Archaeologia Historica Polona
vol. 32, 2024–2025, pp. 267–282, ISSN 1425–3534, DOI: 10.12775/AHP.2024-2025.010

[1] *National Centre for Nuclear Research*
Otwock
Ewelina.Mista@ncbj.gov.pl
Institute of Archaeology
Jagiellonian University in Kraków
ewelina.mista-jakubowska@uj.edu.pl
ORCID ID: 0000-0002-0053-8711

[2] *Institute of Archaeology*
Nicolaus Copernicus University in Toruń
wojchud@umk.pl
ORCID ID: 0000-0003-3409-0991

[3] *Institute of Archaeology and Ethnology*
Polish Academy of Sciences, Centre for
Archaeology of Mountains and Uplands
Kraków
b.szmoniewski@iaepan.edu.pl
ORCID ID: 0000-0003-0737-434X

[4] *Humanitas University*
Sosnowiec
rozmusd@poczta.onet.pl
ORCID ID: 0000-0002-3264-8923

[5] *Copper Museum in Legnica*
przemyslawparuzel@gmail.com
ORCID: 0009-0002-7765-729X

[6] *Regional Museum in Jawor*
Tomasz_stolarczyk@wp.pl
ORCID 0000-0003-1490-0483

EWELINA MIŚTA-JAKUBOWSKA[1], WOJCIECH CHUDZIAK[2], BARTŁOMIEJ SZ. SZMONIEWSKI[3], DARIUSZ ROZMUS[4], PRZEMYSŁAW PARUZEL[5], TOMASZ STOLARCZYK[6]

The earliest Piast coinage in the light of lead isotope analyses: a study of two coins of Bolesław the Brave

Abstract. This study presents the results of a pilot investigation into the provenance of silver bullion based on Lead Isotope Analysis (LIA), carried out on two denarii of Bolesław I the Brave (992–1025), including a specimen of the *Princes Polonie* type. The results indicate a high probability that the silver used for striking both coins derived from silver-bearing zinc-lead ore deposits located in the Silesia-Kraków Upland region. If confirmed by broader datasets, this would constitute the earliest evidence for the use of silver obtained from local sources in Piast coinage. The findings make a significant contribution to research on the raw material base of early Piast minting.

Keywords: Piast coinage, Bolesław I the Brave, silver, lead isotope analysis (LIA), bullion provenance.

Studies on bullion provenance in Central Europe (10th–12th century)

Silver played a key role in the economy of the early Piast state, particularly in coinage (e.g, Suchodolski 1973; 2013) and in the production of elite ornaments (e.g., Kóčka-Krenz 1993; 2020; Duczko *et al.* 2022). In the area of present-day Poland, this metal occurred primarily in the form of hoards until the close of the 11th century (Fig. 1) (Kiersnowski 1960).

In the Early Middle Ages, the supply of silver was dynamic, derived from multiple sources. In the 9th and 10th centuries, substantial quantities of eastern silver flowed into Central Europe, chiefly in the form of Arabic dirhams, which played an important role both in long-distance exchange and in local bullion economies (e.g., Kilger 2011; Kershaw *et al.* 2021, Fig. 1). From the second half of the 10th century

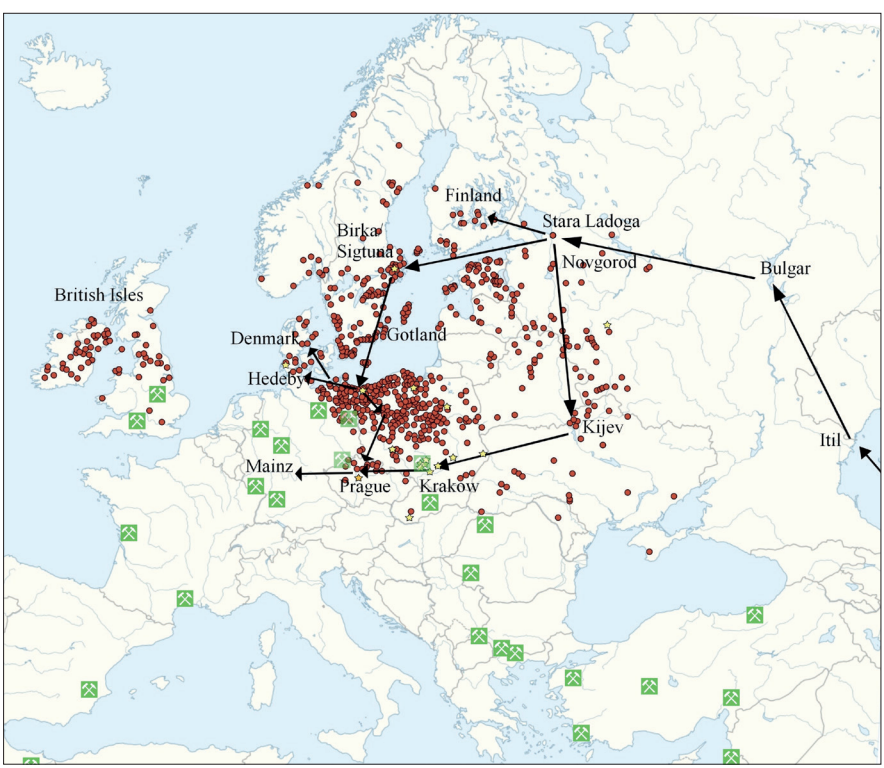


Fig. 1. Map of early medieval silver hoards (red circles), with the principal trade routes indicated, the major silver and lead ore deposits (green markers), and the results of Lead Isotope Analysis (LIA) identifying objects made from raw materials derived from the Silesia-Kraków Upland region (yellow stars); state of research as of April 2026 (after Gruszczyński 2016; Blanchard 2001; Merkel 2016; Duczko *et al.* 2022; J. Kershaw, National Museum Scotland; developed by B.Sz. Szmoniewski)

onwards, however, western European silver was gaining importance, associated, above all, with the exploitation of deposits in the Harz region and other mining centres of the Holy Roman Empire (Blanchard 2001). This process is reflected both in the composition of hoards and in the metal content of some of the earliest coin issues.

