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A STUDY OF THE SILVERING PROCESS OF THE GALLO-ROMAN COINS FORGED DURING THE THIRD CENTURY AD*

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We have observed by fast neutron activation analysis (FNAA) that the global composition of the official silver coins of the Gallic emperor Postumus is not the same as those from the contemporary unofficial mints. In order to explain this phenomenon, we have carried out a metallographic study of the artefacts. Then, we have re-created the silvering process of unofficial coins in order to better understand the manufacturing process of silvering. The different steps of the replication process are explained in this paper.

KEYWORDS: FNAA, SEM, SILVERING PROCESS, *ANTONINIANI*, REPLICATION EXPERIMENTS, GALLO-ROMAN PERIOD

INTRODUCTION

The unofficial production of coins, which dates back almost to the beginnings of coinage in archaic Asia Minor, encompasses different phenomena, which can be distinguished by the production techniques as well as by their scope. The range extends from small private workshops, where forgeries of valuable silver or even gold coins were struck, to epidemic waves of sometimes crudely struck or cast base metal coins in times and regions where small change was urgently needed to enable the local day-to-day trade. In Roman times, unofficial coins were quite common in the daily monetary circulation (see, e.g., Boon 1988). Some of the most spectacular and well-known waves of unofficial coinage occurred during the third century AD in the northwestern provinces. During a certain period of time, many workshops spread from the Rhine and the Danube to the south of Gaul, and from southern Britain to the Alps.

The unofficial production of silvered coins raises a number of questions with regard to their manufacturing process. Investigations of the technology of silver-plated coin forgeries have been undertaken by several authors (Darmstaedter 1929; Campbell 1933; Cope 1972; La Niece 1990, 1993). Various manufacturing processes can be distinguished: (a) the mechanical attachment of a silver foil; (b) soldering, using a low melting point metal or alloy (tin, lead or silver–copper eutectic); (c) self-soldering, using diffusion between the silver foil (or powder) and the copper blank (Zwicker 1993; Anheuser and Northover 1994); (d) coating with molten silver or alloy (Cope 1967; Anheuser and Northover 1994; Beck *et al*. 2005); (e) the application of chloride silver paste (Anheuser and France 2002); and (f) amalgamation with silver–mercury alloy (Vlachou *et al*. 2000). Depletion silvering, also applied to ancient silver coins, is not strictly a plating technique and has been studied in detail elsewhere (Cope 1972; La Niece 1990, 1993; Gitler and Ponting 2003; Beck *et al*. 2003, 2004; Butcher and Ponting 2005).

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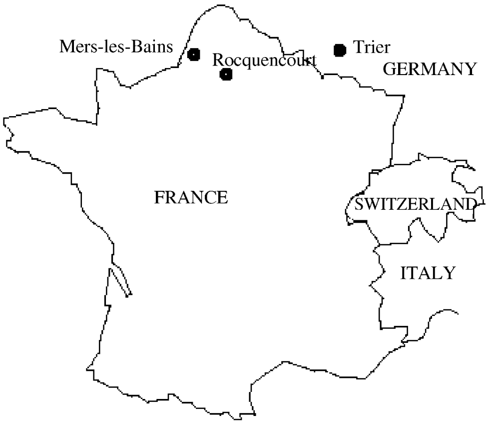

Figure 1 *The location of the mint of Trier and the hoards of Mers-les-Bains and Rocquencourt.*

This paper focuses on the silvering process used during the third century AD to produce false coins called *antoniniani* (these coins are also called 'radiates'). First, the global composition and the microstructure of the official coinage of Postumus (AD 260–269) struck at Trier (Germany) and of the forgeries of this emperor found in two hoards were compared. The hoards were found in Rocquencourt (Hollard and Gendre 1986) and Mers-les-Bains in France (Fig. 1). Second, laboratory replication experiments have been performed in order to attempt to reproduce the composition and the structure of the forgeries, and to better understand the ancient manufacturing process of silvering.

MATERIALS AND METHODS OF CHARACTERIZATION

The *antoniniani* studied are split into two groups: 15 of them are official radiates of Postumus, struck in the mint of Trier between AD 260 and AD 268 (Table 1) and 17 are contemporary forgeries, all of which come from the Rocquencourt and Mers-les-Bains (France) hoards (Table 2).

Compositional analysis was carried out at the Centre d'Etudes et de Recherches par Irradiation (CNRS, Orléans, France) using fast neutron activation analysis (FNAA). Thus the bulk composition of the coinage can be obtained without damage to the sample (Beauchesne *et al.* 1988). Copper, tin, lead, silver, gold, iron, nickel, arsenic, antimony and zinc were quantitatively determined. Neutrons were produced by a cyclotron from nuclear reactions induced by 17.5 MeV deuterons impinging on a beryllium target.

The microstructure was investigated by examining a polished section with a Philips XL 40 Scanning Electron Microscope (SEM), using backscattered electrons. The chemical composition was determined with an energy-dispersive X-ray (EDX) spectrometer coupled to the SEM, producing a 20 keV beam.

