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Analysis of Greek small coinage from the classic period

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ABSTRACT

A series of 25 Greek coins from the 6th to 4th centuries BC was studied by PIXE for their trace element composition, with an aim to discover the origin of their silver ore. The procedure revealed a counterfeited coin, and then concentrated on distinguishing the coins minted from the ore of Laurion on the Attica peninsula and the coins minted from other sources. Linear discriminant analysis based on the impurities and alloying elements of copper, gold, lead and bismuth revealed that discrimination is indeed possible according to a single canonical variable.

1. Introduction

The metal sources exploited by early Greek cities and used for minting their coins is of major historical interest. As the metal silver was mainly extracted by the cupellation method from the lead-silver ores, the most efficient method for studying the provenance of silver and copper ores is the ratio of lead isotopes $^{207}Pb/^{206}Pb$ and $^{208}Pb/^{206}Pb$ [1]. In their pioneering work, Barnes and al. [2] showed that the various mines in the region of Laurion, located at the southeastern part of the peninsula of Attica, showed a very distinct lead isotope ratio. It was homogeneous within the broad mining region, but different from those of other silver mines located around the Mediterranean (Sardinia, Italy, Egypt, Turkey, Iran) and in mainland Europe (England, Germany). Later research concentrated to the mines that were available to the Greeks, like the mines on the islands of Siphnos and Thasos, both mentioned by Herodotus. Siphnos appeared as second important silver source for the Greeks and showed the lead isotope ratio rather different from that of Laurion, while the values for other mines (in Asia Minor, Thasos, Macedonia and Thrace) can be placed in between the two [3,4]. Comparing the silver ores and Greek coins it was found out that in the classical period, the Athens minted coins exclusively from the ores of Laurion, while the other cities used ore from all available sources [3,4]. Identical lead-isotope ratios for the ores from Laurion and Athenian coins also mean that the lead-isotope ratio is insensitive to the smelting processes [5].

Isotopic measurements require sampling, which may not be desired for small objects of historic and aesthetic values, such as coins. In this contribution, we would like to explore the possibility of distinguishing silver coins according to the trace elements in silver ore, relying on the fast and non-destructive features of the PIXE method. Our approach was encouraged by the statement in the work [6], saying: "The analyses already performed on Athenian coins have established that Laureion's silver is characterized by a low gold and copper content and a high content of lead." The statement also cites two older references [3,7], which involve earlier attempts to characterize silver coins according to the trace elements. In newer literature, the Greek drachms from the site Emporion in Spain were also characterized according to the content of trace elements, with the results that the composition cannot be distinguished according to the strike period between the fourth and first centuries BC [8].

The main aim of the present paper is to distinguish the Athenian coins of the 5th century BCE from their contemporary coins of other Greek cities. We shall concentrate on the small coinage, since it was easier accessible to us, and since we expect that point analysis with a proton beam would be more representative of the bulk. The presence of surface enrichment effects [9–11] may not be totally excluded; however, as the coins seem to be made of rather pure silver (we checked the density of one of the coins, a drachma, to be 10.7 ± 0.3 gcm^{-3}) we estimate they are not as pronounced as we detected in the small Celtic coinage [12].

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2. Experimental

The coins were irradiated by in-air proton beam obtained from the Tandetron accelerator of the Jožef Stefan Institute in Ljubljana. The nominal proton energy was 3 MeV, but after passing an 8 μm aluminum exit window and a 1 cm air gap it was reduced to approximately 2.77 MeV on the target. The beam profile at the target was Gaussian, with 0.8 mm full-width at half maximum. The beam current was about 1 nA and each point was irradiated by 300–500 s. The Si(Li) X-ray detector was positioned 6. 5 cm from the target and equipped with an additional absorber of 0.1 mm aluminum foil, which provided good balance between copper and silver K X-rays, and allowed detection of softer X-rays up to iron. The spectra were analyzed by the AXIL program, and the respective elemental concentrations were deduced by the code [13] that allows secondary X-rays excitation correction; the impact proton number was not measured as the sum of all elemental fractions was normalized to unity.