In the existing scientific literature, it has been generally assumed that the exploitation of local silver deposits of economic significance did not develop until a later period, predominantly in the second half of the 11th century and in the 12th century (Molenda 1963; Rozmus 2014; Paszkiewicz 2025). Nonetheless, the results presented below, which are based on the application of Lead Isotope Analysis (LIA) (Miśta-Jakubowska 2025), point to the possibility of an earlier use of these resources. Previous interpretations were founded chiefly on written sources, currently available archaeological evidence, mining archaeology, numismatic studies, and analyses of monetary circulation (e.g., Rozmus 2014; 2023; Kędzierski 2021; Paszkiewicz 2025).

The LIA findings introduce a new and independent category of evidence, making it possible to verify previous hypotheses formulated on the basis of more traditional source materials. Furthermore, one should bear in mind that attempts at determining the provenance of silver used in early Piast coinage have been made already (Pańczyk *et al.* 2015; Miśta-Jakubowska *et al.* 2019). The analytical procedures applied at that time represented an earlier stage in the development of isotopic methods and did not always provide analytical resolution, which limited the possibility of precisely relating the numerical results obtained to comparative geological datasets (Killick *et al.* 2020; Pernicka 2020). Therefore, first and foremost, these earlier findings should be regarded as an important stage in recognising the research problem and as a point of departure for investigations currently carried out by the authors of this study. Unlike previous research, the present results were obtained using high-resolution multi-collector inductively coupled plasma mass spectrometry (MC-ICP-MS), a state-of-the-art analytical approach for lead isotope provenance studies (Killick *et al.* 2020; Karasiński *et al.* 2023; Miśta-Jakubowska 2025). In addition to silver, lead and tin also played an important role in long-distance exchange and craft production in Central Europe (Kilger 2011; Mathur *et al.* 2024). Recent lead isotope studies demonstrate that the supply of silver, lead, and tin in Central Europe was derived from multiple sources, including growing exploitation of ore deposits in the Silesia-Kraków Upland region (Ottenwelter 2022, p. 354; Merkel *et al.* 2024; Miśta-Jakubowska *et al.* 2024; Jakubowska, Czech-Błońska *et al.* 2025; Pankiewicz *et al.* 2025).

The most recent results of lead isotope analyses indicate with a high degree of probability that in the 9th and early 10th centuries, the inhabitants of Great Moravia were using raw materials derived from the Silesia-Kraków Upland region (Robak *et al.* 2026). This interpretation is additionally supported by independent evidence

for early mining activity in that area, including the dating of mining shafts and recorded heavy metals present in peat bogs (Chróst 2013; Malik *et al.* 2023).

Taken together, these data suggest that the presence of standardised lead forms in the hoard from the hillfort of Bojná I, Slovakia, reflects the economic significance of this metal, extending beyond its purely utilitarian functions and including its role in local mechanisms of exchange and redistribution.

Merely a preliminary stage of the planned research involving a broader body of material, the pilot analyses of two coins presented in this paper show that dirham-derived silver was likely supplied to the mints of the Slavníkids and the early Přemyslids in the late 10th century. This phenomenon may be related to the relatively small number of dirham hoards containing dirhams known from the territory of present-day Czech Republic. The reasons for this pattern remain uncertain and require further investigation.

The comparative material included also two coins of King Stephen I of Hungary (997–1038) (Huszár 1979; *Corpus Nummorum* 2016). Preliminary analytical results suggest that they were struck from silver most probably derived from deposits in the Silesia-Kraków Upland region (Fig. 2: c below). This suggests that bullion from this area played a significant role in supra-regional circulation networks extending across the Pannonian Plain and, more broadly, Central Europe (Miśta-Jakubowska *et al.* in print).

Comparable isotopic signatures were also identified in a number of Bohemian coins, including issues of Bretislaus I (1034–1055). This phenomenon may be related both to that ruler's political control over Lesser Poland and to the inflow of silver acquired during the invasion of Poland in 1038–1039. This interpretation, however, should be further examined (Miśta-Jakubowska, Rozmus *et al.* 2025; Miśta-Jakubowska *et al.* in print).

Likewise, analogous signatures were recorded in some later Piast coins of the 12th century, including issues of Bolesław IV the Curly, Bolesław III the Wrymouth, and Władysław II the Exile (Miśta-Jakubowska, Rozmus *et al.* 2025; Miśta-Jakubowska *et al.* in print). This may be interpreted as evidence for the growing importance of silver derived from the Silesia-Kraków Upland region in supplying Piast coinage in the subsequent period (Miśta-Jakubowska *et al.* in print), which is consistent with previous observations (Suchodolski 2013). Nevertheless, it requires confirmation based on a broader corpus of analysed coins.

