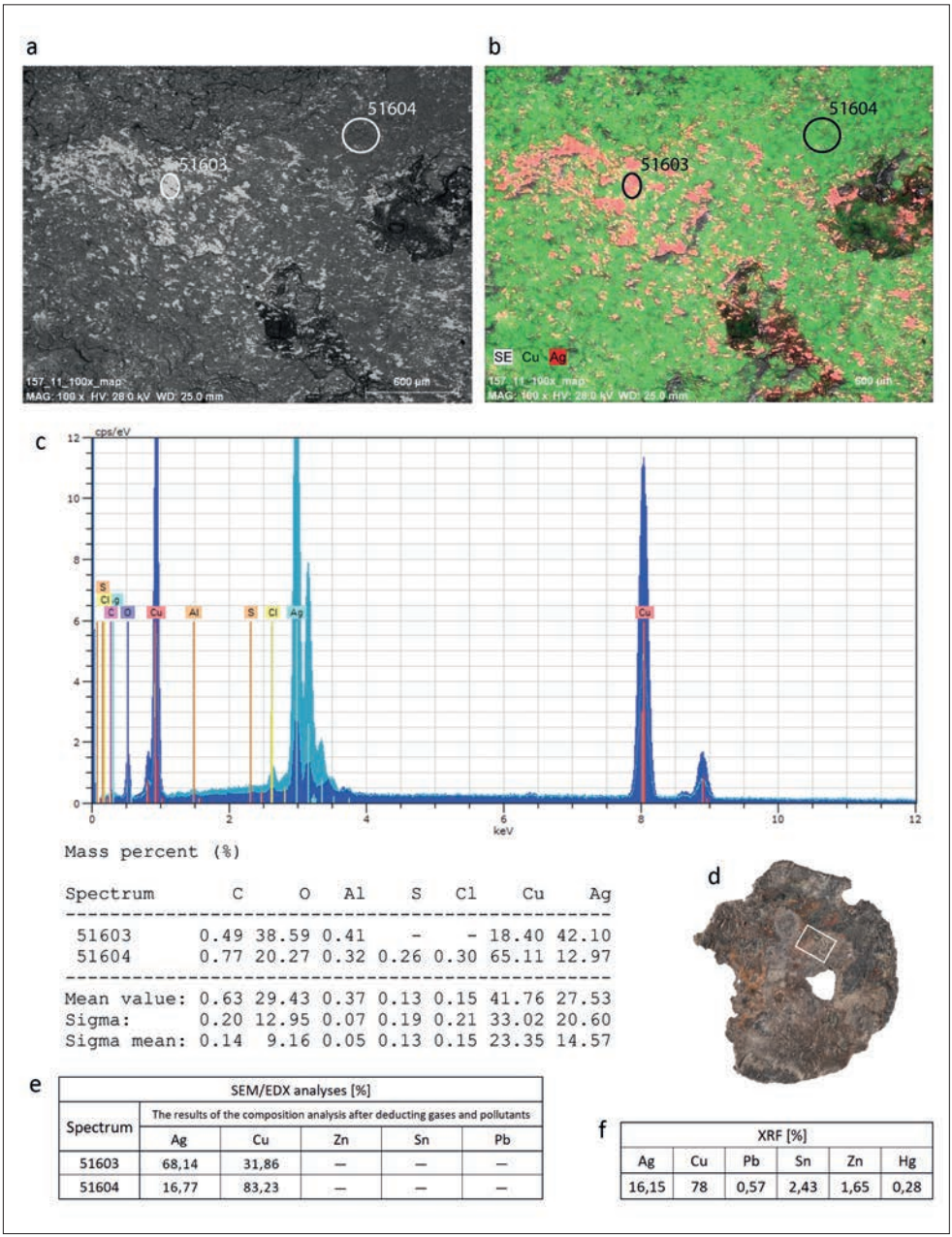


Fig. 4. Pawłówek, Kuyavia-Pomerania Voivodeship, site 11. Coin, feature 136A (inv. no. 157/11). Analysis of the coin surface identification of elements (SEM/EDX): a – BSE image; b – map of the distribution of the elements in the analysed coin surface; c – spectrum diagram and table showing the semi-quantitative contribution of each element in the analysed coin surface; d – coin with the area of research marked using the method SEM/EDX; e – SEM/EDX analyses [%], after purification; f – XRF analyses [%] (developed by W. Ochotny)

(Czechowski *et al.* 2012). This result was not reflected in the research that has been conducted recently, as part of which only two elements were recorded. The first measurement point (no. 51603) was characterised by high silver content 68.14% with significantly lower copper content of 31.86%, whereas in the course of the second measurement (no. 51604), low silver content was identified at 16.77% along with high copper content at 83.23%. This difference between the results for both these measurements reflects the mapping image, which clearly shows zones with better-preserved silver plating on the coin's surface (no. 51603) and its bronze-based core (no. 51604; Fig. 4: a–e).

