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Analysis of ancient silver coins

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Abstract

Writing from the numismatist point of view, the authors open this paper by reviewing critically the use of scientific methods for the studies of ancient coins. They also report about an application of the PIXE method at low incident proton energy to one of the most celebrated and known coinage in the ancient history: the Athenian silver coins of the fifth century BC. The results of those analyses indicate that the metallic composition of several coins usually taken as ancient imitations of Athenian coins does not differ from that of the genuine ones. Those analyses confirm what the authors have inferred from numismatic sources: These coins are probably genuinely Athenian.

Keywords: Athens; Coins; PIXE; Imitations

1. Introduction

We may say that when numismatists call to analytical physicists it is because they are confronted with problems that traditional methods of numismatics cannot solve. And for more than two centuries, their collaboration was quite intensive and also led to open new ways of investigation for numismatists. Without pondering of any methods, we should like first to present a swift overview of use of metallic analyses in numismatics. Barradon and Guerra [1] define three directions in the application of scientific methods to coins: analysis of alloys, determination of provenance of the metal and technological studies. For this paper, we will focus on the first two ones. Before the 20th century, the numismatists were only concerned with the analysis of alloys and used chemical methods or specific gravity [2]. The performed analyses focused then on major components of the coinage alloy. Such studies gave numismatists precious indications, especially of economic order [3]. The question concerning the provenance of the metal used to strike coins emerged doubtless at the end of the 19th century and at the beginning of the 20th century [4]. Certainly numismatists owed their inspiration to collaboration with scientists. The advent of accurate and non-destructive instrumental techniques in the sixties was synonymous with great changes in metallic analysis applied to numismatics. The first step, say Condamin and Picon [5], was to use non-destructive physical

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methods of analysis of the surface of the coins (XRF), then non-destructive physical methods of analysis of the whole coin (NAA). Now, the difficulty is perhaps for a numismatist to choose between all the available methods.

We will now draw attention to the difficulties encountered by numismatists when they had to draw conclusions from the results of such analyses. One of the most dangerous traps is to merge the original composition of the coins and its present composition. Between the minting of a coin and its analysis by modern methods, a lot of years rolled by and the chemical composition of the coin may have suffered important changes. We know, for example, the phenomenon of iron enrichment due to dust incrusted at the surface of the coin, as well as corrosion affecting coins made of copper or of some types of alloys [5]. But numismatists must also bear in mind that in many cases they totally ignore the vicissitudes of the coins kept in public or private collections. This lacking information seriously encumbers their studies, because they do not know, for example, if coins made of different metals were hoarded together or if coins were hidden in a container made of metal. When different metals are contiguous, a galvanic corrosion occurs and the less noble metal is deeply attacked [6]. But the cleaning of the coin can cause alterations as well. Numismatists usually clean silver–copper coins to obtain a metallic surface. This procedure leads to superficial enrichment in silver due to the oxidation of the grains of copper and the relief of the silver grains on the surface. Once again, it is a pity that numismatists usually totally ignore the way by which the coins submitted to analyses were cleaned. We must add to those considerations that the methods used to perform analyses are different and so give different results. They are all windows opened on the same reality, but each gives a sight from its own point of view. For example, if the depth analysed lies within a few micron below the surface, the results do not indicate the total composition but the superficial composition, which is often different from the present total composition, and this latter must also be different from the initial composition. So the results obtained greatly depend upon the more or less important alteration of the surface.

For several reasons, the fifth century BC Athenian "Owls", one of the largest and most famous silver coinages of the ancient world, constitute a breaking point for the traditional methods of numismatics and, therefore, a representative case for which the results of metallic analyses can considerably help numismatists. The main difficulty in studying Athenian coinage lies first in the fixity of the monetary types, as they remain unaltered for more than two centuries [7], see Fig. 1.

Another phenomenon also encumbers the study of this classical coinage: the ancient imitations of Athenian coins [8] issued at the end of the fifth century by foreign rulers or states which have adopted the Attic coins, largely diffused around the Mediterranean world, as their own currency [9]. The identification of those imitations constitutes a huge problem for numismatists. In some cases, foreign Owls bear a distinctive mark or legend that identifies the issuer. There is a famous emission of imitations that bears an inscription in Egyptian demotic instead of the Athenian ethnic [10], see Fig. 2. This inscription can be read as "Pharaoh Artaxerxes III", the Persian King between 359 and 338 BC. Beside this kind of imitations, there is a lot of other specimens that are in all points similar to the genuine, as for the weight and the quality of the metal [11]. The only criterion that allows numismatists to identify them as imitations is the style of

Fig. 1. Illustrations of classical Athenian coins.