Altogether, the available lead isotope data (Robak *et al.* 2026) supported by environmental evidence (Chróst 2013; Malik *et al.* 2023) point to the possibility that the exploitation and distribution of lead derived from the Silesia-Kraków Upland region intensified as early as in the 9th century, around AD 830. Naturally, these data cannot be directly translated into the scale of silver extraction. Nevertheless, they suggest that mining and metallurgical activity in this area likely started earlier than previously assumed. In the existing literature, in general, economically

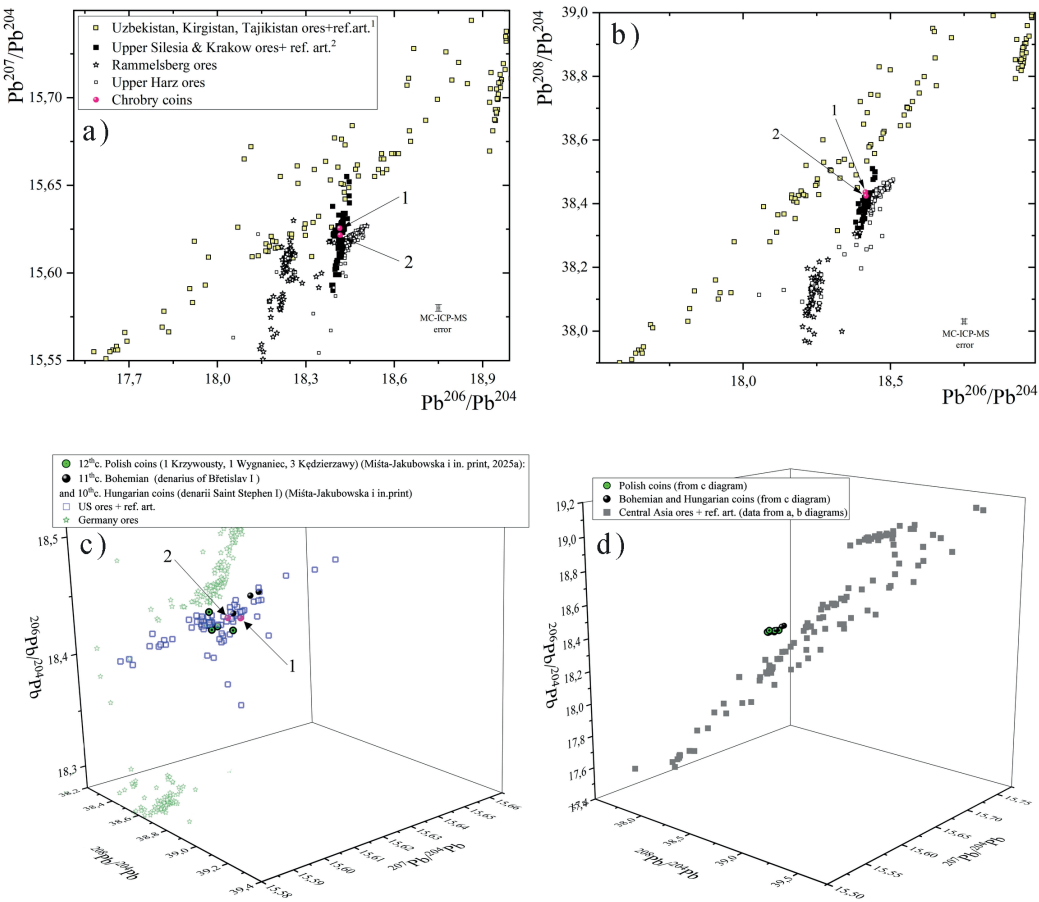


Fig. 2. Lead isotope ratios obtained for the analysed coins (Table 1): a – $^{207}Pb/204Pb$ vs. $^{206}Pb/^{204}Pb$; b – $^{208}Pb/^{204}Pb$ vs. $^{206}Pb/^{204}Pb$; c–d – 3D plots combining $^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$ ratios. The diagrams are compared with selected datasets of archaeological artefacts (after Merkel 2016, pp. 130–131, 195; Kershaw *et al.* 2021, Table 7; Wajda *et al.* 2023; Merkel *et al.* 2024; Mišta-Jakubowska, Dzięgielewski *et al.* 2025; Pankiewicz *et al.* 2025) and geological reference data (after Zartman *et al.* 1979; Church, Vaughn 1992; Pavlova, Borisenko 2009; Lehmann 2011; Chernyshev *et al.* 2017; Dolgopolova *et al.* 2017). Panels (c–d) additionally include comparative data for European coins discussed in the text (after Mišta-Jakubowska *et al.* in print). The plots demonstrate a clear separation between Central European ore sources (including the Silesia-Kraków Upland region/US ores and German deposits) and silver derived from the recycling of dirham bullion, indicating a relatively low level of interpretative uncertainty in provenance attribution for the analysed material (developed by E. Mišta-Jakubowska)

significant silver mining has been linked with the late 11th and 12th centuries (Rozmus 2014; 2023; Paszkiewicz 2025).

From the 11th century onwards, this process was accompanied by the widespread production of high-lead glass objects (Wajda *et al.* 2023; Pankiewicz *et al.* 2025), the development of glazing technologies used for vessels and glazed Easter egg rattles (e.g., Auch 2016; Błoński *et al.* 2025; Szmoniewski, Miśta-Jakubowska, Rozmus *et al.* 2025; Szmoniewski, Miśta-Jakubowska, Zamelska-Monczak *et al.* 2025), and by the manufacturing of ornaments, various craft products, and lead semi-finished goods (Merkel *et al.* 2024; Miśta-Jakubowska, Czech-Blońska 2025; Pankiewicz *et al.* in print). These phenomena are observed across a wide area encompassing the lands of Poland, Rus', Bohemia, and Slovakia (Fig. 1) (Ettler *et al.* 2015; Chugaev *et al.* 2021; Robak *et al.* 2026).

Alongside lead of western provenance arriving via Baltic trade routes (Kershaw, Merkel 2023), raw material from the Silesia-Kraków Upland region was an important component of long-distance exchange. It spread from centres of production along the principal trade routes towards Eastern Europe (Wajda *et al.* 2023; Merkel *et al.* 2024), reaching, among other places, Kyiv (Szmoniewski *et al.* in print), and then further northeast into the Suzdal region, which formed part of northeastern Kievan Rus' (Chugaev *et al.* 2021).

