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Summary

Seventy-one samples were taken from a selection of material relating to the manufacture of official and unofficial coins in Roman Britain. They were analysed chemical by inductively-coupled plasma atomic emission spectrometry and the data were investigated using a variety of univaraite and multivariate statistical procedures. The results provide an insight into the way these coins were produced and how they relate to the official coins produced on the Continent. The use of trace element analysis to study die-linked groups of copies is also investigated.

Keywords

Coin
Copper Alloy
Metal Working-non Fe
Technology
Roman

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Introduction

The crisis of the Romano-British economy in the later third century AD gave rise to an outbreak of local coin production, the scale of which had not been seen before. These coins are now thought to have appeared as a semi-official reaction to the reform of the coinage by Aurelian in AD 274, which had effectively done away with low value coin for everyday transactions. The coins produced were copies of the pre-reform issues that had formed the basis of the economy prior to AD 274, although the quality of the copying varies tremendously. In AD 286 a short-lived independent British empire was established under Carausius, the commander of the British fleet, and began striking coins that initially bore a marked resemblance to the unofficial copies of the earlier coins. Consequently it has been suggested that Carausius' earlier coins were a legitimised extension of the pre-existing unofficial minting system brought in by Carausius as the only source of minting expertise (Boon 1988, 132). Similar 'epidemics' of unofficial coin production occurred in the 330s and 350s, also sparked by official reforms and a subsequent scarcity of low value coin. How these coins (usually referred to as *Barbarous Radiates* or radiate copies, Constantinian copies and FEL TEMP copies respectively) functioned within the economy, where and by whom they were produced are important questions with consequences for the economy and society of later Roman Britain.

The project analysed four groups of material with the aim of addressing two closely related problems; firstly the project was designed to study the relationship between radiate copies, their production waste and the coinage of Carausius that came immediately after, and secondly, to assess the usefulness of chemical analysis to investigate the production of copies through the analysis of die-linked material.

The material analysed

The recent success of the Portable Antiquities Scheme (PAS), funded by the Heritage Lottery Fund (HLF), has resulted in a large number of metal finds being reported to local museums, and the consequent identification of previously unknown classes of artefact. In Norfolk it was noticed that a number of sites known for Roman finds were yielding groups of copper-alloy waste, pellets cut from rod and what appear to be un-struck coin blanks, all alongside radiate copies. It was suggested that the material represents workshops where radiate copies were being produced, and as such offered the opportunity to investigate their manufacture and production. This material comprised 51% (36 pieces) of the total number of samples analysed.

Thirteen radiates of Carausius from the excavations at Piercebridge, County Durham, were analysed specifically to compare their compositions with that of the radiate copies. The aim was to establish how the coinage of the British empire relates to the radiate copies and whether there is any support in the coins' composition for the view that Carausius' coinage developed out of the local copying tradition.

The coins of Carausius that were analysed are listed in Table 1. The three coins marked with * form a stylistic group of un-mint-marked coins that include one with a figure of Felicitas on the reverse and the legend MART. FAV (Mars the favoured) (Fig. 1). This type has been the subject of numismatic debate, being of apparently barbarous style, yet still a unique type with no clear prototype amongst the so-called official coins (Boon 1988, 134). This group of coins falls into what King (1984) reluctantly calls 'semi-official', having '…..features which suggest they are official and features which suggest they are not.’ (King 1984, 3) and is possibly the ‘missing link’ between radiate copies and Carausius’ early coinage.

Table 1. Description of the Carausian coins analysed.

No	Obv	Rev	Mint	Date
2071	IMP CARAVSIVS PP AVG*	Illegible, stg. figure		
2210	IMP CARAVSIVS PP AVG	PAX AVG, P to r., M(C?)	C	286-290
2757	IMP C CARAVSIVS PP AVG	PAX AVG, S C either side, C in ex.	C	291-293
846	IMP (CARAVSIVS P)AV*	(MA)R(T FAV) Felicitas stg (see Boon 1988, pl. VI, 111)		
1779	IMP CARAVSIVS PP AVG	PAX AVG, ML in ex.	London	286-290
1575	IMP C CARAVSIVS PP AVG	FORTVNA AVG		291-293
1633	IMP CARAVSIVS PP AVG*	(P)A(X AVG) Pax stg.		286-290
1937	IMP CARAVSIVS PP AVG	SALVS AVG		286-290
1700	unclear	PAX AVG, S P either side, MLXXI in ex.	London	291-293
2016	IMP C CARAVSIVS PP AVG	standing figure, S and ? either side, MLXXI in ex.	London	291-293
2316	IMP C CARAVSIVS PP AVG	SALVS AVG		291-293
690	IMP CARAVSIVS P AVG	PAX AVG, L to l.(double struck)	London	286-290
730	IMP C DIOCLETIANVS PP AVG	PAX AVG, S P either side, C in ex.	C	292


Fig. 1.Obverse and reverse of coin 846.