Owl of Pharaoh Artxerxes III

Imitations of Buttrey's Style B and M

Fig. 2. Illustrations of imitations of Athenian coins.

the die-engraver. So, specialists usually take the ugly style of a coin as evidence for its non-Athenian origin. But in fact, this criterion rests on what is no more than an assumption. Fig. 2 gives pictures of two series of imitations called "Buttrey's style B and M", from the name of the numismatist who studied those imitations.

2. Experimental arrangement

In 2002 and 2003, we had the opportunity to perform analyses in the Laboratoire d'Analyses par Réactions Nucléaires (LARN) of Namur (Belgium) with the priceless collaboration of Guy Demortier. When we began our collaboration, we hoped first to find in the metallic composition of coins traces of historical events that would enable us to classify and date Athenian coins more accurately. Secondly, we analysed coins usually taken as imitations in order to determine if their metallic composition is actually different from that of the genuine ones. What kind of historical events can we trace in the metallic composition of Athenian coins? It is a well-known fact that the silver of the Athenian coins came from the mining district of Laureion (south of Attica). But in at least two instances, Athenian Mint may have used silver bullion from other silver sources: in 454, after the transfer of the treasury of the Delian League to Athens and consecutively to a decree enforcing uniformity of coinage, weights and measures to the Athenian allies whose date and political significance are still a matter of dispute between modern scholars.

For our measurements, we use *PIXE* at low incident proton energy (2.8 MeV), which enables us to determine the absolute concentrations of copper, silver, lead and gold and to point out the presence of trace elements like Zn, As, Bi, Sn, Sb. The presence of Fe is generally attributed to external pollution with dust incrusted at the surface of the metal. The analytical procedure takes advantage of the linear trajectory of protons in materials. The total range of 3 Mev protons in metals varies from 20 to 40 μm. If the incident beam of protons hits a thin foil of Al (10-μm thick), it crosses it and could travel through the air over a distance of 20 cm. The coin is introduced in the external beam of protons, at 2 cm from exit Al foil. The ionization of atoms in the coin gives rise to the emission of characteristic X-rays of elements. Those X-rays are collected in a solid state detector giving rise to signals of various amplitudes depending on the atomic number of the collided atom. Characteristic X-rays of elements of interest in this study are given in Table 1. The quantitative analysis is performed by using the comparison of the emission rates of each characteristic element in the coin and in a reference

Table 1
Identification of elemental signals

	Useful X-ray lines Name	Energy (keV)	Remarks Possible interferences
Fe	Kα	6.40	No analytical interest, mainly pollution by dust
Cu	Kα	8.05	No interference if Ni and Ta are not present
Zn	Kα	8.64	ZnKα (8.64) with AuLi (8.50)
As	Kβ	11.18	AsKα (10.50) with PbLα (10.55)
Au	Lβ	11.45	AuLα (9.71) with ZnKβ (9.6)
Pb	Lβ	12.61	PbLα (10.55) with AsKα (10.54)
Ag	Kα	22.1	No interference if no Rh
Sn	Kβ	28.5	Kα (25.3) with AgKβ (24.95–25.45)
Sb	Kα	26.1	No interference if no Cd

sample containing those elements in a known concentration. Reference samples and coins are irradiated in the same experimental geometry in order to avoid taking into account parameters that do not belong to the samples. The lowest limit of detection of useful chemical elements lies in the region of 100 ppm. The accuracy of the measurement depends only on counting statistics. Main elements (Cu, Pb, Ag) are analysed with a relative accuracy of 2% relative. The relative accuracy of the analysis of traces elements is about 5% for absolute concentrations about 0.1% and about 20% for elements at a lower level (0.01%). The depth analysed in each case lies between 5 and 8 μm below the surface. Several analyses are made on the same sample to check its homogeneity. Details on the analytical method may be found in Demortier bibliography [12,13]. We know that PIXE is doubtless not the most accurate technique to determine the absolute concentration of trace elements. But it is certainly a suitable method to lead a preliminary inquiry on such an abundant coinage. So we were able to analyse about 100 coins in order to mark exemplars that show an abnormal feature. Those coins analysed come from a part of a hoard discovered somewhere in Egypt, usually called the "Tell el-Maskhouta Hoard" [14], now kept in the Cabinet des Médailles in Brussels. The majority of those coins have been issued during the later half of the fifth century BC. Among those coins, there are also many exemplars usually taken as imitations.

