The Alloy of the 'XI' Coins of Tacitus

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THE purpose of this note is to report the silver content of six of the very rare 'XI' and 'IA' radiates of the Roman emperor Tacitus (AD 275–6). Few comparable alloys have been previously published.[1]

Five of the coins are all from the Antioch mint (*RIC* V,I, Tacitus 211) and have **XI** in the exergue. One is from Tripolis (*RIC* 214) and has **IA** in the exergue. Each was analysed for silver content by Electron Probe Micro Analysis (EPMA), Rutherford Backscattering Analysis (RBA), Energy Dispersive X-Ray Analysis (EDX), or two or more of these methods. Table 1 summarizes the results.

Each piece was analysed at two or more core sites by EDX. The individual results are presented and their average is given in parentheses. Also, the percentage of silver on the surface was obtained for five pieces, including an additional very-well-preserved and boldly struck piece (92.123) from Antioch with full surface-silvering for which the core percentage was not determined.

The results of Callu, Brenot, and Barrandon for 'XI' and 'IA' coins of Tacitus are remarkably consistent – all between 8·75 and 9·8 per cent. Our results demonstrate that this consistency is not universal. But their most important observation, that these coins have a far higher average silver content than the common 'XXI' coins of the period, is assured. Considering all published core silver results and adding in the contribution of surface-silvering, which is probably in the order of one per cent,[2] the mean silver percentage was probably in the eight to ten per cent range. As more examples are published, a more precise picture of the true mean alloy will emerge.

ANALYSIS

There are several significant sources of variation: between coins, between methods applied to a single coin, and between sites on a single coin. Also, there is statistical variation associated with each method. But the largest source of variation is probably preparation of the sample.

Apparently, two very small regions of a single coin can have significantly

[1] J. P. Callu, Cl. Brenot, and J. N. Barrandon, 'Analyses de Séries Atypiques,' *QT* 8 (1979), pp. 241–54, analysed four Tacitus coins of Antioch marked 'XI' and one of Tripolis with the corresponding Greek mark, 'IA'. The results were: 9·7, 8·8, 8·75, 9, and 9·8 per cent. They also obtained 9, 9·1, 8·1 and 8·9 per cent for four coins of the next emperor, Carus, which are strikingly different in appearance, but which are also marked 'XI' or 'X ET I'.

[2] W. W. Esty, 'The contribution of surface-silvering to silver content,' *NC* 151 (1991), pp. 226–8.

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TABLE 1

Results of analysis

ID number, officina	*Weight*	*EDX core % AR*	*EDX surface % AR*	*RBS core % AR*	*EPMA core % AR*
89.11 Є	3·43 g	2·58, 5·66, 3·32 (3·85)	63·09	11·0	13·6
90.4 Є	3·31 g	4·75, 11·98 (8·36)	—	20·0	22·7
91.86 Α	3·84 g	13·43, 12·07, 11·88 (12·46)	51·78	17·7	—
92.2 Δ	3·78 g	10·81, 9·06 (9·94)	74·84	—	—
92.39 Γ	4·06 g	4·16, 7·34 (5·75)	—	—	—
92.3 (Tripolis)	3·55 g	3·80, 2·32 (3·06)	19·58	—	—
92.123 Δ	4·01 g	—	79·96	—	—
		6 piece average: 7·24 %			

different silver contents, as seen in the EDX column. The differences between methods can probably be explained by differing success in preparing the site to avoid the surface-silvering, as will be discussed further when the sample preparation is described. The substantial differences between coins are apparently real and reflect inconsistent alloy preparation by the mints.

Coins 89.11, 90.4, 91.86, and 92.2 show only a little wear, but 89.11 and 90.4 are weakly struck and appear only 'VF' and 'F'. Their surfaces are mostly dull silver-grey with much silvering evident. Coins 91.86 and 92.2 are fairly well-struck and almost 'EF'. Coin 91.86 is quite silvery on the obverse with much dark and some red encrustation on the reverse and coin 92.2 has much dark silver toning. In contrast, coins 92.39 and 92.3 appear to be copper with only the smallest visual indications of having been silvered. Coin 92.39 is 'VG', perhaps weakly struck and certainly very worn. Coin 92.3 from Tripolis is a well-worn 'almost F'. All seven were purchased on separate occasions and their original find sites are unknown.

Not all coins were analysed by all methods. The two pieces from officina Є were first analysed by Peter Northover at Oxford using electron probe microanalysis (EPMA). We appreciate his help with this project. Later the third coin was acquired for analysis at Montana State University and it was decided also to reanalyse the first two with the available RBS equipment because the EPMA results were so remarkable. Still later, Montana State acquired a JEOL 6100 Scanning Electron Microscope (SEM) energy dispersive X-ray detector and software package by NORAN. In the meantime, the remaining coins were purchased. Then all the coins were reanalysed using EDX.