The last specimen in this group (inv. no. 27/11), identified, likewise, as a denarius of an unspecified type with the mark of the cross, was characterised by a clear separation of the surface layer visible both in the microscopic photograph and in the macroscopic observation (Fig. 5: d, Fig. 6). The studies conducted in 2012 and 2022 showed the same quality elemental composition, though considerably different quantitative composition. The results of the first study show very high copper content 88% and significantly lower silver (7.14%) and zinc (4%) content (Czechowski *et al.* 2012). In the two measurements taken in 2022, significant differences were observed in the quantitative composition. In the first one (no. 51498), high copper content (51.03%) was reported along with a somewhat lower silver (40.35%) and zinc (8.62%) content. The second measurement (no. 51499) showed most distinctively copper (78.83%), followed by zinc (15.32%) silver (2.89%), and tin (2.97%). This difference is also evident in the mapping of the artefact, which highlights a very thin layer of silver plating of the coin still preserved in areas on its brass core (no. 51498; Fig. 5: a–e).

In all these cases, the elemental composition determined using SEM/EDX at the Institute of Chemistry, NCU, was also verified by means of X-ray fluorescence (XRF) spectroscopy. Due to the area of the collected data, the obtained results are averaged and point to differences in elemental composition of the examined surface (Fig. 2: f, Fig. 3: f, Fig. 4: f, Fig. 5: f). However, owing to this method, it was possible to identify the elemental composition in the examined specimens more accurately. As for the denarius of Aethelred II (inv. no. 2/10), silver content did not exceed 14.38%, copper content was estimated at 80.18%, lead at 1.9%, tin at 1.77%, and zinc at 1.41%, where the latter was not shown in the SEM/EDX measurement (Fig. 2: f). Another specimen (inv. no. 36/10) contained 21.39% silver, 62.77% copper, 0.66% lead, 11.6% zinc and 2.9% tin, the latter not documented in the SEM/EDX readings, whereas the identified absence of lead could be due to its low content (Fig. 3: f). In terms of elemental composition, the XRF reading for the next coin (inv. no. 157/11) was closest to the SEM/EDX analysis performed back in 2012. It showed 16.15% silver, 78% copper, only 0.57% lead and 1.65% zinc. Additionally, tin was also recorded in the amount of 2.43% along with traces of mercury not exceeding 0.28% (Fig. 4: f). A situation similar to that of coin 36/10 was recorded