Figure 1 illustrates the concentration of early medieval silver hoards within the Baltic zone and Central Europe, as well as the spatial distribution of raw materials originating from the Silesia-Kraków Upland region. Traces of these materials, identified by means of Lead Isotope Analysis (LIA), extend from the territories of Bohemia and Poland to Kievan Rus', Scandinavia, and the Volga regions.

Research objective

Determining the provenance of the silver used for striking the earliest Piast coins is of considerable importance for understanding the relationship between long-distance exchange networks and the emergence of a politically controlled monetary system.

Bolesław I the Brave introduced the first Polish coinage, with more than 185 specimens currently known, associated with mints in Gniezno, Poznań, and Mogilno (Suchodolski 2025). His denarii fall into two principal groups, specifically, types that carry ideological messages referring to the ruler or the state and economic imitations of popular German, Bohemian, and Anglo-Saxon issues.

This paper seeks to identify the likely sources of the silver used for striking two early coins, including a specimen of the *Princes Polonie* type – the earliest coin bearing the name of *Polonia* – and to situate the obtained findings within a broader context of the metal supply networks operating in Central Europe in the 10th and 11th centuries.

It should be noted that this study is based on a limited sample. Although more than 185 coins of Bolesław I the Brave are currently known, in practice, expanding the analytical dataset continues to pose difficulties. Given that these coins are rare objects of exceptional historical and museum value, a permission for micro-destructive analyses is granted only in exceptional cases. Although the analytical procedure requires only very small samples taken from the edge of a coin and does not significantly affect its integrity, these limitations inevitably influence the size and representativeness of the available research sample.

Materials and methods

Two coins of Bolesław I the Brave were selected for analysis with the objective to determine the composition of their silver alloy and to undertake an assessment of the provenance of the bullion used in the minting process. One of the examined specimens is a Chapel-type denarius dating to ca. 1000–1010 that comes from the collection of the Copper Museum in Legnica. Although its findspot remains unknown, the coin is considered an authentic issue of Bolesław I the Brave (Fig. 3: a).

By contrast, the *Princes Polonie* type coin was discovered in a hoard deposited after 1039 or 1045 in grave 210 at site 4 in Kałdus (Fig. 3: b, c) (Chudziak *et al.* 2010; Bogucki *et al.* 2016, p. 250). It represents the latest type of denarius of this kind, minted on one side only, its weight relatively low (0.98 g) (Suchodolski 2025, p. 26). This denarius was most likely minted as late as 1010–1020 (Bogucki *et al.* 2016, no. 93).

The elemental composition of the coins was determined using portable X-ray fluorescence spectrometry (XRF) (Spectro Midex xSort), with measurements taken from areas visually unaffected by degradation processes (Duczko *et al.* 2022, pp. 265–274; Robak *et al.* 2026). Micro-samples were then taken from the rims of the coins for lead isotope analysis carried out by MC-ICP-MS, in accordance with the procedures described by Jakub Karasiński *et al.* (2023). The results are presented in Table 1.

Table 1. Elemental composition (wt.%) and lead isotope ratios determined by MC-ICP-MS (values reported with analytical uncertainties) of the analysed coins (Mišta-Jakubowska *et al.* in print)

No.	Ag	Cu	Pb	$^{208}Pb/^{204}Pb$	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb$	$^{208}Pb/^{206}Pb$	$^{207}Pb/^{206}Pb$
1	96.2 ±0.03	2.3 ±0.02	0.8 ±0.01	38.436 ±0.008	18.415 ±0.002	15.626 ±0.005	2.0865 ±0.0004	0.8483 ±0.0001
2	95.4 ±0.02	3.7 ±0.04	0.6 ±0.01	38.424 ±0.008	18.417 ±0.002	15.622 ±0.005	2.0857 ±0.0004	0.8480 ±0.0001



Fig. 3. The analysed denarii of Bolesław I the Brave: a – the Chapel type (ca. 1000–1010), no. 1; b – the *Princes Polonie* type (ca. 1010–1020) from the Kałdus hoard, no. 2; c – grave 210 containing the hoard in the 11th-century cemetery at Kałdus, site 4 (museum display) (developed by E. Miśta-Jakubowska)

Results

The elemental composition analysis showed that both coins were struck from high-grade silver alloy (95–96% Ag), containing a minor admixture of copper and a low concentration of lead, corresponding to good-quality mint alloy typical of early denarius issues (Matosz *et al.* 2023; Suchodolski 2025). Therefore, owing to the preliminary elemental analysis of the coin surfaces focused on the principal alloy components, it was possible not only to assess the quality of the bullion

examined, but also to verify the character of the lead present within it. It was particular important to determine whether this element was naturally associated, in geological terms, with the silver that the metal was derived from, or whether it had been intentionally introduced during metallurgical processing, a possibility discussed in the literature, especially where clearly elevated lead concentrations are observed (Pernicka 2014).

As shown by the data presented in Table 1, the lead content recorded in both analysed coins (0.6–0.8%) suggests that rather than a secondary technological addition, it was naturally associated with the silver. This means that the measured lead isotope ratios may be interpreted as an indicator of the provenance of the silver bullion that the lead originally co-occurred with in the ore rather than the result of subsequent alloying with an external metal. In other words, when discussing the LIA results on isotopic diagrams, we refer here primarily to the possible provenance of the silver itself, rather than to lead considered as an independent alloy component (Duczko *et al.* 2022, pp. 219–226; Miśta-Jakubowska 2025).