3. Discussion of the results

The analyses already performed on Athenian coins have established that Laureion's silver is characterised by a low gold and copper content [15] and a high content of lead [16]. Gold is usually taken as an indicator of the origin of the silver used because this metal does not oxidize when ore is melted down to obtain silver. So, the gold/silver ratio of the coin normally reflects those of the ore [17]. And as we know that the concentration of gold is very low in the Laureion silver, a high concentration of gold may indicate a foreign provenance of the silver. But experiences have proved that the gold/silver ratio sometimes varies from one emplacement to another in the mining district of Laureion [18]. So, with due care, we may say that coins with a high level of gold must draw attention of the numismatists who have then to take under consideration the other trace elements in silver, like lead for example. The high amount of lead in Laureion's metal can be explained by the fact that this silver is obtained by refining lead extracted from galena. Because the silver was originally in lead, the concentration of that metal in the coin remains important and the ancient Greeks were not apparently able to remove it totally. So, if we find a coin with a high level of gold and a low level of lead, we may suspect that it has been issued with foreign silver.

Among the coins analysed by the LARN, 18 were coins usually taken as imitations, 12 exemplars of "Buttrey's style B" [1] and 6 of "Buttrey's style M". [2] It appears that the metallic composition of these coins, especially the amount of gold, is not different from the composition of the other Athenian specimens struck during the first half of

[1] Cabinet des médailles of Bruxelles, inventory no: 305, 452, 453, 454, 455, 466, 467, 468, 498, 500, 505, 517.

[2] Cabinet des médailles of Bruxelles, inventory no: 390, 440, 461, 462, 485, 521.

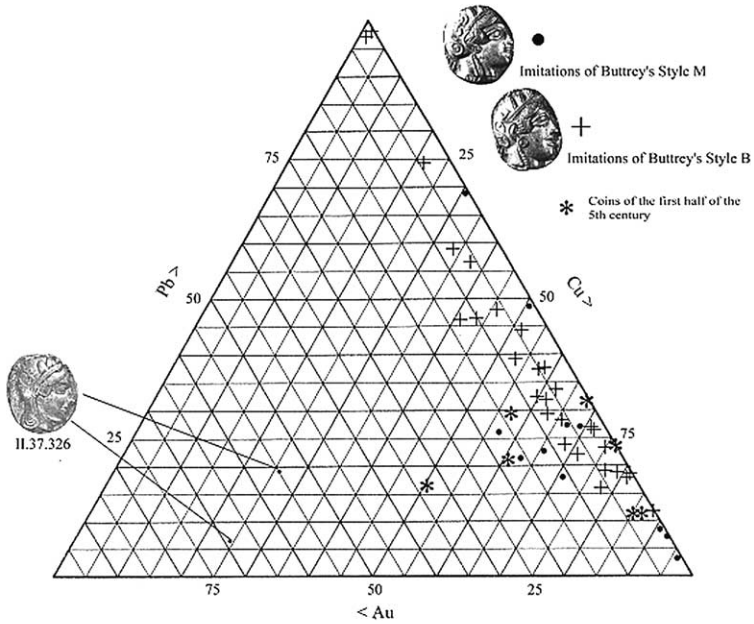

Fig. 3. Ternary diagram of Cu, Pb and Au concentrations in coins usually taken as imitations, in coins struck during the first half of the fifth century and in a coin with a high concentration of gold.

the fifth century that were, certainly, genuine ones (see ternary diagram, Fig. 3). In fact, on the basis of gold and lead concentrations, no coin seems to have been made of foreign silver, except one (II.37.326 in Fig. 3) for which the two measurements taken at the surface show a high concentration of gold, approximately 1%, and a low level of lead.

4. Conclusion

The results of those analyses confirm what we have inferred from numismatic sources [19]: These coins usually taken as imitations, despite their careless style, are genuinely Athenian. The style of the coin with a high concentration of gold is quite fine and nothing can allow a numismatist to suspect an imitation. So it is perhaps an exemplar issued during one of the two periods when Athens used foreign silver. But to avoid precipitate conclusions, we must try to analyse other similar coins. As the results of our preliminary inquiry are encouraging, further analyses will probably help us to go further in our comprehension of Athenian coinage. We envisage for example the analyses of foreign coins, like those struck by Thracians during the fifth century, in order to determine how the PIXE method is accurate to distinguish silver from two distinct ores.

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