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EDXRF and PAA analyses of Dacian gold coins of "koson" type

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Twenty-one gold coins of koson type, considered to be the only kind of gold coins issued by Dacians, were analyzed using EDXRF and PAA methods. Three groups of coins of different compositions were found, corresponding to coins with simple monogram, complex monogram and no monogram. The gold of koson coins is not a natural one (electrum) from present Romania's territory, but is similar to the gold of pseudo-Lysimachan staters. Some possible historical conclusions are discussed.

Introduction

Many isolated pieces or large treasures of ancient gold coins (staters) were discovered in Romania, especially around Sarmizegetusa – the capital of Dacia.[1] The largest treasure consisting of 40000 gold coins of Lysimachus (Thracian king 360–281 BC) type and kosons was discovered around AD 1540 in the Strei riverbed. Most of the coins analyzed in this work (19 pieces) come from the recently discovered treasure (around 1000 kosons) at Târsa-Luncani.[2]

This quaint type of coins is usually considered the only kind of gold coins issued by the Dacians. The strangeness consists in its Roman iconography (the obverse – an eagle standing left on a scepter holding a wreath in one claw – is inspired by the silver denarii issued by O. Pomponius Rufus; the reverse – three togate male figures advancing left, the first and third of which carry an axe on their left shoulder – seems to be inspired by a silver denarius issued in 54 BC by M. Junius Brutus), coexisting with a Greek legend (ΚΟΣΩΝ) and a Persian weight system (the gold daric,[3] established by Darius I in 515 BC and also used sometimes by the Greeks and Macedonians). The controversies are connected with (1) the significance of the inscription, (2) the place of mint and (3) the issuer. Some of the more important hypotheses are given in References 1 and 4. A photo of such a coin is shown in Fig. 1. As far as we know, no attempt to clarify these controversies on the basis of compositional analyses for this type of coins has been made up to date.

Experimental

Energy-dispersive X-ray fluorescence

The energy-dispersive X-ray fluorescence (XRF) was used. Three annular excitation sources ^{238}Pu (30 mCi), ^{241}Am (50 mCi) and ^{241}Am (10 mCi, with nickel window for absorption of soft X-rays) and two X-ray (a Si(Li) and an HPGe) detectors with beryllium windows were used. The plutonium source is more suitable for Cu, Fe and Pb detection, and the americium source for Ag, Sn, Au and, possibly, any other elements with Z around 50. Since the copper concentration is sometimes very small (down to 2–300 ppm) and Cu Kα is situated on the tail of the Au Ll line, the energetic resolution is fairly important. At the same time the counting rate should be high in order to obtain a good statistics in a reasonable time. The whole coin has been analyzed in order to avoid possible inhomogeneities as well as to arrive to a convenient counting rate. Therefore, the resolution was only about 200 eV for Cu Kα. When the copper concentration was very small, a gold spectrum obtained with a 10 Canadian dollar 99.99% Au coin, was subtracted from the measured coin spectrum, the two spectra being normalized to the Au Lα line.

The XRF computational program[5] for element concentrations, taking into account secondary fluorescence, attenuation coefficients, and X-ray cross sections, was strictly tested using gold objects and coins with known compositions, in the range between 58.3% and 99.99% Au. For instance, an item with certified values Au/Ag/Cu = 58.3/7.7/34%, a composition Au/Ag/Cu = 58.6(4)/7.6(1)/33.8(2)% was obtained by this method. Since the result for iron concentration strongly depends on the cleanliness of the coin surface (no cleansing has been done by us), it is preferable to omit the Fe concentration value when it is less than 0.2%. Even when Fe is reported (see Table 1), it must be treated with some caution.

Proton activation analysis

Three koson coins, a pseudo-Lysimachus and two standards (a 20 francs coin, Swiss, 90% Au + 10% Cu, issue 1934, and a 14 K Au-Ag-Cu alloy, previously analyzed by neutron activation) were analyzed by instrumental proton activation analysis (PAA).