The set of analyzed silver coins includes 25 species obtained from private collections and from the numismatic cabinet of the National Museum of Slovenia. Nine coins belonged to the Athens (one of them was identified as a modern forgery during the study) and 16 coins belong to other Greek cities located in the Aegean, South Italy and Black Sea coast (Table 1, first two columns). Beside the small pieces, we also analyzed two larger nominals that were on our disposal, a tetradrachm from Athens and a drachm from Parion. The coins were not polished before the analysis, but only gently washed with alcohol. The smoothest and patina-free region of the coin was used for analysis. Though the measured surface was not completely plain and smooth we chose an impact angle of 22° and the X-ray emission angle of 23° in our calculations. By variation of the angles in the calculation, we estimated that deduced concentration uncertainties were about 5–10%.

3. Results

The deduced concentrations are shown in Table 1. Generally, only one measurement was made per coin, and two in a few examples. For these we either calculated a mean (like for the tetradrachm that was measured on both sides) or chose a value that showed presence of less corrosion products (like bromine).

4. Discussion

The majority of coins exhibit a low coper content, which excludes intentional alloying with copper (Fig. 1). All but one Athenian coins are indeed characterized by a low copper content (below 2%) and a high content of lead (above 0.5%). The exception is an Athenian coin that contains a much higher content of copper (about 10%) and undetectable content of gold. If this were a true Athenian coin, such composition would indicate an inflationary debasement of the original silver. However, this coin showed itself as a modern fake. During our study, we were able to acquire an additional coin that is a die-copy of the coin in question (Fig. 2, Nos. 3, 4), but its analysis showed 0.25% Fe, 13.6% Ni, 71.8% Cu, 10.3% Zn and 4.03% Ag. This indicates a modern nickel-copper-zinc alloy, also known as new silver, alpaca or German silver, with a silver wash. The use of this alloy was common in the late 19th and early 20th century, but for a recent forgery, it is likely that the counterfeiter used an alloy that is easily obtainable, such as those in modern coins. Silver-like alloys in modern coin are mostly cupro-nickel, while those that also contain zinc are relatively rare and might point to the region of forgery. The normalized fractions in the counterfeited coin (14.2% Ni, 75.0% Cu, 10.8% Zn) matches closely to the composition of the modern Turkish lira with nominal concentrations 14% Ni, 75% Cu, 10% Zn [14].

The Athenian coin with 10% Cu can then be excluded from our analysis, yet we keep it in the figures for comparison and as a test

Table 1
Coins involved in the analysis and the respective concentrations in mass %. Abbreviations: SNG – Syllogae Nummorum Graecorum; n.d. – not detected. The first of the Athenian coins also showed 0.17% Mn, which, together with a high iron content, may be impurity from the earth.