The results of the LIA analyses (Fig. 2: a, b, based on Table 1) indicate that the silver used for striking both analysed coins of Bolesław the Brave shows isotopic correspondence with Pb/Ag/Zn ores occurring in the Silesia-Kraków Upland region. This constitutes one of the earliest indications that Piast coinage may have drawn upon metal obtained from areas within the sphere of local control, rather than relying exclusively on western imports or the remelting of dirhams. Such an interpretation may point to access to relatively nearby deposits and suggest that the Piast rulers exercised tangible influence over regional raw material resources, which may in turn have strengthened Bolesław's position in his relations with the Empire and neighbouring political entities.

If confirmed in the course of further studies, the use of locally derived silver would suggest that the earliest Piast coinage was embedded in indigenous economic structures rather than functioning solely within an ideological or prestige-oriented framework.

With a high degree of probability, this perspective allows the beginnings of Polish coinage to be situated within the broader context of the Central European raw material economy at the turn of the 10th and 11th century.

Comparable isotopic signatures have also been identified in some later Piast coins dated to the early 12th century (Fig. 2: c, d). This may indicate a gradual transition from a supply model based primarily on imported metal towards one making greater use of regional resources. Such an interpretation is consistent with the increasing circulation of lead-silver raw material derived from the Silesia-Kraków Upland region documented in written sources for the closing decades of the 11th century, while also underscoring the strategic importance of this area within the economic networks of Central Europe (Rozmus 2014; Miśta-Jakubowska *et al.* in print).

When these observations are considered together with the broader comparative dataset currently under investigation (Miśta-Jakubowska, Rozmus 2025; Miśta-Jakubowska *et al.* in print), they also lend grounds for revisiting the hypothesis that the silver acquired during Bretislaus I's invasion of Poland (1038–1039) may have reached the Prague mint and influenced Přemyslid monetary policy. This hypothesis, however, requires further verification, particularly in light of the limited number of analysed coins attributed to Bretislaus I, of which only two exhibit isotopic signatures broadly comparable to those of the Silesia-Kraków Upland ores (Fig. 2: c). In addition, two analysed coins of King Stephen I of Hungary likely derive from a similar raw material base (Fig. 2: c). This may reflect broader patterns of silver circulation across Central Europe, linking the Piast, Přemyslid, and Árpád polities within shared networks of raw material supply.

Ongoing analyses of a larger corpus of Piast, Hungarian, and Přemyslid coins should allow this hypothesis to be verified and contribute to a deeper understanding of the geopolitical significance of the deposits of the Silesia-Kraków Upland region within the economic systems of Central Europe in the Early Middle Ages.

New data and the problem of silver provenance in early Piast coinage: a discussion

The previously expressed scepticism towards the hypothesis of the local origin of the silver in question should be considered justified given the limited state of research and the absence of data that would allow a direct assessment of bullion provenance (Paszkiewicz 2025).

The problem of the provenance of silver used in the earliest Piast coinage has been long subject to a scholarly debate (Kiersnowski 1960; Molenda 1963; Suchodolski 1973; 2013; Paszkiewicz 2025). Previous literature has rightly emphasised both the importance of silver derived from external sources – especially in the form of coins and bullion of eastern and western-European origin – and the methodological limitations that hindered the unambiguous identification of raw material sources (Duczko *et al.* 2022). Consequently, the hypothesis that the silver obtained from the local deposits played a significant role lacked sufficient documentation.

The findings presented in this paper, based on the analysis of two denarii of Bolesław I the Brave, do not definitively resolve the problem of bullion supply. Nevertheless, they provide a new significant body of material evidence in this debate. Both coins display comparable isotopic parameters consistent with the signatures observed for ores from the Silesia-Kraków Upland region (Fig. 2: a, b, d). This may suggest that, already in the early eleventh century, Piast coinage made at least partial use of silver derived from regional raw material sources.

The significance of this observation increases when considered alongside the authors' parallel studies of a broader group of 11th- and 12th-century coins, including Piast issues (Fig. 2: c, d) (Miśta-Jakubowska, Rozmus *et al*. 2025) and comparative material from Central Europe (Miśta-Jakubowska *et al.* in print). Preliminary results of these analyses indicate that isotopic signatures comparable to those obtained for the denarii examined in this study are not isolated occurrences, but may reflect a broader pattern of silver circulation connected with the Silesia-Kraków Upland region. This interpretation, however, requires final confirmation following the completion of the research programme and the publication of the full dataset.

At the same time, the data obtained do not exclude the continued use of imported silver or the repeated remelting of older bullion, both of which were typical features of the early medieval monetary economy. A mixed model therefore appears the most probable, in which the significance of regional raw materials gradually increased alongside incoming silver. From this perspective, the beginnings of Piast coinage may be interpreted as the result of the coexistence of different channels of metal supply, rather than as a system based exclusively on a single source of bullion. The new results do not close the debate on the provenance of silver in early Piast coinage, but they substantially broaden the evidential basis of that discussion.

Conclusions and postulates for further research

This study provides some of the earliest direct material indications that Piast coinage during the reign of Bolesław I the Brave may have used silver most probably derived from deposits in the Silesia-Kraków Upland region. The particular value of these findings lies in the fact that Lead Isotope Analysis (LIA) relates to measurable properties of the metal used to strike the coins themselves, and therefore to evidence directly connected with the bullion under investigation, rather than solely to indirect historical or archaeological indicators. The results obtained invite a reconsideration of the view that the earliest monetary production relied exclusively on silver derived from western imports or from the remelting of dirhams, instead suggesting a more complex model of bullion supply.