Two groups of later copies were also analysed to test the potential of chemical analyses to identify stylistic and die-linked copies; these were twelve die-linked copies of the Constantinian period from Norfolk, and ten copies of the Fel Temp issues of the mid-fourth century from Piercebridge.

Analytical procedure

Bulk chemical analysis was by inductively-coupled plasma atomic emission spectrometry (ICP-AES) and energy dispersive X-ray fluorescence (ED-XRF) and was conducted on all 71 pieces. A small area on each piece was ground to reveal bright metal and then polished prior to analysis by ED-XRF. Sampling for ICP-AES was by drilling a small hole into the object and collecting the turnings after first discarding the initial millimetre or so of material so as to avoid the effects of corrosion. The ICP-AES was calibrated using matrix matched standard solutions and accuracy and precision were checked against certified standard reference materials and data quality control solutions. Details of the analytical methods used can be found in appendix 1 and the results are given in table 6.

The data were initially divided into three groups; the radiate copies (including production waste and coins of Carausius), Constantinian copies and FEL TEMP copies. These groups were then examined individually.

Results and discussion of the radiates and their copies

The coins of Carausius

The compositions of the13 coins of Carausius are compared with those of the radiate copies and their production material. It is also possible to make some useful observations on the composition of the Carausian coins in isolation, although it should be remembered that only a small number of coins were analysed and that therefore any conclusions will be tentative.

The major alloying components (silver, tin, zinc and lead) vary significantly between the mints; both tin and zinc show a significant (at the 0.05 level) negative correlation with silver, indicating that both tin and zinc contents become lower as the silver content increases (Figs 2 and 3).

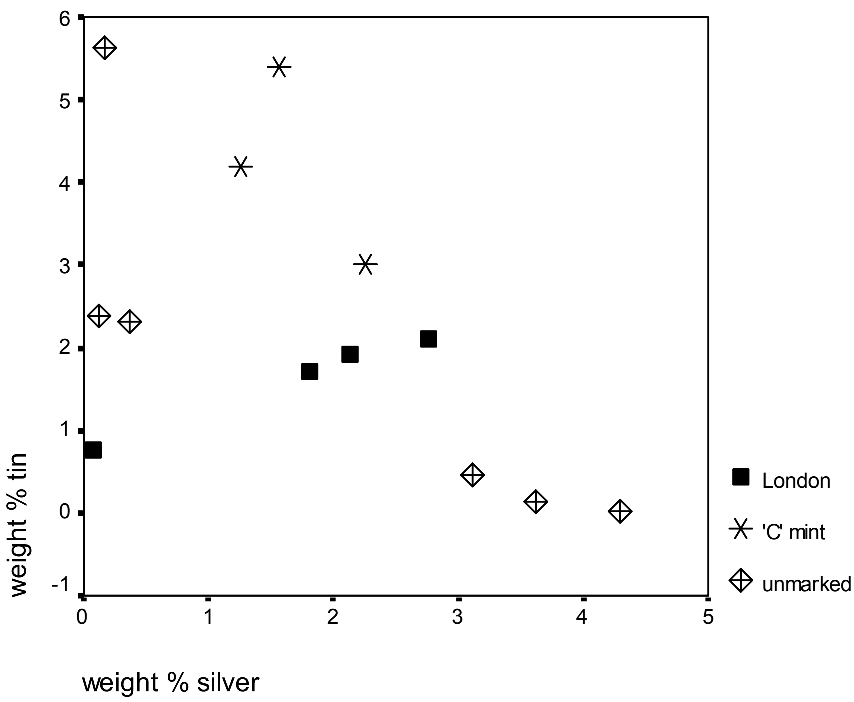

Fig. 2. Scatterplot of silver against tin.