RESULTS AND DISCUSSION

Bulk compositions using FNAA

In the official coins of Postumus, silver contents vary from 13% to 20%, with a mean value of 16% (Table 3). Silver represents from a fifth to a quarter of the silver–copper alloy. In the third

Table 1 *A list of the studied official coins, which all come from private collections*

Reference	*Series*	*Year* AD *(approx.)*	*Types*
A1	Série I	260	Elmer 123 Cunetio 2372
A2	Série I, 3	261	Elmer 132/188 Cunetio 2381
A3	Série II	262	Elmer 299 Cunetio 2395
A4	Série III, 1	263	Elmer 333 Cunetio 2405
A5	Série III, 2	264–5	Elmer 336 Cunetio 2413
A6	Série IV, 1	266	Elmer 385 Cunetio 2425
A7	Série IV, 1	266	Elmer 414 Cunetio 2423
A8	Série IV, 2	267	Elmer 383 Cunetio 2437
A9	Série IV, 2	267	Elmer 394a Cunetio 2440
A10	Série V	268	Elmer 565 Cunetio 2450
A11	Série Ic	261	Elmer 189 Cunetio 2386
A12	Série I	260	Elmer 125 Cunetio 2374
A13	Série I	260	Elmer 125 Cunetio 2374
A14	Série III	265–7	Elmer 593 Cunetio 2444
A15	Série III, 2	end 262 to 264	Elmer 336 Cunetio 2413

century AD, the official silver coinage was progressively devalued. For that purpose, copper was added to silver. Other elements are impurities. Our results are in perfect agreement with Cope's results published in 1997 (Cope *et al*. 1997).

Unlike the official coins, the forgeries of Postumus *antoniniani* found in the Rocquencourt and Mers-les-Bains hoards are characterized by a low silver content, ranging from 0.4% to 4.5% (mean value 2.4%, Table 4). The analysis shows that the samples contain tin (0.7–4.7%, mean value 2.1%) and lead (0.5–2.5%, mean value 1.0%). The presence of lead in these coins can originate from the recasting of older objects. On the other hand, when the lead content is very low, it is due to impurities introduced with the silver.

The official coins and forgeries can be distinguished by means of the silver content (Fig. 2). For the official coins, as already mentioned, devaluation is mainly due to the addition of copper to the silver–copper alloy. For the forgeries, the main component is copper, with higher contents of either tin or zinc (Fig. 3). Thus the forgeries are the result of the recasting of bronze or brass. From a general point of view, we notice a large variability in the copper alloy compositions used to produce the forgeries, while the official coins have similar compositions.

Table 2 *A list of the studied forgeries, which all come from private collections*

Reference	*Hoard*	*Year* AD *(approx.)*	*Types imitated*
B1	Rocquencourt 4838	263–8	Cf., Elmer 299
B2	Rocquencourt 4852	265–6	Cf., Elmer 332
B3	Rocquencourt 4898	266–8	Cf., Elmer 336
B4	Rocquencourt 4899	266–8	Cf., Elmer 336
B5	Rocquencourt 4900	266–8	Cf., Elmer 336
B6	Mers-les-Bains	266–8	Cf., Elmer 335
B7	Mers-les-Bains	266–8	Cf., Elmer 337
B8	Private collection	268–70	Cf., Elmer 336
B9	Private collection	268–70	Cf., Elmer 336
B10	Private collection	268–70	Cf., Elmer 336
B11	Private collection	265–6	Cf., Elmer 337
B12	Rocquencourt 4889	267–8	Cf., Elmer 336
B13	Rocquencourt 4850	265–6	Cf., Elmer 332
B14	Rocquencourt 4885	266–7	Cf., Elmer 336
B15	Mers-les-Bains	266–7	Cf., Elmer 299
B16	Mers-les-Bains hoard	266–8	Cf., Elmer 299
B17	Mers-les-Bains hoard	266–7	Cf., Elmer 299

Table 3 *The global composition of the Postumus official coins, obtained by FNAA (in %)*

Reference	*Ni*	*Sn*	*Zn*	*Sb*	*Pb*	*Au*	*Ag*	*As*	*Fe*	*Cu*
A1	0.00	<0.1	0.014	0.08	0.9	0.07	14	0.028	<0.1	85
A12	0.00	0.2	0.012	0.36	1.9	0.10	19	0.039	0.6	76
A13	0.12	0.20	0.020	0.12	1.7	0.13	16	0.027	0.7	79
A2	0.02	<0.1	0.011	0.07	0.8	0.07	13	0.022	<0.1	86
A11	0.05	0.3	0.007	0.07	1.6	0.08	14	0.002	0.3	83
A3	0.02	<0.1	0.010	0.06	0.4	0.08	15	0.028	<0.1	84
A15	0.00	0.13	0.026	0.12	2.5	0.12	20	0.024	<0.1	75
A4	0.02	0.00	0.014	0.07	1.0	0.09	15	0.026	<0.1	84
A5	0.02	0.03	0.018	0.12	0.6	0.10	17	0.079	<0.1	78
A14	0.00	0.62	0.012	0.10	1.8	0.11	20	0.082	0.4	74
A6	0.00	0.01	0.031	0.09	0.8	0.08	17	0.074	<0.1	81
A7	0.03	0.01	0.005	0.08	0.9	0.08	16	0.075	<0.1	82
A8	0.03	0.01	0.005	0.08	0.9	0.08	16	0.070	<0.1	82
A9	0.04	0.00	0.006	0.14	0.9	0.08	15	0.058	<0.1	84
A10	0.03	0.00	0.008	0.08	0.9	0.07	13	0.059	<0.1	86