		Fe	Ni	Cu	Zn	As	Br	Mo	Ag	Au	Hg	Pb	Bi
Aegina, obol, 550–456 BCE	SNG Cop. 511	0.12	n.d.	0.396	0.164	n.d.	0.55	n.d.	97.4	0.576	n.d.	0.847	n.d.
Boetia, Thebes, 550–480 BCE	SNG Cop. - (2 5 5 –)	1.47	0.018	0.167	0.020	n.d.	0.019	n.d.	98.1	0.043	0.020	0.107	n.d.
Ionia, indet. archaic, tetartemorion, 6th c. BC	SNG Mün. – (ad 13)	0.95	n.d.	1.02	n.d.	0.020	n.d.	n.d.	97.6	0.138	n.d.	0.159	0.075
Ionia, Miletus, 6th c. BC	SNG Cop. 945	0.06	n.d.	0.294	0.008	n.d.	n.d.	n.d.	98.7	0.065	0.098	0.498	0.252
Ionia, Miletus, 6th c. BC	SNG Cop. 952	0.28	n.d.	0.114	n.d.	n.d.	0.035	n.d.	98.6	0.823	n.d.	0.091	0.016
Lesbos, Methymna, obol, 420–377 BCE	SNG Cop. 351	1.01	n.d.	1.48	n.d.	n.d.	n.d.	0.070	96.3	0.042	n.d.	1.11	0.026
Lucania, Metapontum, diobol, 6th-early 5th c. BC	SNG Cop. 1181	0.62	n.d.	0.86	n.d.	n.d.	0.452	n.d.	97.3	0.549	n.d.	0.196	0.061
Macedonia, Mende, hemiobol, 480–450 BCE	SNG Cop. 207	0.37	n.d.	0.253	n.d.	n.d.	0.59	n.d.	98.5	0.065	n.d.	0.063	0.205
Mysia, Lampsacus, diobol, 4th c. BC	SNG Cop. 184	0.22	n.d.	3.76	0.024	n.d.	0.043	n.d.	95.3	0.545	n.d.	0.098	n.d.
Mysia, Lampsacus, diobol, 500–470 BCE	SNG Cop. 189	1.00	n.d.	0.05	n.d.	n.d.	n.d.	n.d.	98.3	0.367	n.d.	0.248	0.026
Mysia, Parium, drachma, 5th c. BC	SNG Cop. 256	0.17	n.d.	0.073	0.006	n.d.	0.079	n.d.	98.0	0.025	n.d.	1.61	0.069
Thracia, Apollonia Pontica, hemiobol, late 5th-4th c. BC	SNG BMC 149 var.	0.10	n.d.	1.19	n.d.	n.d.	n.d.	n.d.	98.6	0.118	n.d.	0.006	0.017
Thracia, Apollonia Pontica, hemiobol, late 5th-4th c. BC	SNG BMC- (149-)	0.61	n.d.	0.408	0.016	n.d.	n.d.	n.d.	98.3	0.598	n.d.	0.053	0.043
Thracia, Apollonia Pontica, diobol, late 4th c. BC	SNG BMC 167	0.13	n.d.	2.65	0.008	n.d.	0.041	n.d.	96.1	0.594	n.d.	0.475	n.d.
Thracia, Mesembria, diobol, 4th c. BC	SNG BMC 268	0.04	0.039	13.3	n.d.	n.d.	n.d.	n.d.	85.4	0.033	n.d.	0.285	n.d.
Troas, Antandros, triobol, 440–400 BCE	SNG Cop. 214	0.19	n.d.	0.29	n.d.	0.020	n.d.	n.d.	99.2	0.140	n.d.	0.190	0.018
Attica, Athens, obol, 566–490 BCE	SNG Cop. 24	3.00	n.d.	0.49	n.d.	n.d.	n.d.	0.069	94.6	0.081	n.d.	1.50	0.039
Attica, Athens, obol, 566–490 BCE	SNG Cop. 24	0.29	n.d.	0.09	n.d.	n.d.	n.d.	n.d.	98.3	n.d.	n.d.	1.34	0.028
Attica, Athens, hemiobol, 479–393 BCE	SNG Cop. 59	0.51	0.003	0.102	0.004	n.d.	0.095	n.d.	97.8	0.007	n.d.	1.47	0.013
Attica, Athens, hemiobol, 479–393 BCE	SNG Cop. 59	0.74	n.d.	0.88	n.d.	n.d.	0.657	n.d.	97.0	0.121	n.d.	0.612	0.015
Attica, Athens, obol, 479–393 BCE	SNG Cop. 53	0.24	n.d.	1.92	n.d.	n.d.	0.028	n.d.	96.0	0.036	n.d.	1.75	0.029
Attica, Athens, obol, 479–393 BCE	SNG Cop. 53	0.85	n.d.	0.36	n.d.	n.d.	0.005	n.d.	97.3	0.095	n.d.	1.24	0.163
Attica, Athens, tetradrachma, 479–393 BCE	SNG Cop. 31	0.03	n.d.	0.025	n.d.	n.d.	n.d.	n.d.	98.3	0.020	n.d.	1.58	0.028
Attica, Athens, diobol, 393-3rd c. BC	SNG Cop. 53	0.10	n.d.	0.061	n.d.	n.d.	n.d.	n.d.	99.2	0.014	n.d.	0.630	0.031
Attica, Athens, obol, 479–393 BCE (false)	SNG Cop. 53	0.09	n.d.	9.20	n.d.	n.d.	n.d.	n.d.	90.7	n.d.	n.d.	0.064	n.d.

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