The data presented also make it possible to place the beginnings of Polish coinage within the broader context of the raw material economy of Central Europe, while contributing significantly to discussion of state formation processes and mechanisms of control over natural resources in the Early Middle Ages. They further suggest that access to regional metal sources may have constituted one of the key factors strengthening the economic foundations of the power of the first Piast rulers.

At the same time, it must be emphasised that further progress in this field requires an expansion of the evidential base, which in the case of the earliest Piast coins remains difficult owing to their rarity, high heritage value, and limited availability for micro-destructive analysis. These constraints mean that even small groups of new determinations retain substantial research value.

Acknowledgements

We would like to express our sincere thanks to Director of the Copper Museum in Legnica Marcin Makuch for granting access to the research material. We are especially grateful to Renata Czech-Błońska for collecting the sample from the Legnica coin, without which the present study would not have been possible. Likewise, we are grateful to Zofia Stos-Gale, PhD, for her invaluable scholarly guidance.

The research presented in this paper is part of the National Science Centre (Poland) project, "Silvery Dawn. Bullion Economy in the Piast State" (grant no. 2024/55/D/HS3/01791) and was also supported under grant no. 2022/45/B/HS3/01572.

References

Auch M., 2016, *Wczesnośredniowieczne naczynia szkliwione z terenu Małopolski*, Warszawa.

Blanchard, I., 2001, *Mining, metallurgy and minting in the Middle Ages. Asiatic Supremacy 425–1125*, vol. 1. Stuttgart.

Błoński M., Szmoniewski B.Sz., Miśta-Jakubowska E., Czech-Błońska R., Karasiński J., Kosiński T., 2025, *A glazed Easter egg rattle from a grave in the cemetery in Kołozą b. Technological features and lead provenance*, Światowit, vol. 63, pp. 63–78.

Bogucki M., Ilisch P., Suchodolski S., 2016, *Frühmittelalteriche* Münzfunde aus *Polen. Inventar II. Pommern*, Warszawa.

Chernyshev I.V., Golubev, V.N., Chugaev, A.V., 2017, *Anomalous lead isotopic composition of galena and age of altered uranium minerals: a case study of Chauli deposits, Chatkal--Qurama District, Uzbekistan*, Geology of Ore Deposits, vol. 59, no. 6, pp. 551–560.

Chróst L., 2013, *Ołowiowy ślad „Wiślan" odczytany z torfowisk obszaru kruszconośnego śląsko-małopolskiego*, [in:] *Argenti fossores et alii. Chronicum*, ed. P. Boroń, Wrocław, pp. 175–188.

Chudziak W., Bojarski J., Stawska V., 2010, *Wyposażenie grobów*, [in:] *Wczesnośredniowieczne cmentarzysko w Kałdusie*, ed. W. Chudziak, *Mons Sancti Laurentii*, vol. 5, Toruń, pp. 79–103.

Chugaev A.V., Merkel S.V., Zaytseva I.E., 2021, *Lead isotopic characteristics and metal sources for the jewelry in the medieval rural settlements from the Suzdal Region (Kievan Rus')*, Metalla, vol. 25, no. 2, pp. 101–125.

Church S.E., Vaughn R.B., 1992, *Lead isotopic characteristics of the Cracow-Silesia Zn-Pb ores, southern Poland*, U.S. Geological Survey, Open File Report 92–393.

Corpus Nummorum, 2016, *Corpus Nummorum Hungariae. Hungary's medieval coinage*, vol. 1: *(1000–1301)*, ed. Cs. Tóth, Budapest.

Dolgopolova A., Seltmann R., Konopelko D., Biske Yu.S., Shatov V., Armstrong R., Belousova E., Pankhurst R., Koneev R., Divaev F., 2017, *Geodynamic evolution of the western Tien Shan, Uzbekistan: insights from U-Pb SHRIMP geochronology and Sr-Nd-Pb-Hf isotope mapping of granitoids*, Gondwana Research, vol. 47, pp. 76–109.

Duczko W., Miśta-Jakubowska E., Czech-Błońska R., 2022, *Metale – Ozdoby – Historia. Relacje elit słowiańskich i skandynawskich w epoce Wikingów/Metals – Ornaments – History. Contacts of Slavic and Scandinavian Elites in the Viking Age*, Wrocław.

Ettler V., Johan Z., Zavřel J., Wallisová M.S., Mihaljevič M., Šebek O., 2015, *Slag remains from the Na Slupi site (Prague, Czech Republic), evidence for early medieval non-ferrous metal smelting*, Journal of Archaeological Science, vol. 53, pp. 72–83.

Gruszczyński J., 2016, Viking Age silver hoards in the Baltic Zone. Deposition and (non) retrieval, Medieval Archaeology Seminar, Institute of Archaeology, University of Oxford, 25 I 2016.

Huszár L., 1979, *Münzkatalog Ungarn von 1000 bis heute*, München.

Karasiński J., Bulska E., Halicz L., Tupys A., Wagner B., 2023, *Precise determination of lead isotope ratios by MC-ICP-MS without matrix separation exemplified by unique samples of diverse origin and history*, Journal of Analytical Atomic Spectrometry, 38, pp. 2468–2476.

Kershaw J., Merkel S., 2023, *International trade in outland resources: the mining and export of lead in early medieval England in light of new isotope data from York*, Medieval Archaeology, vol. 67, issue 2, pp. 249–282.

Kershaw J., Merkel S.W., Oravisjärvi J., Kooijman E., Kielman-Schmitt M., 2021, *The scale of dirham imports to the Baltic in the ninth century. New evidence from archaeometric analyses of early Viking-Age silver*, Fornvännen, vol. 116, no. 3, pp. 185–204.