The zinc would almost certainly have been added to the alloy in the form of orichalcum, a brass that should contain around 25% zinc although this figure can be somewhat lower in third century orichalcum coinage (Dungworth 1996). The tin could have been added as tin metal, but more likely as bronze, whilst the silver could have come as a silver-copper or copper-silver alloy of varying proportions depending on source.

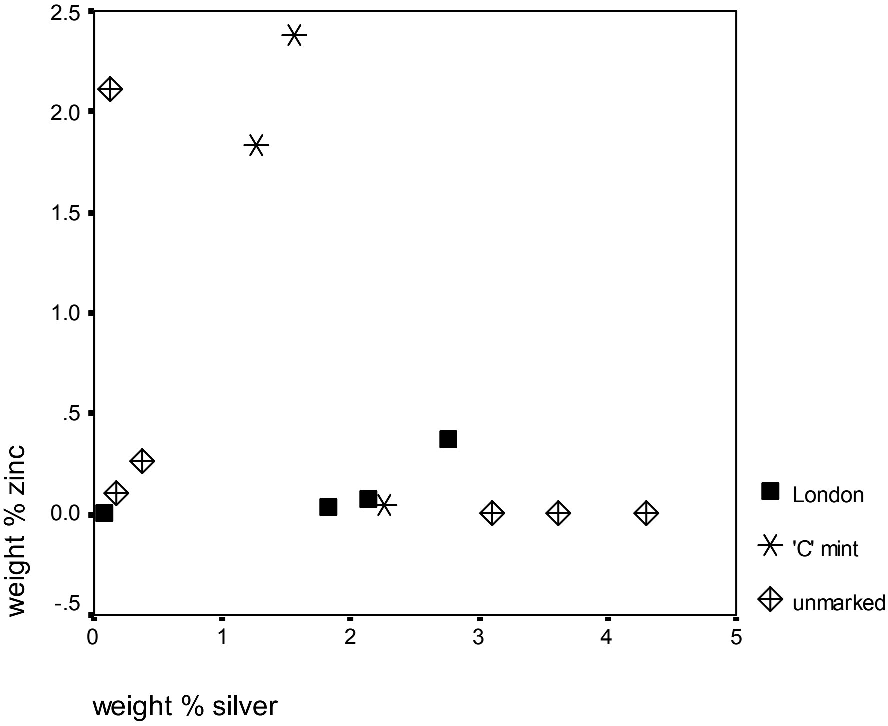

Fig. 3. Scatterplot of silver and zinc contents.

The correlations suggest an economic role for these three metals with zinc (as orichalcum) and tin substituting for silver in certain issues. Three of the unmarked coins (Um B: 1937, 2316 and 1575) have the highest silver contents (3-4%) as well as the lowest tin and zinc contents. Three of the four coins struck by the London mint (2016, 1700 and 690) are characterised by having about 2% of both silver and tin, but less than 0.5% zinc. Two of the three coins issued by the so-called ‘C’ mint (2210 and 2757) are distinguished by relatively high levels of zinc (~2%) and tin (~5%) and low levels of silver (~1.5%). These relationships are presented in Table 2.

Table 2. Means and standard deviations of the four main groups of Carausian coins.

Group	silver	tin	zinc	lead
Um A	0.22 (0.13)	3.44 (1.9)	0.83 (1.1)	16.7 (5.7)
Um B	3.68 (0.6)	0.2 (0.2)	0.004 (0.002)	0.51 (0.13)
‘C’ mint	1.41 (0.2)	4.8 (0.8)	2.1 (0.4)	1.98 (2.0)
London	2.24 (0.5)	1.9 (0.2)	0.16 (0.19)	2.05 (0.4)

There are two coins that do not fit into these groupings. One with a ‘C’ mintmark (730*) has 2.3% silver and only 0.05% zinc. This is one of an issue of coins struck by Carausius with the bust and name of Diocletian, and therefore represents a specific and special issue. Was this an issue where the amount of silver in the alloy was increased, thereby requiring less orichalcum to be added to achieve the required intrinsic value? One of the London marked coins (1779) is virtually pure copper with 2% lead and less than 1% of silver (0.08%), tin (0.76%) or zinc (0.01%). It is of small module and may be overstruck on an earlier coin of the Gallic emperors or Claudius II, as the composition is consistent with these issues (Ponting 1998).

