Correction to: Archaeometric studies on early medieval jewellery from central and Eastern Europe

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We would like to thank Prof. Nicholas Conard for interest in our paper and we are glad that our work has attracted attention of Prof. Ernst Pernicka who is an eminent authority in the field of archaeometry. We have studied Professor Pernicka's remarks in details and we would like to clarify doubts concerning the appropriateness of use of laser ablation coupled with a quadrupole mass spectrometer in archaeometry.

Silver finds which are discovered, among others, in hoards from Poland are a resultant of many technological processes which left their mark in the elemental and isotopic composition of these artefacts. The earlier a given find is, the more probable it is that it was manufactured from scrap metal in the course of re-melting. While considering the Pb isotopic composition as a “deposit's fingerprint” one must take into account not only the contribution provided by a given deposit (which may be isotopically homogeneous or not, see Baron et al. 2009; Baron et al. 2014; Brill and Wampler 1967), but also intentional additions. What

was intentionally added to silver was copper (Ashkenazi et al. 2017) in order to improve the toughness of the resulting alloy. In the case of ornaments, copper-based solders and additions of alien lead can be found. These may have also been remains left by the PbS cupellation process (Merkel 2016), where alien lead was also applied (Baron et al. 2009) as a component of soldering recipes (see Leyden Papyrus X, Recipe 11; Stawicki 1987). Copper co-occurs with silver deposits in Ag – Cu – Pb – S systems, as it is the case with Pribram, Romania, Poland, Germany, or Slovakia deposits (benjaminite¹ and bournite² minerals). Therefore, an addition of copper as an element of Pb – Cu ores (e.g. boumonite, bournite) can also contribute to a measured value of a Pb isotopic ratio (Cattin et al. 2009). The process of thermal treatment in the case of ornament manufacture is not homogeneous in the macroscale, which may cause imperfect mixing of the raw material. Thus, it may not cause averaging of isotopic results (Baron et al. 2006; Merkel 2016) in the microscale. In order to identify all these variables, a LIA methodology based on developed measurement statistics was proposed in this work. An LA-ICP-QMS technique was applied, due to its availability, quick results and its applicability in archaeometallurgical examinations (Segal and Halicz 2004; Halicz et al. 1996; Guerra et al. 1999). In spite of the fact that this technique produces a considerable error as compared with MC-ICP-MS or TIMS, it seems sufficient for preliminary research (Marzo et al. 2007). This is confirmed by results of comparative analyses (own unpublished research) carried out on dirhams which have been well-identified both historically and geologically (among others, Merkel 2016; Merkel et al. 2013). Figure 1 offers results of own examinations (acquired with the LA-ICP-QMS method, analogously to ornament examinations which are discussed in the paper) on dirhams from the Al-Shash mint (Uzbek deposit) and the Andaraba mint (Afghan deposit). Data on the deposit composition, acquired with the MC-ICP-MS and LA-MC-ICP-MS techniques, were obtained from available literature (Merkel 2016; Merkel et al. 2013).

In order to illustrate the convergence of literature data and the results yielded by own research, a provenance study was

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Fig. 1 LDA graph with the provenance of the examined coins. DeAF – Deposit Afghanistan; DeUZS – Deposit Uzbekistan (Slag); DeUZO – Deposit Uzbekistan (Ore) (Merkel 2016; Merkel et al. 2013)

carried out. It concerned dirhams from mints in Afghanistan (Balkh, Andaraba, Panjhir – literature data: Merkel 2016; Andaraba – own research) and Uzbekistan (Al-Shash, Samarquand – literature data: Merkel 2016; Al-Shash – own research). Coin data was compared with available data on Pb isotopic ratios of silver deposits (Merkel 2016; Merkel et al. 2013). Both the literature data as well as the data from own research are averaged results of a dozen or so measurements for a given find. In order to study the coin provenance, Linear Discriminant Analysis was applied, which is a method commonly used in provenance studies (see, e.g., Żabiński et al. 2020; Leroy et al. 2017, with further reading; see also Baxter 2016; Baxter 2003).

As it can be seen in Tab. 1, there are strong differences between Pb isotopic ratios of Afghan and Uzbek silver deposits and there is no overlapping between the two. Partial overlapping of data concerning Uzbek ore and slag is of no significance for further discussion.