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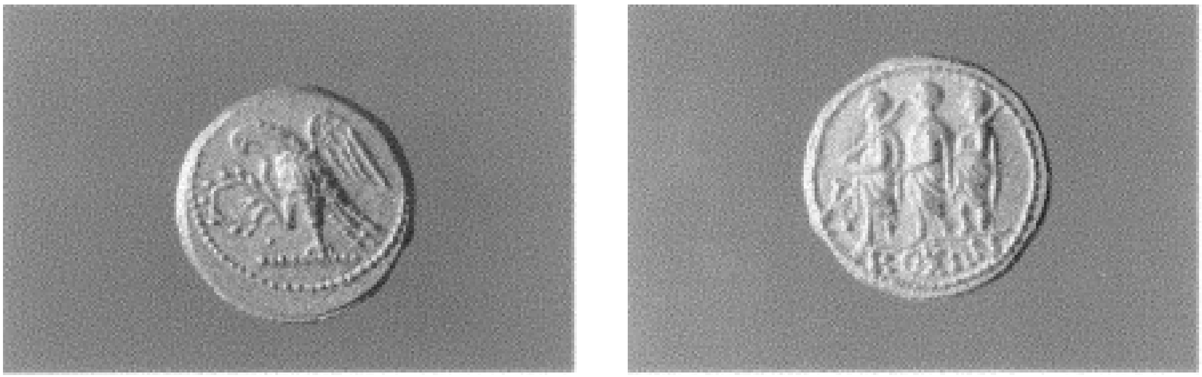

Fig. 1. The photograph of a Koson coin

Table 1. Results of the determination of metals in gold coins

No.	King	Provenance*	Weight g	Diameter mm	Cu %	Ag %	Other elements
1	Coson	MNIR 2520	8.454	20.2×20.5	0.85(2)	10.71(5)	Sn: 250(100) ppm
2	Coson	MNIR 293335	8.46		0.20(1)	5.06(5)	
3	Coson	MNIR 293337	8.70		0.14(1)	2.82(3)	
4	Coson	MNIR 293342	8.586	17.6×18.2	0.12(1)	2.31(1)	
5	Coson	MNIR 293358	8.593	18.2×18.8	0.15(1)	3.46(2)	
6	Coson	MNIR 293408	8.53	17.5×18.0	0.14(1)	3.16(3)	
7	Coson	MNIR 293417	8.31		0.09(1)	0.98(1)	
8	Coson	MNIR 293419	8.671	18.1×18.6	0.18(1)	2.60(1)	
9	Coson	MNIR 293423	8.485	18.3×19.6	0.19(1)	2.86(2)	Sn: 100(70) ppm
10	Coson	MNIR 293433	8.50		0.26(1)	5.14(9)	
11	Coson	MNIR 293434	8.303	19.4×20.5	0.28(1)	4.69(2)	Sn: 80(40) ppm
12	Coson	MNIR 293441	8.545	17.2×18.0	0.05(2)	0.62(1)	Fe: 0.4(1)
13	Coson	MNIR 293486	8.17		0.13(1)	3.33(5)	
14	Coson	MNIR 293717	8.53	17.5×19.0	0.25(1)	3.12(5)	
15	Coson	MNIR 293718	8.53	17.5×18.0	0.19(1)	3.28(5)	
16	Coson	MNIR 293726	8.457	19.3×19.8	0.14(1)	2.14(2)	Fe: 0.3(1)
17	Coson	Private collection	8.541	18.0	0.16(1)	2.60(2)	
18	Coson	Private collection	8.462	19.7×20.1	0.20(1)	5.04(2)	Sn: ≈ 200 ppm
19	Coson	Private collection	8.513	17.3×17.6	0.18(2)	3.11(2)	
20	Coson	Private collection	8.302	19.8×20.3	0.23(1)	4.92(3)	
21	Coson	MNIR 74971	8.552	20.8×21.0	0.19(2)	3.09(2)	
22	Caesar	MNIR B.195			0.017(7)	0.22(2)	
23	Celtic	MNIR O.78	7.451	17.0×18.0	0.09(1)	1.30(9)	
24	Celtic	MNIR O.80	0.388	9.0	3.70(10)	17.6(3)	Fe: 1.0(4)
25	Lysimach (I)	MNIR 2517	8.232	19.0×19.6	0.20(2)	2.19(2)	
26	Lysimach (K)	MNIR 2515	8.252	19.0×19.6	0.31(2)	2.49(2)	
27	Lysimach (T)	MNIR 2518	8.223	18.0×19.0	0.22(1)	1.96(1)	
28	Athena	Private collection	3.080		0.17(2)	0.50(3)	
29	Philip II	Private collection	8.462	17.0×17.5	0.14(1)	0.55(3)	Sn: 170(50) ppm

* MNIR = Muzeul Național de Istorie a României;
O = Orghidan collection.

Each coin was irradiated in vacuum for 5 hours at an incident proton energy of 11 MeV provided by NIPNE-Bucharest HVEC-Tandem accelerator at a current of ca. 50 nA. Since a focalized proton beam was used, the inhomogeneity of the alloy may yield different concentrations by PAA in comparison with XRF results. After a cooling time varying between 22 hours and 16 days the coins were counted at least three times each using a properly protected Ge(Li) gamma-spectrometer (resolution 2.1 keV for 1.332 MeV γ-line of ^{60}Co). In order to prevent the pile-up effect of the soft lines of ^{197}Hg, a 0.6 mm cadmium filter was interposed between the detector and coin.