We have assumed that this variability in composition could be caused by the recasting of a miscellany of copper-based objects.

Despite their different silver contents, the official and unofficial coinages have the same external appearance (Fig. 2). The difference in composition is likely to be related to differences in the manufacturing process. Metallographic investigations and microanalyses were undertaken to study those processes.

Table 4 *The global composition of the forgeries that come from hoards, obtained by FNAA (in %)*

Reference	*Ni*	*Sn*	*Zn*	*Sb*	*Pb*	*Au*	*Ag*	*As*	*Fe*	*Cu*
B1	0.02	1.9	<0.03	0.09	0.6	0.037	4.4	0.04	0.3	91
B2	0.03	1.9	<0.1	0.08	0.7	0.023	4.5	0.11	0.0	91
B3	0.02	2.0	0.95	0.09	0.5	0.014	2.8	0.16	0.0	92
B4	0.02	2.3	<0.1	0.10	1.0	0.005	0.9	0.04	0.0	93
B5	0.02	2.6	<0.1	0.07	0.8	0.007	0.4	0.04	0.0	94
B6	0.02	1.0	<0.2	0.07	0.6	0.013	1.5	0.05	0.0	96
B7	0.02	1.7	6.42	0.13	1.6	0.011	1.9	0.07	0.2	87
B8	0.02	2.7	<0.1	0.12	0.6	0.018	3.3	0.04	0.0	91
B9	0.02	2.0	5.59	0.13	2.1	0.017	2.8	0.05	0.0	86
B10	0.03	1.7	4.23	0.12	2.5	0.017	3.1	0.06	0.2	87
B11	0.02	4.7	<0.1	0.09	0.8	0.014	3.2	0.03	0.0	88
B12	0.01	2.7	<0.1	0.12	1.4	0.020	2.6	0.04	0.1	91
B13	0.01	1.6	<0.1	0.10	0.7	0.015	2.8	0.03	0.0	93
B14	0.01	2.0	<0.1	0.08	1.2	0.022	2.3	0.05	0.0	93
B15	0.02	1.8	<0.1	0.09	1.0	0.014	1.6	0.03	0.0	95
B16	0.03	0.7	3.51	0.14	0.7	0.006	1.2	0.07	0.3	93
B17	0.02	2.7	<0.1	0.10	0.6	0.007	1.3	0.04	0.0	95

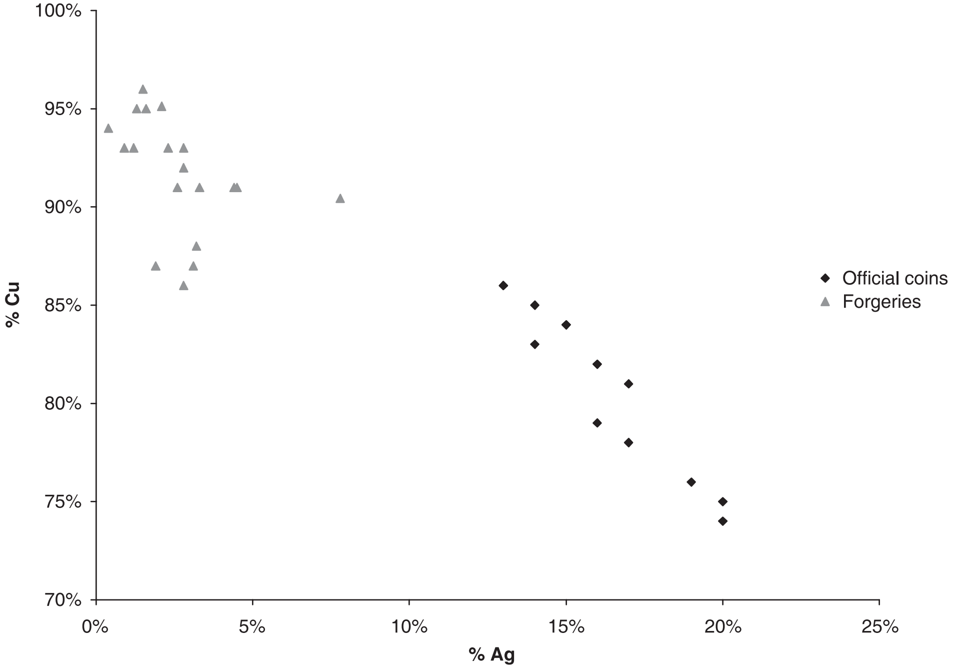

Figure 2 *A silver content scatter diagram for the official and unofficial coinages of Postumus.*