The unmarked coins fall into two distinct groups; Um A defined by high lead, moderate tin, variable zinc and no added silver, Um B by relatively high silver and no added lead, tin or zinc. This very marked compositional distinction is paralleled by stylistic differences; Um A is the same as the stylistic group that includes coin 846, the MART. FAV. type, and the other ‘semi-official’ coins, whilst Um B consists of coins of more regular, official size and style.

The coins of the ‘C’ mint and the London mint are also quite distinct in their composition, both from each other and from the unmarked issues. The issues of the ‘C’ mint show a similarity to the Um A coins in that a percent or two of zinc is usually present, however the ‘C’ mint coins contain somewhat more silver and less lead. The London coins are more akin to the products of the central imperial mints, although their silver contents, whilst being an apparently consistent 2%, are lower than the contemporary issues of the Central Empire (5% silver from AD 274) but are closer to the coins issued before the great coinage reform of Aurelian in AD 274 in terms of their alloying components.

If the trace elements (antimony, nickel, iron, arsenic, gold and cobalt) in the Carausian radiates are compared with those in radiates of the Gallic emperors and the Central Empire’s western mints (Fig. 4) some of the exceptions and other features of the Carausian coins become clearer.

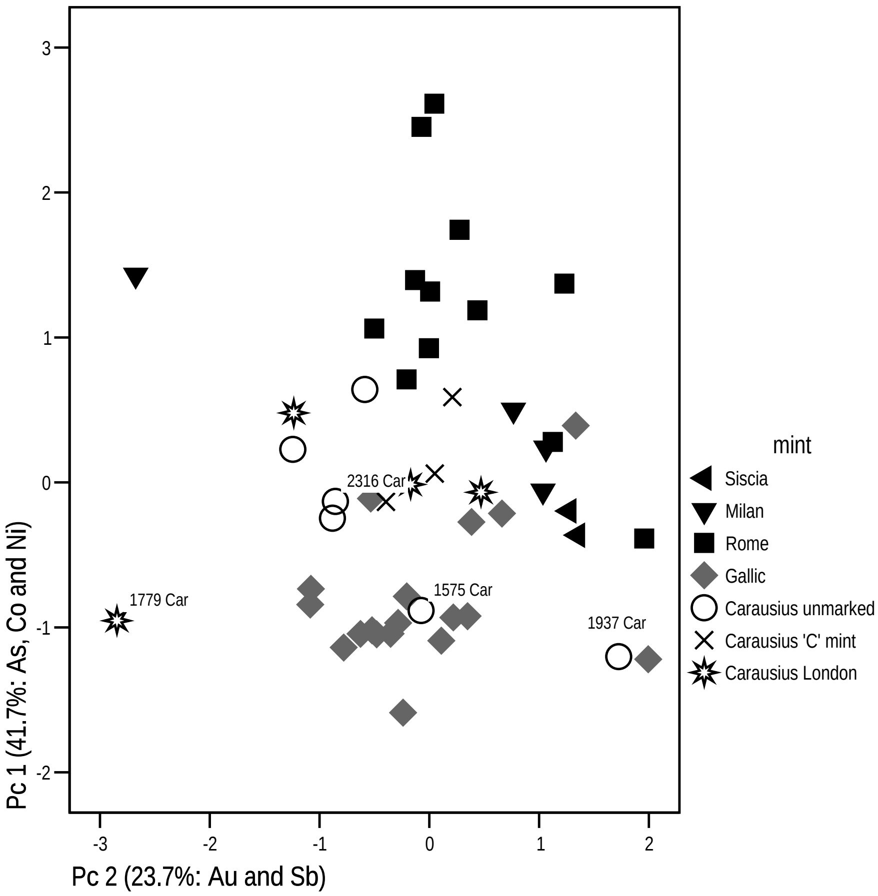

Fig 4. Principal component plot of Carausian and continental issues (unpublished data from the Wallbottle hoard). Elements listed on the axes are only those that contribute to the data structure.

The three unmarked coins made of argentiferous copper (Um B: 1937, 2316 and 1575) fall within the spread of the Gallic issues, with 1575 and 1937 being well separated from the other Carausian issues. This strongly suggests that these coins were produced from either re-melted Gallic issues or directly overstruck on them, as has been observed by King (1984, 2) and Boon (1988, 132). However, the three coins of Um B show no visible signs of being overstrikes; it is their composition, both major and trace elements, that links them strongly with the issues of the Gallic empire. Similarly, the compositionally odd London coin (1779) is also grouped with the Gallic issues thereby explaining it's odd composition. The unmarked coins of Um A together with the rest of the marked coins largely fall in the gap between the Gallic issues and the issues of the Central Empire, with the exception of 1633, 730 and 690 (coins from London, the 'C' mint and the Um A group). Of these, 730 is the compositionally odd issue struck for the emperor Diocletian. Of the other two coins, only one (1633) is likely to be an overstrike (Fig. 5) although this may also be the explanation for 690 as well.