The concentration (c_i) of an element i was only determined[6] relatively to the gold (matrix) concentration (c_{Au}). In this way the integrated charge of protons becomes unimportant. Eventually, the element concentration was obtained considering $\Sigma_i (c_i) = 1$. Besides the two standards, gamma-yields for the (p,n) reaction taken from References 7 and 8 were also used.

Results

A set of 21 coins of Koson type was analyzed by XRF. All of them came from the Târsa-Luncani treasure and had simple or complex monogram, excepting No.2520 (without monogram) and No. 74971, both of unknown origin. For the sake of comparison, some ancient Greek, Roman, Celtic and pseudo-Lysimachan (Black Sea Greek towns – Istros, Kallatis and Tomis) as well as Transylvanian (16th and 17th centuries) coins were analyzed. The results are listed in Tables 1 and 2. Figure 2 shows the results of this analysis as compared to those of MEYERS' analyses[9] on Roman coins as well as the PAA results obtained by COJOCARU[10] on 12 nuggets of Romanian natural gold.

The PAA results are presented in Table 3 (the statistical errors are given in brackets). A gamma-ray spectrum of an irradiated coin is shown in Fig. 3.

A more detailed Cu/Ag plot only for kosons is given in Fig. 4. It shall be noticed that the three types of kosons (without monogram, with simple monogram and with complex monogram) are evidently clustered. Moreover, the concentrations of the two elements (copper and silver) are correlated. The correlation coefficient, $\rho = \mathrm{cov}(x,y)/\sigma_x\sigma_y = 0.80$, is fairly near the value 1 for total correlation. This fact is difficult to explain, but one can guess that it has some connection to the separation / refining technology of gold. It is interesting to mention that for the 12 gold nuggets,[10] ρ is near 0 (no correlation).

Results of the PAA analysis are listed in Table 3. Generally, Cu, Ag and Sn concentrations found in PAA are consistent with those from XRF analysis, except for the coin No. 2517. For this coin Cu and Ag concentrations by PAA are sensibly higher. This can be an expected effect of inhomogeneity. From this point of view, XRF is more reliable since the whole coin is analyzed. Except for Ti, Fe, Cu, Pd, Ag, Sn, Sb, Pt and Pb, no other element was seen in the activation gamma-ray spectra.

Table 2. Composition of some Transylvanian gold ducats from the 16th and 17th centuries

Year	Prince	Inventory number	Cu %	Ag %	Pb %	Others
1577	Christofor Bathory	MNIR O.950	0.40(1)	2.17(1)	n.m.	
1591	Sigismund Bathory	MNIR O.962	0.11(1)	0.63(1)	n.m.	
1592	Sigismund Bathory	Private coll.	0.89(1)	2.14(1)	n.d.	Fe -traces
1606	Ştefan Bocskay	MNIR O.970	0.16(2)	1.06(1)	0.16(8)	Sn:270(120) ppm
1607	Sigismund Rakoczi	MNIR O.973*	0.15(1)	1.72(1)	n.m.	
1625	Gabriel Bethlen	MNIR O.997	0.92(1)	2.29(1)	n.m.	Fe - traces
1631	Gheorghe Rakoczi I	MNIR O.1002	0.72(2)	1.09(3)	n.m.	
1660	Achatius Barcsai	MNIR O.1015*	0.30(2)	2.95(1)	0.20(9)	
1666	Mihail Apafi	MNIR O.1019	0.26(2)	1.22(1)	≤0.15	Sn: ≤140 ppm
1667	Mihail Apafi	MNIR O.1020	0.51(3)	2.09(1)	0.15(8)	Fe - traces
1669	Mihail Apafi	MNIR O.1021*	0.57(2)	2.48(1)	0.17(8)	
1670	Mihail Apafi	MNIR O.1022*	0.09(2)	1.44(1)	0.24(8)	Fe - traces
1687	Mihail Apafi	MNIR O.1028	0.15(2)	12.79(3)	n.m.	

* 10 ducats.
n.m. = not measured.
n.d. = not detected.