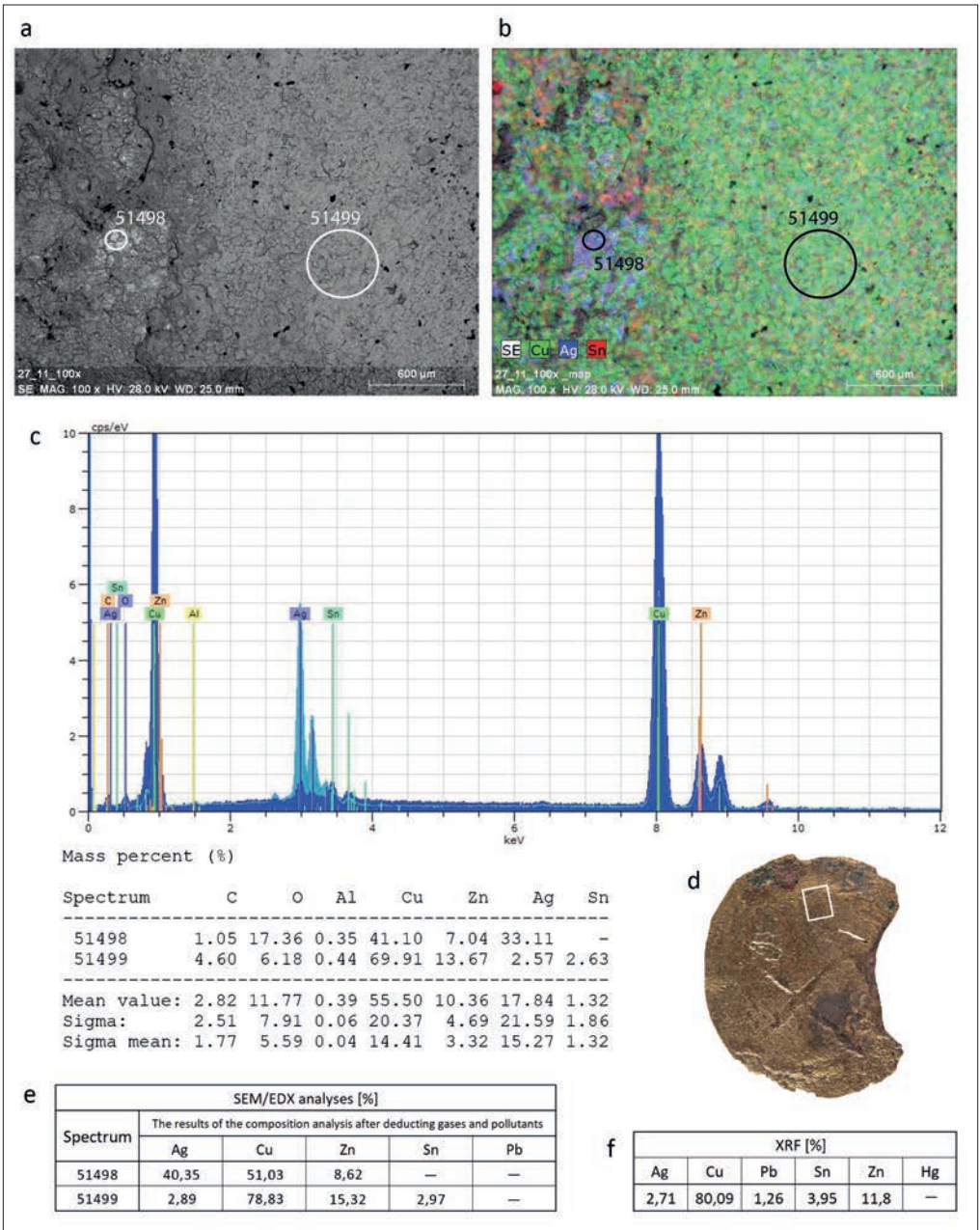


Fig. 5. Pawłówek, Kuyavia-Pomerania Voivodeship, site 11. Coin, feature 136 (inv. no. 27/11). Analysis of the coin surface identification of elements (SEM/EDX): a – BSE image; b – map of the distribution of the elements in the analysed coin surface; c – spectrum diagram and table showing the semi-quantitative contribution of each element in the analysed coin surface; d – coin with the area of research marked using the method SEM/EDX; e – SEM/EDX analyses [%], after purification; f – XRF analyses [%] (developed by W. Ochotny)

No	Inv. no	Origin	Description	Comments	Figure
1	2/10	England, Aethelred II (978-1016), *„Helmet"* type denarii, (after 1003-1009)	Obverse: unreadable; Reverse: Hollow cross, arms ending in 3 crescents, corners of the square ending in half leaves, one-sided? References: North 1994, 775	flat, with irregular edge; weight 0,65 g; ø 18,0 mm	
2	36/10	cross denarii, Type VI ? (after 1015-1025)	Obverse: in denticulated border straight cross with rings at shoulder angles. In border effaced pseudo-inscription; Reverse: in serrated border bachelor's cross. In border effaced pseudo-inscription References: like CNP VI, 691?	flat, with irregular, polygonal edge, coin cracked, bent; weight 0,83 g; ø 18,0 mm	
3	27/11	fragment of an unidentificated cross denarii	On both sides the sign of the cross in the rim	flat, with an irregular, broken edge on one side; weight 0,53 g; ø 16,6 mm	
4	157/11	unreadable fragment of denarii	mint stamp faintly legible	flat, with irregular edge damaged on edge, cracked inside; weight 0,56 g; ø 17,6 mm	

Fig. 6. Pawłówek, Kuyavia-Pomerania Voivodeship, site 11. List of forged coins included in the publication (developed by W. Ochotny)

for the specimen inv. no. 27/11, where the estimated content was 80.09% copper, 11.8% zinc, 2.71% silver, 3.95% tin and 1.26% lead, not confirmed by the SEM/EDX readings, likewise (Fig. 5: f).