Kędzierski A., 2021, *Skarb Słuszków I. Denary krzyżowe z przełomu XI i XII wieku. The Słuszków I hoard Cross denarii from the end of the 11th and the beginning of the 12th century*, Warszawa.

Kiersnowski R., 1960. *Pieniądz kruszcowy w Polsce wczesnośredniowiecznej*, Warszawa.

Kilger Ch., 2011, *Hack-silver, weights and coinage: the Anglo-Scandinavian bullion Coinages and their use in late Viking-Age society*, [in:] *Silver economies, monetisation and society in Scandinavia, AD 800–1100*, eds. J. Graham-Campbell *et al.*, *Silver Economies*, 4, pp. 259–281.

Killick D.J., Stephens J.A., Fenn T.R., 2020, *Geological constraints on the use of lead isotopes for provenance in archaeometallurgy*, Archaeometry, vol. 62, pp. 86–105.

Kóčka-Krenz H., 1993, *Biżuteria północno-zachodniosłowiańska we wczesnym średniowieczu*, Poznań.

Kóčka-Krenz H., 2020, *A goldsmith's workshop in the Poznań stronghold as an indication of cultural contacts between the Piast and Přemyslid dynasties*, Historia Slavorum Occidentis, 25 (2), pp. 91–108.

Lehmann R., 2011, Archäometallurgie von mittelalterlichen deutschen Silberbarren und Münzen, typescript of a doctoral thesis in the Leibniz Universität Hannover, Hannover.

Malik I., Bohr M., Wistuba M., Raab T., Bonhage A., Verschoof-van der Vaart W., Raab A., Woskowicz-Ślęzak B., 2023, *Multi-period ore exploitation in Upper Silesia, Central Europe*, Journal of Field Archaeology, vol. 48, no. 5, pp. 366–379.

Mathur R., Powell W., Miśta-Jakubowska E., Duczko W., Czech-Błońska R., Błoński M., Janowski A., Żołędziowski K., Jagodziński M., Gójska A., Kamenov G., 2024, *Isotopic metal compositions of Viking and medieval tin artifacts from Poland reveal expansive trade network*, Journal of Archaeological Science: Reports, vol. 53, https://doi.org/10.1016/j.jasrep.2023.104296.

Matosz M., Krupska-Wolas M., Hoyo-Melendez del J.M., 2023, *A multidisciplinary approach to the study of Polish silver denars minted in medieval Poland concerning their provenance and archaeological aspects*, Open Access Journal of Archaeology and Anthropology, 4 (3), doi: 10.33552/OAJAA.2023.04.000589.

Merkel S.W., 2016, *Silver and the silver economy at hedeby. Raw materials, innovation, technology of ancient cultures RITaK 2*, Der Anschnitt, 33, Bochum–Rahden/Westf.

Merkel S.W., Florkiewicz I., Jansen M., Bode M., Wołoszyn M., 2024, *Evidence for Slavic lead mining and trade: early Rus' lead seals from Czermno and Gródek on the Polish-Rus' border*, Journal of Archaeological Science: Reports, vol. 56, 104539, https://doi.org/10.1016/j.jasrep.2024.104539.

Miśta-Jakubowska, E., 2025, *Izotopy metali (Pb, Sn, Ag)*, [in:] *Mikroprzeszłość*, part 2: *Badania specjalistyczne w archeologii*, eds. A. Kurzawska, I. Sobkowiak-Tabaka, Poznań, pp. 211–228.

Miśta-Jakubowska E., Czech-Błońska R., Duczko W., Antowska-Gorączniak O., Szeliga M., Karasiński J., 2025, *Pochodzenie surowca wykorzystywanego w XI-wiecznym warsztacie złotniczym w Rybitwach na stanowisku 12 koło Ostrowa Lednickiego. Badania wstępne*, Studia Lednickie, vol. 24, pp. 91–115.

Miśta-Jakubowska E., Czech-Błońska R., Duczko W., Gójska A., Kalbarczyk P., Turos A., Żabiński G., 2019, *Origin and production of silver in early medieval Poland*, Archaeologia Polona, vol. 57, pp. 241–255.

Miśta-Jakubowska E., Duczko W., Kowalska A.B., Czech-Błońska R., Mathur R., Gójska A., Rozmus D., Siuda R., Oleszak D., Brojanowska A., Klimaszewski J., 2024, *Amulets from Viking-age Baltic coast: a unique hoard from Piaski-Dramino (Poland) in the light of provenance and technological research of silvercraft art*, Journal of Archaeological Science: Reports, 53, 104356, https: //doi.org/10.1016/j.jasrep.2023.104356.

Miśta-Jakubowska E., Dzięgielewski K., Rozmus D., Czech-Błońska R., Szymaszkiewicz M., Michnik M., Gójska A., Karasiński J., Garbacz-Klempka A., Wagner B., Duczko W., 2025, *The first isotopic evidence of Early Iron Age lead ore exploitation in the Silesian-Krakow Upland, Poland*, Archaeometry, vol. 67, issue 3, pp. 552–569.

Miśta-Jakubowska E., Matla M., Rozmus D., Kędzierski A., Szmoniewski B.Sz., Czech-Błońska R., Duczko W., Pankiewicz A., Gójska A., Karasiński J., Tetfejer K., Chudziak W., Kowalska A.B., Bojarski J., in print, Silvery dawn: the first use of local silver in early Piast coinage (11th–12th century Poland), Journal of Archaeological Science: Reports.

Miśta-Jakubowska E., Rozmus D., Kędzierski A., Szmoniewski B.Sz., Czech-Błońska R., Duczko W., Pankiewicz A., Matla M., Gójska A., Karasiński J., Tetfejer K., 2025, "*Silvery Dawn*": *an introduction to monetary geopolitics in the early Piast state – a study of coinage silver provenance using lead isotope analysis*, SSRN, https://doi.org/10.2139/ssrn.5649946.