Table 3. PAA results of the analyses of four gold coins. Concentration in $\mathrm{mg \cdot kg^{-1}}$ (ppm) except for Cu and Ag in weight%

Inventory No.	Ti	Fe	Cu	Pd	Ag	Sn	Sb	Pt	Pb
2517	10.8(3)	265 (2)	0.831 (2)	57 (3)	3.03 (8)	≤21	≤2	126 /(5)	96(12)
2520	7 (1)	931 (3)	11.26 (10)	42 (3)	11.26(10)	465(19)	10 (2)	57 (6)	25(15)
293337	1.7(2)	65 (1)	0.162 (2)	46 (2)	2.83 (6)	22 (3)	2.5(5)	69 (2)	38 (4)
293486	7 (1)	180 (2)	0.156 (2)	62 (3)	3.21 (8)	13 (6)	n.d.	72 (3)	59 (8)

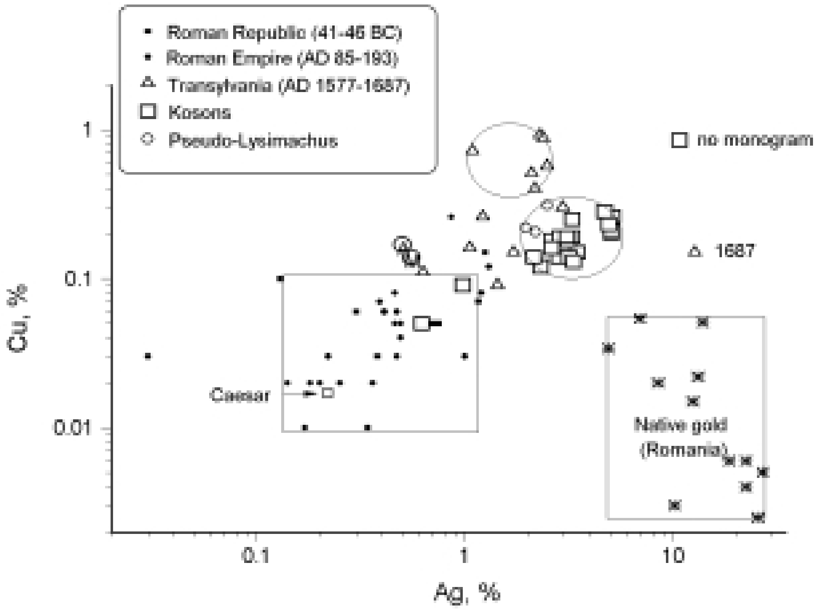

Fig. 2. Cu vs. Ag plot of the coins analyzed in this work (open symbols) and, for comparison, the results of other authors

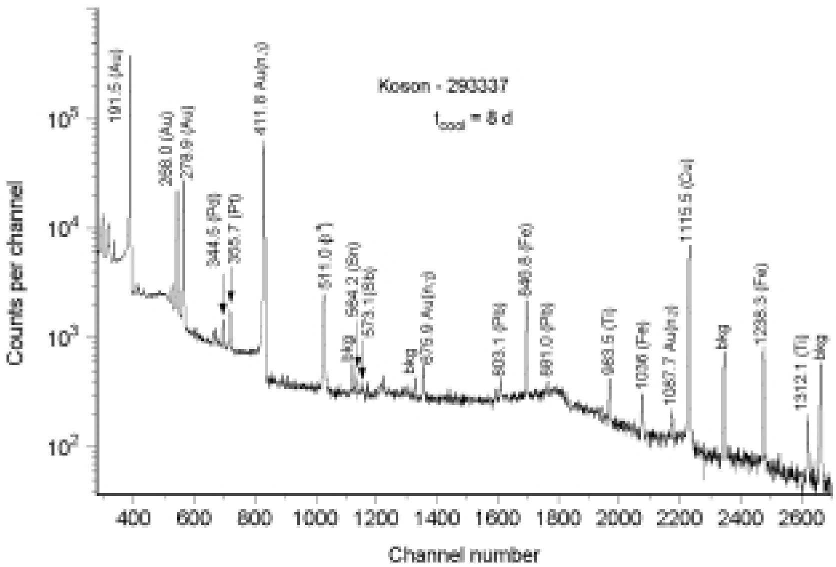

Fig. 3. Part of a gamma-spectrum of a Koson coin activated with 11 MeV protons

Discussion

There are many elements sustaining the Dacian origin of this type of coin. One of them is their style which is fairly different from that of all types of contemporary gold coins. The gold coins minted in Greece, Thrace, Macedonia, the Roman Empire or the Pontic Greek Colonies are real bas-reliefs revealing an extraordinary cult of the toreutic workers for details or for the polishing of dies. On the contrary, kosons were made in a marked globular style,[2] without many details, specific for the Dacian toreutic artists in the first century BC, when, according to PÂRVAN, "the Dacian coinage art was totally degenerate"[11] and the coinage struck by the Dacian princes was "very ugly".[11] Instead of engraving, the die was made using a stamp (many globules) and chisel, usually straight chisels.