Discussion and conclusions

Determining the elemental composition of coins with a complex structure typical of early medieval counterfeits requires applying methods adapted to particular specimens. In the research process, the state of preservation of each specimen is of key importance. Owing to the macroscopic and microscopic analyses (done first, after the corrosion products had been removed), it was possible to carry out initial classification of the coins and to determine specific analyses involving relevant measurement tools for each of them. In the case of counterfeits, the basic method is scanning electron microscopy (SEM/EDX). However, this method requires doing many analyses in pre-defined areas, which serves as the basis for imaging the chemical composition of the coins, discussing the technology employed for making them and the history of particular specimens. As shown by the studies conducted using this method in 2011 and 2012, determining the chemical composition of a coin based on solely one measurement without considering its structure can be misleading. In two cases, the findings suggested that we are dealing with a silver coin (inv. no. 2/10) and a coin minted using copper alloy (inv. no. 36/10). Only re-analyses allowed for the verification of these data and the unambiguous determination that the first case involves a denarius struck from a copper alloy with a silver-plated surface (inv. no. 2/10), while the second is a coin with a brass core and a silver-washed surface (inv. no. 36/10). Such technology has been well-recognized in the case of Western European early medieval coins and is associated with intentional counterfeiting (Kędzierski 2021, p. 208). Proper application of scanning electron microscopy should be based on choosing a specific research area based on the mapping of a given object, followed by taking numerous point measurements or linear measurements of a cross-section. The analyses conducted according to this assumption made it possible to determine whether the coin's surface was silver-washed or silver-plated., what elements made up its core and what was the distribution of specific elements in the examined areas. The obtained data allow us to conclude that the differences in specific measurements stem predominantly from the elemental composition of the alloy alone, as well as the preservation state of the plating. The rationale for inferring the technology used in the coin-making process was also obtained. The elemental content of zinc, among others, may suggest the use of eutectic processes (Wiechmann 2013). The objective cannot be attained by using the X-ray fluorescence (XRF) method only. The differences observed in the quantitative elemental composition compared to the results obtained using

scanning electron microscopy (SEM/EDX) primarily result from the larger area covered by the XRF analysis. This can lead to false conclusions regarding the alloys and production techniques of individual coins, thus precluding an unambiguous determination of whether the object is a counterfeit or a coin minted from a low-grade silver alloy. Discrepancies between the results of both methods are evident in all the discussed cases (Fig. 2: e, f, Fig. 3: e, f, Fig 4: e, f, Fig 5: e, f), whereas any occasional correlations in the quantitative content of certain elements – especially silver and copper – result from the specific areas selected for metallographic analyses based on surface imaging (Figs. 4, 5).

Given the results of the tests conducted by means of both these methods, for two coins (inv. no. 36/10 and 27/11), it can be assumed that their cores are substantially different to those of the other two specimens, and that they were made in a similar alloy with high zinc content above 11%. One of these coins (inv. no. 27/11) was unearthed in the context of a feature of an artisanal function (feature 136) where fragments of cut brass plaques of a similar composition were also found; it is likely that the latter were used in the local coin forgery. In turn, in terms of chemical compound, the core of the coin of Aethelred II (inv. no. 2/10) was probably made using a bronze plate with low content of lead, tin, and zinc, none of which exceeded 2%. A different elemental composition was determined for the cross denarius (inv. no. 157/11), where mercury was also identified. The issue of assessing the chemical composition of the analysed coins is further complicated when we consider the mechanisms involved in their running and sub-depositional processes, which affect the significant degradation of the coin structure.

The problem of identifying counterfeits is different in the case of coins seemingly made of silver preserved in the so-called "good condition", where their surface structure remains intact. Such specimens are typically considered to be high quality silver coins, as in the case of the initial interpretation of the denarius of Aethelred II (inv. no. 2/10). Nonetheless, it cannot be ruled out that these include counterfeit coins. In this case, mapping the surface of a coin is usually pointless due to the well-preserved surfaces of these coins. However, it is likely that many of them have a copper alloy core beneath the relatively tight silver coating. In this case, the least invasive method is laser-induced breakdown spectroscopy (LIBS), which allows one to investigate the chemical composition not only on the surface of the artefact, but also in its deeper parts, albeit to a limited extent due to ablation. Therefore, it is worth using this method particularly to examine the cross denarii of younger types minted in the second half of the 11th century in Poland, which are commonplace in hoards. In the literature, the current view holds that many of them show increased zinc and copper content in the alloy (Chabrzyk, Młodecka 2013). The question is, whether they were all made of a single alloy, or do they hide a bronze or brass core unobservable in the course of a macroscopic observation (Miśta-Jakubowska 2019; Kędzierski 2021, p. 211).

Lastly, it is worth stressing that the above analytical findings serve predominantly for identifying counterfeit coins and determining the chemical composition of their complex structures. In general, to obtain optimal data, two methods can be used, namely, mapping of both surfaces of a coin and structure profiling, as it is essential for evaluating the core of the coin. Another issue that should be investigated based on an extended analysis of the available source material is the production technology applied in coin forgery, including the fluxes employed in this process.

Funding information
Grant under the "Excellence Initiative – Research University" programme of the Nicolaus Copernicus University in Toruń: "A study of early medieval monetary finds from the Dobrzyń Land, Kuyavia and Pomerania. Analysis-conservation-publication".

Acknowledgments
The authors wish to convey their sincere appreciation to Wojciech Zaleszczyk of the Institute of Physics of the Polish Academy of Sciences in Warsaw. We would like to extend our gratitude to Adam Musiałowski for performing the numismatic expertise. We thank Joanna Zahorska for translating the text.

Data availability statement
The data that support the findings of this study are available from the corresponding author upon reasonable request.

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