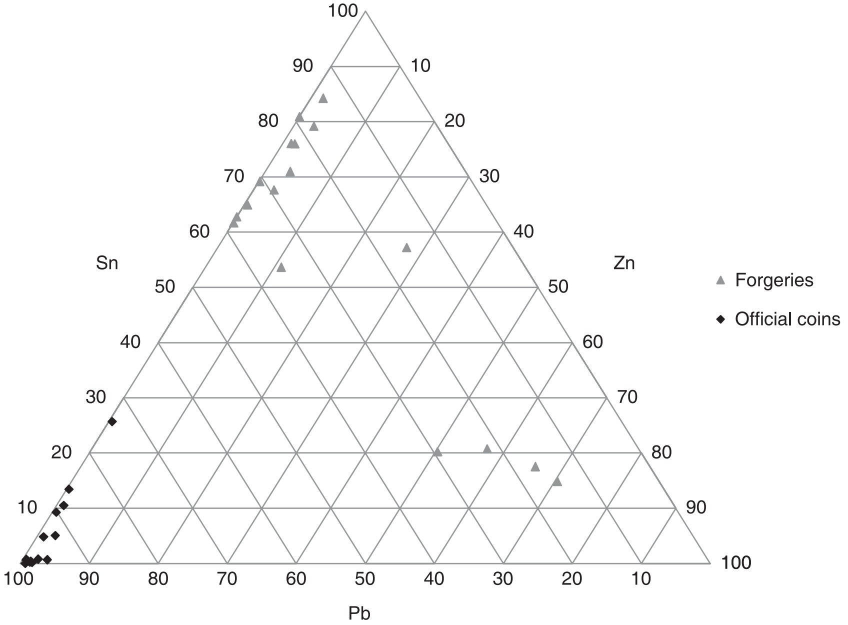

Figure 3 *A ternary diagram of the tin, lead and zinc contents in the forgeries and the official coins.*

Metallographic studies

Archaeological sample Five official coins struck for Postumus in the mint of Trier (Germany) were cut and polished. The bulk of the sample is a silver–copper alloy, with silver contents varying from 10% to 20%. The two characteristic phases of a copper–silver alloy are observed and are distributed in an almost homogeneous way in the coin. The silver-rich phase forms lines parallel to the coin surface due to the striking of the blank (Fig. 4).

Six forgeries found in hoards in the north of France, and thus in a good state of preservation, have been studied. An example of a forgery is presented in Figure 5. Sample B12 (Fig. 5) is coated with a silvering layer that contains 21% of silver. The core is a leaded bronze with 2.3% of lead, 2% of tin and 88.7% of copper. The copper grains are rounded and are surrounded by a eutectic phase (72% silver and 28% copper). Sample B13 (Fig. 6) has the same microstructure, but the thickness of the silver layer is greater than that of sample B12.

The shape of the copper grains in the silvering layer could be explained by the area selected for the analysis. Copper grains are round in shape when no deformation takes place, and elongated where deformation due to striking is strong.

The microstructures of the forgeries and the official coins are very different. Unlike the official coins, the forgeries are composed of two distinct parts:

- A copper alloy (78–98% Cu) core.
- A silver–copper alloy silvering constituting of copper grains surrounded by a eutectic phase.

This as-cast structure proves that the alloy had been molten.

According to the analysed coin, the silvering layer is composed of from 16% to 34% of silver (mean value 26 ± 6%) and its thickness fluctuates from 20 μm to 100 μm.

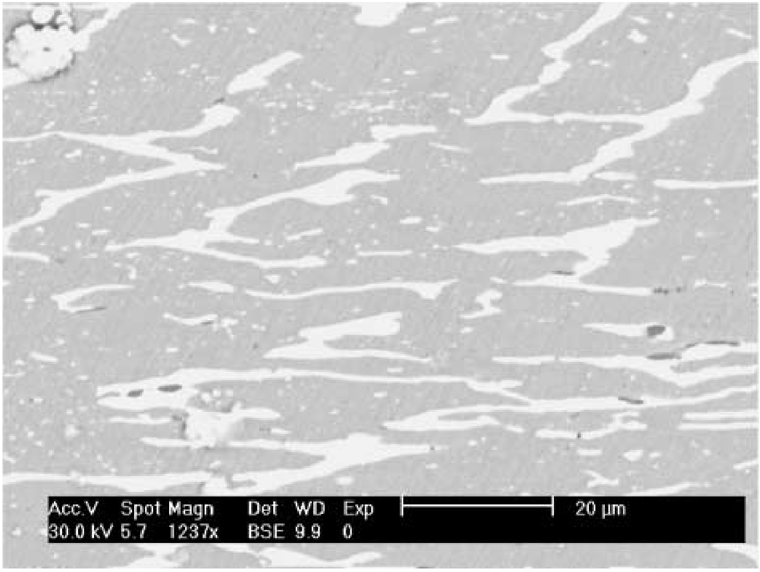

Figure 4 *A 20 keV backscattering electron SEM micrograph of sample A15, showing a section through an official coin: in grey, the copper with elongated remnants of silver dendrites (white).*