While assessing the provenance of the coins, it was assumed that the coins from Afghan mints were struck from Afghan silver and those from Uzbek mints – from Uzbek silver (the

Table 2 Results of LDA-based provenance classification of dirhams

Mints	Classification		Total	% proper
	proper	improper		
BaLi(AF)	1	4	5	20.00
AndLi(AF)	0	6	6	0.00
PanLi(AF)	0	2	2	0.00
ASLi(UZ)	15	0	15	100.00
SaLi(UZ)	12	0	12	100.00
All Literature Data	28	12	40	70.00
ASRe(UZ)	3	0	3	100.00
AndRe(AF)	1	1	2	50.00
All Research Data	4	1	5	80.00

BaLi(AF) – Balkh, Afghanistan (literature data: Merkel 2016); AndLi(AF) – Andaraba, Afghanistan (literature data: Merkel 2016); PanLi(AF) – Panjhir, Afghanistan (literature data: Merkel 2016); ASLi(UZ) – Al-Shash, Uzbekistan (literature data: Merkel 2016); SaLi(UZ) – Samarquand, Uzbekistan (literature data: Merkel 2016). ASRe(UZ) – Al-Shash, Uzbekistan (research data); AndRe(AF) – Andaraba, Afghanistan (research data)

afore-mentioned partial difference between ore and slag was omitted). Therefore, only such a provenance assessment was considered “correct”. Obviously, such an approach neglects possible cases of minting coins from silver which was composed from raw material of various deposit provenance (such differences would be tangible in examinations on individual measurement values and not on their averages). However, in this case the main objective is to compare the quality of data that was acquired with the MC-ICP-MS and the LA-ICP-QMS methods.

As it can be seen, a vast majority of the literature data is “correctly” classified (100% for the Al-Shash and Samarquand mints). On the other hand, there is also a considerable share of “incorrect” classifications (all for the Andaraba and Panjhir mints and a majority for the Balkh mint). While comparing these results to those obtained for the research data, it is remarkable that in the assemblage of the Al-Shash mint coins (which are present both in the literature data and the research data) the share of “correct” classifications is 100% in both cases. Furthermore, there was a 50% correct classification of the Andaraba mint coins. This seems to strongly suggest that the quality of the data obtained with the LA-ICP-QMS method is not worse than the quality of the MC-ICP-MS data and the share of “correct” classifications depends more on the analysed finds (made from homogeneous metal or not) than on the applied research method. A more extensive study on this subject is under preparation.

In the paper it was stated that: “In the latter case, geological data (as means) was taken from available literature (Ettler et al., 2015; Merkel et al. 2013; Hatz et al., 1991)”. The

Table 1 Confusion matrix for the training sample (deposit data)

from \ to	DeAF	DeUZO	DeUZS	Total	% correct
DeAF	9	0	0	9	100.00%
DeUZO	0	7	3	10	70.00%
DeUZS	0	0	11	11	100.00%
Total	9	7	14	30	90.00%

DeAF – Deposit Afghanistan; DeUZS – Deposit Afghanistan (Slag); DeUZO – Deposit Afghanistan (Ore) (Merkel 2016; Merkel et al. 2013)

reference should be changed into: (Höppner et al. (2005); Andráš et al. (2010); Černyšev et al. (1984); Ettler et al. (2004), Legierski and Vaněček (1967), quoted after Ettler et al. 2015); De Vleeschouwer et al. (2009); Niederschlag et al. (2003) and Hatz et al., 1991: Tab.6, p. 96–97; Merkel 2016: Tab.7, p. 199; Merkel et al. 2013). All geological data which was processed in the text is a preliminary recognition, including published data on metallurgical centres (that is, Gammersheim and Buchberg), which are the closest with regard to their location. The use of this data could be correlated with the manufacturing process of jewellery as part of intentional additions in the soldering process. The latest research of Polish scientists on the potential exploitation of Zn-Pb and MVT ore deposits as early as the 10th and 11th centuries in the Silesia-Cracow region in southern Poland should also be noted here. The geochemical and mineralogical methods that were used in this research allowed to identify mineralogical phases formed during metallurgical processes and ore processing without resorting to a Pb ratio study (Cabała et al. 2020, see also Rozmus 2014). Apart from those listed, there is no reliable deposit data for Central Europe. Apart from that, while discussing the isotopic composition of complex artefacts (such as ornaments), it is necessary to take into consideration not only isotopic data of “clear” geological deposits, but also semi-products understood as possible admixtures of scrap metal. The chronology of the examined ornaments is conventional, too, as the hoards are dated to on the basis of the latest coin which was present within the assemblages (the so-called *terminus ante quem*). This does not exclude a possibility that other finds that were part of these hoards had been used earlier or later. The discussed results will be developed when new deposit data is obtained. It is also intended to complete them, if necessary, with high-precision MC-ICP-MS analyses.

We believe that our discussion has dispelled all doubts concerning methodological and scientific reliability of our research that have been raised by Prof. Pernicka. Furthermore, we assume that our work will bring a new value to the academic discussion and thus will contribute to further studies on the provenance of early medieval silver from Central and Eastern Europe.

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² https://www.mindat.org/minlocsearch.php?frm_id=mls&cform_is_valid=1&cf_mls_page=1&minname=bournonite®ion=romania&fbclid=IwAR0K-X21JfoXr_yVA6A_roiy0mnBrQUdSfkRphIN0CS_UsuY_IzzE-P11QfDw access on 10 April 2020b

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