Fig. 5. Reverse of 1633 showing both a beaded and a solid line at the edge of the design indicative of overstriking.

The overall impression given by the compositions of these few coins of Carausius is of great variability that appears linked to style and (where attribution is possible) to mint. Much use was clearly being made of earlier Gallic issues that are known to have been common currency in the third quarter of the third century and indeed, it was these coins that provided the prototypes for the radiate copies and still formed a large part of the currency in the early 290's (Boon 1988, 130). However, some attempt was clearly being made to issue coins from a prepared alloy that is clearly quite different from that being use to produce either the Gallic issues or the issues of the Central, or indeed, the Restored Empire. Whilst the unmarked issues of Um A could possibly be dismissed as 'barbarous copies' on account of their module size and style, the issues of the 'C' mint are clearly 'official' (Fig. 6), yet their composition (with the obvious exception of 730) is very different to that of either the Gallic or Central Empire's coins.

The most distinctive feature of the alloy of both the Um A coins and those of the 'C' mint is the presence of zinc. This is quite significant since, despite zinc having become a common component of much Roman copper-alloy metalwork, it is never found as an added component of coinage alloys except for of the orichalcum issues of the first and second centuries. Radiate copies, on the other hand, have been shown to frequently contain levels of zinc very similar to those found in the coins of Carausius (for examples see Zeepvat *et al* 1994; Ponting 1994 and 1998). It is therefore of some interest to compare the composition of the Carausian coins with that of radiate copies.

Fig. 6. Obverse and reverse of Carausian 'C' mint coin 2757.

Metal waste from Norfolk

The material from Norfolk comprises radiate copies, un-struck coin blanks and various pieces of copper-alloy that appear to be associated with the manufacture of radiate copies (Fig. 7).

Fig. 7. A selection of the Colkirk finds.

The majority of the material comes from Colkirk, with other pieces from various adjacent locations within the county. All the material was found by metal detector enthusiasts and therefore has no archaeological context. In the light of this, a quick survey of all the material was undertaken by XRF to establish the broad range of composition types and to see if any clearly non-Roman compositions would enable suspect material to be removed. This was indeed the case, with two non-descript lumps being rejected on account of having high antimony contents and other compositional features consistent with post-medieval cauldrons and skillets (Dungworth and Nicholas 2004). A section of gate or sprue, in the clear form of a tree, was regarded as questionable because it had a particularly high zinc content

(27% by XRF). A sample of this was analysed by ICP-AES, but the data were later omitted from this study when these analyses showed that the zinc content was closer to 30% and the trace element pattern was quite different to any of the other material. All the other pieces have compositions that are consistent with their assumed date.

Plotting the zinc and tin contents against each other (Fig. 8) shows that the majority of pieces have zinc contents of less than 5%, although there are six pieces with zinc contents between 10% and 20%. These six pieces comprise a possible coin blank or section of cut bar (35) and a pellet (32) whilst the remaining four pieces are scrap metal associated with radiate copies from Colkirk. Two of these pieces of scrap are second or third century sestertii that were very worn and damaged; one had been cut in half whilst the other was partially melted (Fig. 9).