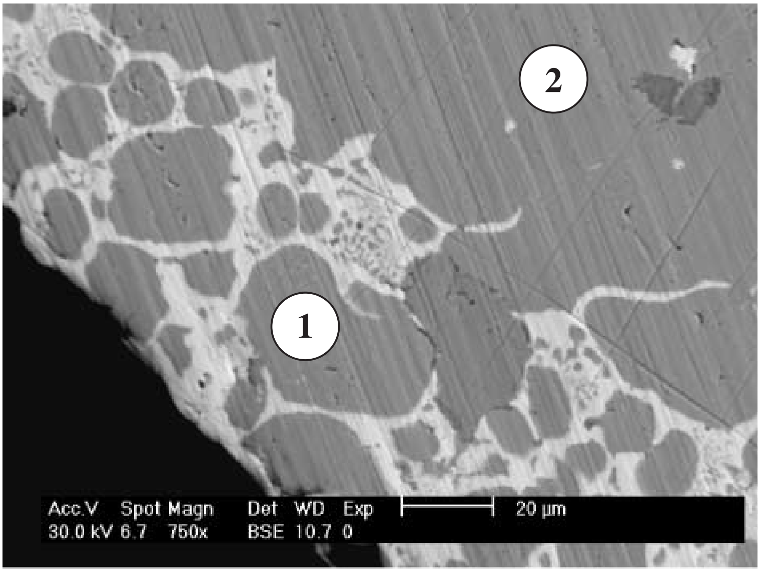

Figure 5 *A 20 keV backscattering electron SEM micrograph of sample B12, showing a section through a third-century forgery. The sample is divided into two areas: 1, the silvering, with copper grains surrounding an eutectic phase; 2, a copper alloy core.*

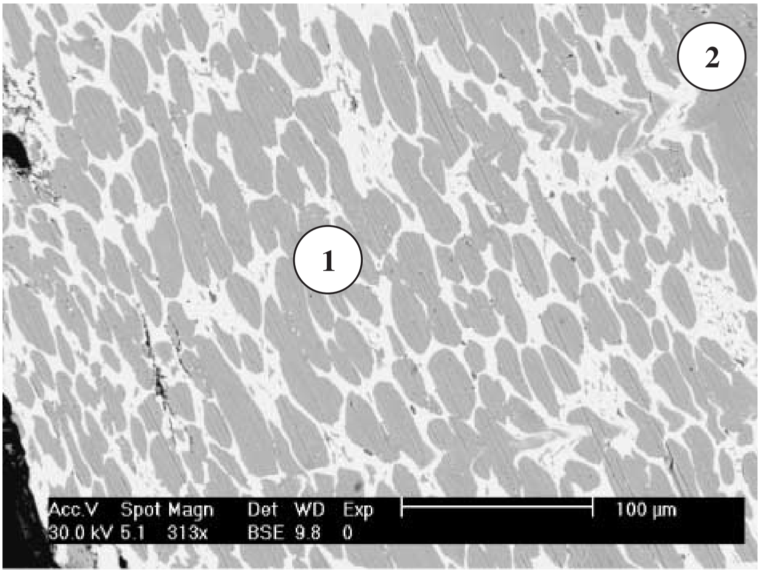

Figure 6 *A 20 keV backscattering electron SEM micrograph of sample B13, showing a section through a third-century forgery: 1 and 2, as in Figure 5.*

Experimental replication Replication experiments were carried out in the laboratory in order to understand the ancient manufacturing process for silvering the forgeries (Bozzoni *et al*. 2003; Caillaud *et al*. 2003).

Copper discs with a diameter of 1 cm and a thickness of 4 mm were cut off and then wrapped in a pure 50 µm thick silver foil. The samples were then placed in a graphite crucible along with charcoal, to produce a reducing atmosphere that would prevent the formation of copper oxide. Experiments were conducted for temperatures varying from 750°C to 1000°C and a range of times up to 30 min. The sample was loaded in the oven once the expected temperature was reached. Usually, the temperature drops by 80°C when the door is opened for loading. It then takes 6 min to reach the initial temperature again. The time $t = 0$ min represents this moment. The melting points of silver and copper are 961.93°C and 1084.5°C, respectively. For the eutectic phase (72% silver and 28% copper), the melting point is 779°C.