In order to avoid the surface-silvering for the three RBS core analyses, each coin was prepared by scraping a 2 mm diameter region of the reverse field with a knife until the shiny copper of the core was fully exposed. Care was taken to attempt to scrape away the surface-silvering, rather than scrape it into the core, which could lead to overestimating the silver content. Then

each area was scraped again, a bit deeper. The prepared areas appear to be shiny copper and are very clearly visible on the coins. For the EDX analyses, the same areas scraped for the RBS analysis were scraped again. This third scraping led to significantly lower results. On the coin 89.11, the results from the first two regions (which were only about 0·3 mm apart) were so much lower than the RBS and EPMA results that another region several mm away was very thoroughly scraped and a third result obtained (3·32 %). The third percentage confirms that the lower percentages from the previous regions were representative. We conclude that the preparation of the samples is very important and that the depth of the surface removed can strongly affect the results. Therefore, for the EDX analyses the surfaces were very thoroughly scraped.

The column labelled 'EDX surface % AR' reports on the silver content of unprepared surfaces in spots where the SEM image appeared to show an uncorroded surface. Coin 92.123 shows that on well-preserved specimens the surface can be 80 % silver. Even on coin 92.3, which appears to be copper, the surface is 19·6 % silver. Clearly, if this surface-silvering is not thoroughly removed, any reported core content will not be reliable. Furthermore, it is not clear that the core content is uniform below the surface. Considering the surface preparation for the successive methods used (EPMA, then RBS, then EDX), it appears that the more thorough the scraping, the lower the percentage obtained.

The surface-silvering adds an uncertain amount to the silver of the coin as a whole and the irregularity of the core composition, especially near the surface, prevents us from asserting that the composition in a 2 mm disk would be duplicated throughout the entire coin. The statistical uncertainty for the measured yield using RBS is a factor of about 3 per cent, a smaller source of possible inaccuracy than the other sources mentioned above. Therefore, although we report the RBS percentages to the first decimal place, we only expect them to be within a couple of per cent of the true value at the surface of the scraped spot. The statistical variation of the EDX method is much less.

For the record, the detailed analyses are given in Table 2. The coins were not so deeply scraped for the EPMA analyses, and the EPMA analysis of coin 90.4 may have been affected by corrosion. Apparently, lead is associated with silver and is therefore more likely to be found with the surface-silver layer.

TECHNIQUE

All RBS and EDX analyses were conducted by N. Equall. For the EDX analyses the coins were mounted and placed in the SEM where the scraped regions were easily identified and magnified. For each of the two or three analyses the 25 kV electron beam was focused on a different smooth 10-

TABLE 2

Results of detailed analyses

ID	*Run*	*Silver*	*Copper*	*Lead*	*Tin*	*Si*	*Al*	*Other*
89.11	1	2·58	96·14	—	1·28	—	—	—
	2	5·66	93·08	—	1·01	0·25	—	—
	3	3·32	95·65	—	1·02	—	—	—
	EPMA	13·65	83·90	0·81	0·80	—	—	0·84
90.4	1	4·75	94·24	—	1·01	—	—	—
	2	11·98	88·02	—	—	—	—	—
	EPMA	22·67	67·70	4·37	4·58	0·04	—	0·64
91.86	1	13·43	85·72	0·55	—	0·31	—	—
	2	12·07	87·93	—	—	—	—	—
	3	11·08	85·74	2·38	—	—	—	—
92.2	1	10·81	86·77	0·73	1·46	0·22	—	—
	2	9·06	87·11	0·68	1·55	0·78	0·83	—
92.39	1	4·16	94·75	—	1·10	—	—	—
	2	7·34	89·51	—	—	—	—	Cl 2·87 Fe 0·27
92.3	1	3·80	95·69	—	0·51	—	—	—
	2	1·38	97·32	—	0·35	—	—	S 0·95
Surface								
89.11		63·09	34·07	1·86	—	0·66	0·32	—
91.86		51·78	22·95	3·51	—	4·50	0·27	Ca 17·00
92.2		74·84	10·13	7·87	—	5·62	0·85	Fe 0·33 P 0·37
92.3		19·58	73·28	4·00	—	2·45	0·27	S 0·25 Ca 0·17
92.123		79·96	12·79	3·40	—	2·84	0·66	Fe 0·34

micron square subregion of the scraped region and an X-ray spectrum was collected and analysed by the software package by NORAN. The surface analysis of coin 92.123 used a 1 mm square region.

For the RBS results, the unscraped portion of the coin was covered with an aluminium mask having a hole with a diameter somewhat smaller than the 2 mm scraped area. The hole in the mask was aligned with the scraped portion of the coin. Helium ions of 1·5 MeV energy were normally incident on the coins, and backscattered ions were counted with a surface barrier detector at a scattering angle of 170 degrees. Since He ions recoil from the heavier Ag atoms with greater energy than that of ions which scatter from the lighter Cu atoms, the signals from the two elements are easily distinguished. It is a straightforward analysis to convert the ratio of the number of ions scattered from Ag and Cu atoms in the target to a ratio of atomic per cent, Ag-to-Cu, using the known Rutherford scattering cross-section.[3] The backscattered ion signal from the aluminium mask does not interfere with the analysis since that signal appears at a lower backscattered ion energy.

[3] W. K. Chu, J. W. Mayer and M.-A. Nicolet, *Backscattering Spectrometry* (New York, 1978).