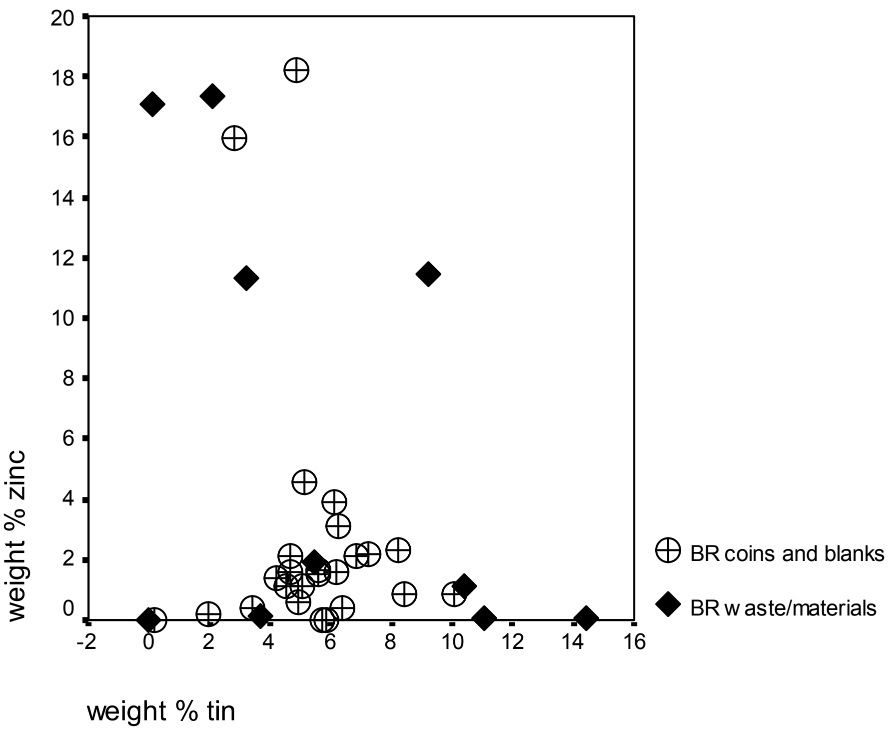

Fig 8. Scatter of zinc against tin for radiate copies and associated waste metal etc.

These two damaged sestertii (13 and 14) both have zinc contents of around 11% and tin contents of 3% and 9% respectively. There is another cut sestertius in the assemblage (15) but, despite the denomination, this coin is made of a highly leaded bronze, but is the most identifiable of the three; the neck and strands of a beard are visible and suggest that the coin bore the head of Marcus Aurelius or Commodus (AD 161-192); the zinc-free composition makes the latter more likely. The use of worn and damaged sestertii and dupondii for the production of radiate copies has been discussed by Ponting (1998, 281-2) and more recently by Abdy (2003) with reference to the hoard of worn sestertii from Longhorsley, Northumberland. The main link between sestertii and radiate copies is that both contain zinc; as stated above, zinc is only ever found in sestertii and dupondii and almost never in the alloy of any other Roman imperial base metal coins. This fact, coupled with the finds of damaged sestertii and/or dupondii in association with radiate copies makes a strong case for their use as raw material for the copiers. Furthermore, the difference in the zinc levels in the two sestertii here and the radiate copies suggests that the sestertii were mixed with other metal that did not contain zinc, thereby diluting the zinc to the levels found in the copies. The presence of relatively high zinc contents in other pieces that are not sestertii or dupondii suggest that orichalum in other forms than coin was being used; either sestertii and dupondii were melted down and orichalcum was circulated in another form (such as ingot) or other orichalcum objects were being selected and re-cycled via ingot form as well. Interestingly, a piece of a casting sprue was found with the Longhorsely hoard that may be made of orichalcum, although the reported analysis is ambiguous (Abdy 2003, 137). This may support the idea that sestertii and dupondii were sometimes cast into interim forms before being alloyed with other metal to make radiate copies. What these interim forms may have been can be suggested by the cut pieces of bar and rod with compositions that are consistent with first and second century sestertii (see Étienne and Rachet 1984 for analyses of sestertii and dupondii).

Fig. 9. Cut and partially melted sestertii from Colkirk (from L to R, samples13-15).

Evidence for the mixing of orichalcum with other metal to produce the alloy for radiate copies comes not only from the analyses of the radiate copies and their blanks, but also from the waste/raw materials analysed that contain little or no zinc (e.g. Samples 4-7 in Table 6). The latter plot at either end of the tin axis in Figure 8 and divide into copper and relatively high-tin bronze, with the radiate copies and the ingot of 'radiate copy metal' (sample 8) clustering in-between.

This suggests that the radiate copy compositions are the result of mixing the copper, bronze and orichalcum found in association. The one missing part of this equation is, of course, the silver, but this is perhaps not surprising given the small amounts of silver that were being used. Table 3 gives notional values for the composition of copper, bronze and orichalcum (based on the analyses) and silver (based on the composition of Severan denarii [Gitler and Ponting 2003]). If combined in the proportions suggested in the table, the resulting alloy, labelled "radiate alloy" is similar to the average composition of the analysed coins, blanks etc., labelled "radiate copy".