The development of the silver surface was studied as a function of two parameters: time and temperature. The first experiment was carried out at 750°C, for 10 min. No adhesion of the silver foil was observed. Higher temperatures (850°C, 900°C, 950°C and 1000°C) were tested. Figure 7 presents the sample made at 950°C during $t = 4$ min. We observed copper dendrites surrounded by an eutectic phase. At this temperature, the microstructures of the replication and of the archaeological artefact are similar.

The composition of the silvering layer as a function of temperature and time is presented in Figure 8. Four curves with similar profiles are drawn. At 850°C, the silver content decreases progressively, until a threshold is reached at $t = 4$ min. Then, the silver–copper alloy has a constant concentration of silver, of about 60%. At 900°C, the same phenomenon occurs, with a silver content of 50% in the alloy. At 950°C, the silver content is 30%; and at 1000°C, it is as low as 20%.

We have observed that the higher the temperature, the lower is the silver content. This is due to diffusion. The silver content decreases until $t = 4$ min due to the diffusion of copper from

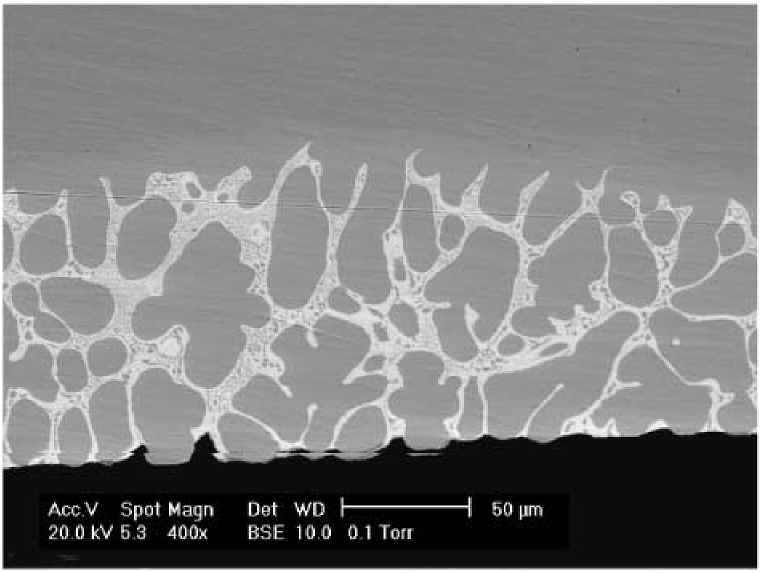

Figure 7 *A 20 keV backscattering electron SEM micrograph of a cross-section of a sample re-created at 950°C during a time period of 4 min: copper grains surrounded by eutectic alloy.*

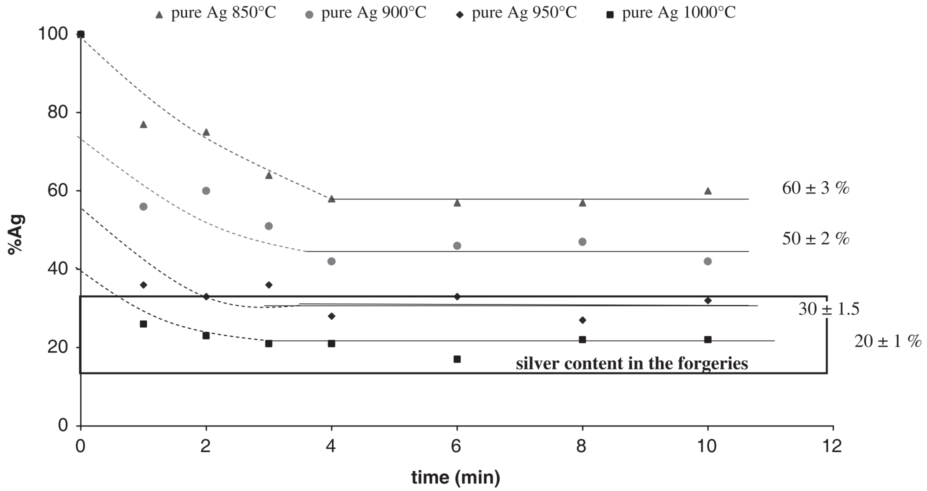

Figure 8 *The evolution of the composition of the silvering layer in terms of time and temperature.*

the core through the silver foil. Because the silver foil has not entirely melted down, a solid diffusion occurs. A silver–copper alloy is progressively formed and when the oven temperature reaches the melting point of this alloy, the silver–copper alloy becomes soft. When the sample is removed from the oven, a solidification process takes place, and this process explains the presence of copper dendrites and eutectic.