Molenda D., 1963, *Górnictwo kruszcowe na terenie złóż śląsko-krakowskich do połowy XVI wieku*, Wrocław.

Ottenwelter E., 2022, *Early medieval elite jewellery from Great Moravia and Bohemia. Manufacturing processes, construction, materials and condition*, Mainz.

Pankiewicz A., Miśta-Jakubowska E., Karasiński J., in print, Utility and origins of lead in the Early Middle Ages: based on finds from Ostrów Tumski in Wrocław, Sprawozdania Archeologiczne, vol. 78/1.

Pankiewicz A., Miśta-Jakubowska E., Siemianowska S., Czech-Błońska R., Błoński M., Mathur R., Karasiński J., Siuda R., Żabiński G., Gójska A., 2025, *Origins of medieval lead glass ornaments in Central Europe in the light of lead isotopic analysis of finds from Wrocław and Sypniewo (Poland)*, Journal of Archaeological Science, vol. 176, https://doi.org/10.1016/j.jas.2025.106168.

Paszkiewicz B., 2025, *Habebanturne in regno polonie montana argenti? Silver mining versus coinage and power in medieval Poland*, Wiadomości Numizmatyczne, 69 (213), pp. 95–143.

Pańczyk E., Sartowska B., Waliś L., Dudek J., Weker W., Widawski M., 2015, *The origin and chronology of medieval silver coins based on the analysis of chemical composition*, Nukleonika, 60 (3), pp. 657–663.

Pavlova G.G., Borisenko A.S., 2009, *The age of Ag-Sb deposits of Central Asia and their correlation with other types of ore systems and magmatism*, Ore Geology Reviews, vol. 35, issue 2, pp. 164–185.

Pernicka E., 2014, *Provenance determination of archaeological metal objects*, [in:] *Archaeometallurgy in global perspective: methods and syntheses*, eds. B.W. Roberts, C.P. Thornton, Heidelberg, 239–268.

Pernicka E., 2020, *Lead isotope ratios and the provenance of medieval silver. A comment on "Archaeometric studies on early medieval silver jewelry from Central and Eastern Europe"*, Archaeological and Anthropological Sciences, vol. 12, p. 165.

Robak Z., Miśta-Jakubowska E., Szmoniewski B.Sz., Czech-Błońska R., Karasiński J., Pieta K., 2026, *Tracing the origins: isotopic evidence from early medieval lead ingots from Great Moravian hillforts in Slovakia*, Journal of Archaeological Science: Reports, 71, 105680, https://doi.org/10.1016/j.jasrep.2026.105680.

Rozmus D., 2014, *Wczesnośredniowieczne zagłębie hutnictwa srebra i ołowiu na obszarach obecnego pogranicza Śląska i Małopolski (druga połowa XI–XII/XIII wiek)*, Kraków–Dąbrowa Górnicza.

Rozmus D., 2023, *20 Years of research on the beginnings of early medieval mining and metallurgy of lead and silver in Poland/20 Jahre Forschung zu den Anfängen des Bergbaus und der Verhüttung von Blei und Silber in Polen*, [in:] *Frühmittelalterliches Hacksilber im nördlichen westslawischen Raum. Archäologie und Archäometallurgie*, eds. F. Biermann *et al.*, Bonn, pp. 175–200.

Suchodolski S., 1973, *Mennictwo polskie w XI i XII wieku*, Wrocław.

Suchodolski, S., 2013, *W sprawie pochodzenia srebra w monetach polskich z XI–XII wieku*, [in:] *Argenti fossores et alii. Znaczenie gospodarcze wschodnich części Górnego Śląska i zachodnich krańców Małopolski w późnej fazie wczesnego średniowiecza (X–XII wiek)*, ed. P. Boroń, Wrocław, pp. 257–260.

Suchodolski S., 2025, *Co już wiemy, a czego jeszcze nie wiemy o monetach Bolesława Chrobrego*, Warszawski Pamiętnik Numizmatyczny, vol. 13, pp. 11–41.

Szmoniewski B.Sz., Miśta-Jakubowska E., Rozmus D., Czech-Błońska R., Siuda R., Karasiński J., Trela K., 2025, *Technological insights into early medieval Slavic lead-glazed pottery: local craftsmanship and its broader archaeometric context*, Światowit, vol. 63, pp. 79–97.

Szmoniewski B.Sz., Miśta-Jakubowska E., Söderberg A., Czech-Błońska R., in print, Across half of Europe: tracing the supply chain from Olkusz via Kyiv to Sigtuna, Situne Dei.

Szmoniewski B.Sz., Miśta-Jakubowska E., Zamelska-Monczak K., Siuda R., Kolenda J., Czech-Błońska R., 2025, *Medieval glazed ceramics from Kraków Nowa Huta-Zesławice, site 88, Lesser Poland voivodeship. Their formal and technological analysis*, Sprawozdania Archeologiczne, vol. 77 (2), pp. 475–506.

Wajda S., Merkel S.W., Florkiewicz I., Jansen M., Marciniak-Maliszewska B., Wagner B., Wołoszyn M., 2023, *Early mediaeval lead glass bangles from Czermno, Poland: results of elemental and lead isotopes analyses*, Archaeometry, https://doi.org/10.1111/arcm.12907.

Zartman R.E., Pawłowska, J., Rubinowski, Z., 1979, *Lead isotopic composition of ore deposits from the Silesia-Cracow mining district*, [in:] *Research on the genesis of zinc-lead deposits of Upper Silesia, Poland*, Prace Instytutu Geologicznego, 95, pp. 133–151.