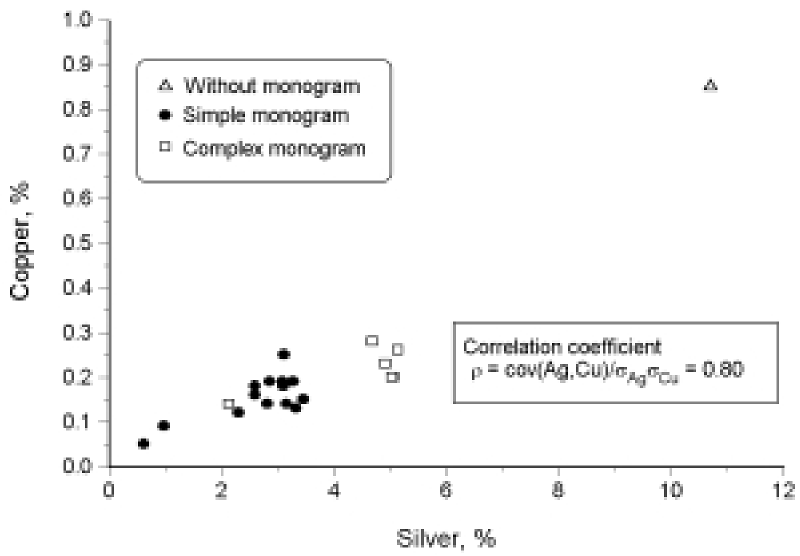

Fig. 4. Plot of the XRF results obtained for Koson coins, suggesting a correlation Cu-Ag and the existence of clusters

Another element of the technical level could be the dispersion in the weight of coins, since usually gold coins have not circulated. Whereas gold coins from the Black Sea Greek Colonies have a "dispersion" (in fact the square mean deviation) of the weight of 0.14%, the kosons analyzed herein have a dispersion of 1.4%, an order of magnitude higher. Moreover, the dispersion of the diameters is over 5%, and the edges of some coins were hammered in order to bring them to a wanted diameter.

The most recent hypothesis that the kosons are of medieval make[4] can clearly be ruled out by the present analyses. The alloy used for kosons is not electrum, but it is not Romanian (Dacian) gold either, since the latter's features (very little Cu, no Sn and Pd, presence of As, Hg, Te)[10] are missing. The conclusion is that the gold used for the kosons is not Dacian gold. In the pre-Roman period Dacians were only collectors of gold auri leguli from placers and the sand of rivers, therefore the Dacian gold was a native one, i.e., electrum.[12]

One can suppose that kosons were minted in Cotiso's kingdom, who, as shown by BAHRFELD[13] and DAICOVICIU,[14] based on the twelve existing manuscripts after Suetonius' "De vita Caesarum" (LXIII, 4), is the same person as "Cosoni Getarum regi". With a relatively small army Cotiso/Coson pillaged Pannonia, Illiria and Thrace, reaching Dalmatia and Macedonia.[15] The aim was evidently plunder and noble metals were especially important from this perspective.

The alloy of kosons is almost similar with that used for coinage in Istros, Tomis and Kallatis. Except for one coin, the alloy is not electrum but refined gold. The refining level is not as high as for the Greek (Athena), Macedonian (Philip II) or Early Roman Empire coins. It is a moderate refining. The refinement, according to Diodoros Siculus, was made by cementation of the gold dust with break dust and common salt at high temperature for several days.[16] One may assume that the refinement level depended on the temperature and the heating period.

From Fig. 4 one can see that at least four alloys were used: (1) $c_{Ag}<1\%$, (2) $2\%<c_{Ag}<3\%$, (3) $4\%<c_{Ag}<5\%$ and (4) $c_{Ag}>10\%$. What is more interesting is that there is a connection between the type of the monogram and the coin composition; the coin without monogram is more impure, probably made of electrum. Unfortunately, we were unable to find more than one coin without monogram, but many such coins did exist (BAHRFELD[13] in 1911 analyzed 37 such coins). In the third group there are only coins with complex monogram, whereas in the first two groups all coins, except one, bear a simple monogram. It is possible that the monogram is connected with the workshop/s where the coins were minted, using gold from different places.

As a conclusion concerning the strangeness of the kosons, it should be noted that they have (1) a Roman iconography, (2) a Greek inscription and (3) a Persian weight system. It will be interesting to have more coins analyzed by atomic and nuclear methods and especially to look for iridium, which is very good element for provenance studies.[17]

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