The EDX compositional analysis of the archaeological coins shows that the silvered layer contains about 26% of silver. This composition is similar to the composition of the re-created

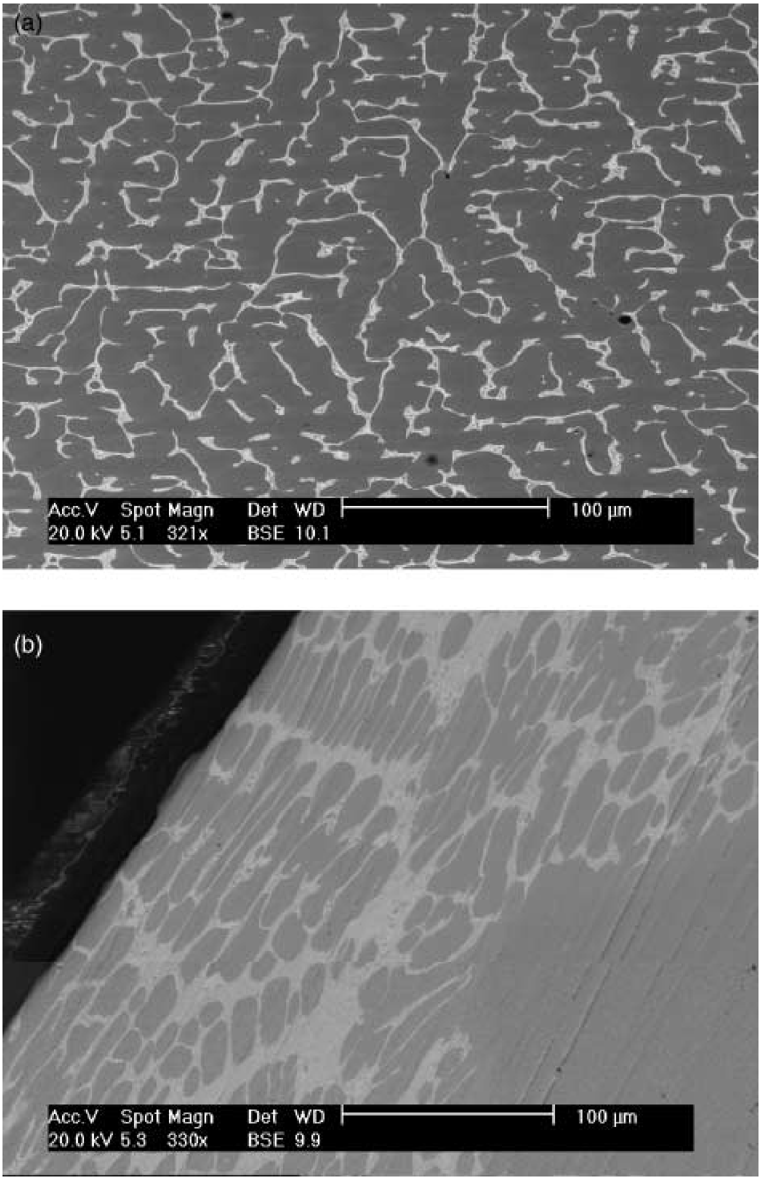

Figure 9 *A 20 keV backscattering electron SEM micrograph of a cross-section of a sample re-created at 950°C during a time period of 4 min after* (*a*) *hot striking and* (*b*) *cold striking.*

sample obtained at $T = 950°\text{C}$, after 4 min. In this case, the thickness of the silvering is 200 µm, whereas the archaeological coins have a maximum silvering thickness of 100 µm. Striking experiments were carried out under room temperature conditions. The sample was placed under a press and a pressure equivalent to 8 tons was applied to it. The thickness of the silvering decreased by half. Hot and cold striking has also been tested (Fig. 9). The microstructure obtained for cold striking was similar to that of the archaeological sample.

Our experiments finally showed that ancient silvered coins can be re-created when a copper disc is wrapped in a silver foil heated to at least at 950°C for more than 4 min. In these conditions, the plating is obtained by the combination of different phenomena:

- solid diffusion between the copper blank and the silver foil;
- melting of the alloy when its melting point corresponds to the heating temperature (self-soldering);
- liquid–solid diffusion between the copper–silver liquid phase and the blank until the equilibrium composition is reached;
- solidification of the alloy at the equilibrium composition; and
- striking of the blank at room temperature (cold striking).

CONCLUSIONS

The global analyses have shown that the official coins and the forgeries have different compositions. Moreover, the study of the microstructure has shown that the silver is not distributed in the same way: in the official coinage, silver is mixed with copper in the whole coin; whereas in the forgeries, there is a silvered layer of about 100 μm that covers a copper-based core.

The replication experiments have successfully reproduced the composition and the microstructure observed in the forgeries. For the *antoniniani* forgeries (third century AD) consisting of a plating layer containing 30% silver, a temperature of about 950°C was necessary. The plating replications were obtained by a self-soldering method, which has been overheated so that the silver–copper alloy thus formed has melted down (950°C for a 30% silver layer).

As a result, the plating presents a cast silver–copper alloy structure similar to that which could be obtained by directly dipping the blank in molten metal. However, the use of a silver foil seems to be more convenient and consumes less of the noble metal.

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REFERENCES

Anheuser, K., and France, P., 2002, Silver plating technology of the 3rd century Roman coinage, *Historical Metallurgy*, **36**(1), 17–23.

Anheuser, K., and Northover, J. P., 1994, Silver plating on roman and Celtic coins from Britain—a technical study, *The British Numismatic Journal*, **64**, 22–32.

Beauchesne, F., Barrandon, J.-N., Alves, L., Gil, F. B., and Guerra, M. F., 1988, Ion beam analysis of copper and copper alloy coins, *Archaeometry*, **30**, 187–97.

Beck, L., Bosonnet, S., Réveillon, S., Eliot, D., and Pilon, F., 2004, Silver surface enrichment of silver–copper alloys: a limitation for the analysis of ancient silver coins by surface technique, *Nuclear Instruments and Methods*, **B226**, 153–62.

Beck, L., Réveillon, S., Bosonnet, S., Eliot, D., and Pilon, F., 2003, Experimental evidence of direct silver surface enrichment on silver–copper alloys. Application to the analysis of ancient silver coins, in *Proceedings of the International Conference on Archaeometallurgy in Europe, September 2003*, vol. 2, 561–8, Associazione Italiana di Metallurgia, Milan.

Beck, L., Bregiroux, D., Bosonnet, S., Eliot, D., Réveillon, S., and Pilon, F., 2005, Metallographic investigation and microanalysis of plated *antoniniani* of Postumus, in *Proceedings of the 33rd International Symposium on*

Archaeometry, Amsterdam, April 2002 (eds. H. Kars and E. Burke), *Geoarchaeological and Bioarchaeological Studies*, 3, 293–6.

Boon, G. C., 1988, Counterfeit coins in Roman Britain, in *Coins and the archaeologist*, 2nd edn (eds. J. Casey and R. Reece), 102–88, Seaby, London.

Bozzini, B., Giovanelli, G., Natali, S., and Calcagnile, L., 2003, A metallurgical characterization of some surface silvered roman denarii, *Proceedings of the International Conference on Archaeometallurgy in Europe, September 2003*, vol. 1, 361–8, Associazione Italiana di Metallurgia, Milan.

Butcher, K., and Ponting, M., 2005, The Roman denarius under the Julio-Claudian emperors: mints, metallurgy and technology, *Oxford Journal of Archaeology*, **24**(2), 163–97.

Caillaud, F., Ienco, M. G., Piccardo, P., Poggi, C., and Poggio, E., 2003, Experimental essays and metallurgical investigation on Roman republican denarii serrati and subaerati (I century B.C.): the hoard from S. Varano (Forli, Italy), *Proceedings of the International Conference on Archaeometallurgy in Europe, September 2003*, vol. 2, 577–90, Associazione Italiana di Metallurgia, Milan.

Campbell, W., 1933, *Greek and Roman plated coins*, Numismatics Notes and Monographs 57, American Numismatic Society, New York.

Cope, L. H., 1967, A silvered bronze false *antoninianus* ascribed to the Roman emperor Gordian III, AD 238–244, *Metallurgia*, January, 15–20.

Cope, L. H., 1972, Surface-silvered ancient coins, in *Methods of chemical and metallurgical investigation of ancient coinage*, vol. 8 (eds. E. T. Hall and D. M. Metcalf), 261–78, Royal Numismatic Society, London.

Cope, L. H., King, C. E., Northover, J. P., and Clay, T., 1997, Metal analyses of Roman coins minted under the Empire, *British Museum Occasional Paper* **120**, 31–2.

Darmstaedter, E., 1929, Subaerate Münzen und ihr Hestellung, *Mitteilungen der Bayerischen Numismatischen Gesellschaft*, **47**, 27–38.

Gitler, H., and Ponting, M., 2003, The silver coinage of Septimus Severus and his family (193–211 AD): a study of the chemical composition of the Roman and Eastern issues, in *Glaux: collona di studi e ricerchi di numismatica*, 157, Edizioni Ennerre srl, 16, Milan.

Hollard, D., and Gendre, P., 1986: Le trésor de Rocquencourt et la transformation du monnayage d'imitation sous le règne de Postume, *Trésors Monétaires*, **VIII**, 9–23.

La Niece, S., 1990, Silver plating on copper, bronze and brass, *Antiquaries Journal*, **LXX**, 102–14.

La Niece, S., 1993, Technology of silver-plated coin forgeries, in *Metallurgy in numismatics III* (eds. M. M. Archibald and M. R. Cowell), 227–39, Royal Numismatic Society Special Publication 24, London.

Vlachou, C., Janaway, R., and McDonnell, G., 2000, The metallurgical examination of the tetrarchic nummi, *Proceedings of 2000 archaeometry conference*, Mexico City, CD-ROM.

Zwicker, U., 1993, *Katalog der Münzen in der Universitätsbibliothek Erlangen-Nürnberg, Band 2: Römische, byzantinische und Münzen der Völkerwanderungszeit aus den Sammlungen Will, Gerlach und Pick*, Schriften der Universitätsbibliothek Erlangen-Nürnberg 23, Universitätsbibliothek Erlangen.