It seems clear that the zinc-rich orichalcum forms a distinct compositional sub-group of the metal waste and BR coins from Norfolk that was essentially a raw material for alloying with other metal to produce the alloy used for radiate copies. We can therefore remove this material from the data set and re-evaluate the remaining pieces. A scatterplot of the silver and zinc contents (Fig. 9) shows how the remaining low zinc pieces of production waste are also mainly without silver (<0.5%).

Table 3. Notional values for the metals alloyed to make radiate copies.

	copper	bronze	orichalcum	silver		
Proportions	30	50	20	0.5		
	copper	bronze	orichalcum	silver	Radiate copy	Radiate alloy
Sn	1	10	2	0	6.1	6.0
Zn	0	0	11	0	2.5	2.5
Pb	1	8	3	2	5.8	6.0
Ag	0	0	0	45	0.5	0.5
Cu	98	82	84	53	87	87

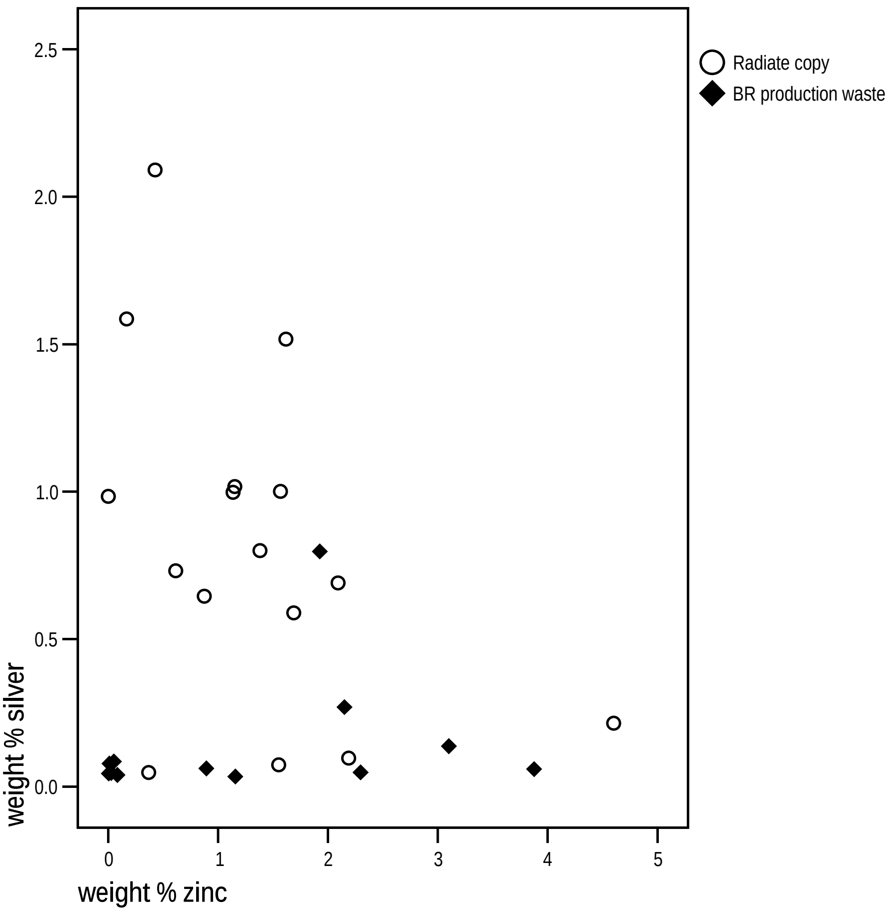

Fig. 9. Scatterplot of silver and zinc contents in radiate copies.

The exception to this is the small ingot (8) that has the same composition as the radiate copies themselves and therefore represents a final stage of prepared alloy stored in ingot form (Fig 10). There is also a suggestion of a negative correlation between the zinc and silver in Fig. 9 which, when the low zinc (< 1.5%) pieces are removed, is statistically significant (coefficient of -0.7, significant at the 0.01 level), which suggests that the zinc/orichalcum content was increased when silver was not available.

Fig.10. Ingot of radiate copy alloy.

Additionally, when the tin contents are plotted against the silver contents (Fig. 11) a negative correlation is also apparent and this is significant at the 0.05 level (coefficient of -0.6). Therefore, it appears that both the tin and zinc contents were controlled and adjusted according to the amount of silver available – and where silver was not available greater amounts of orichalcum and tin (or bronze) were added.

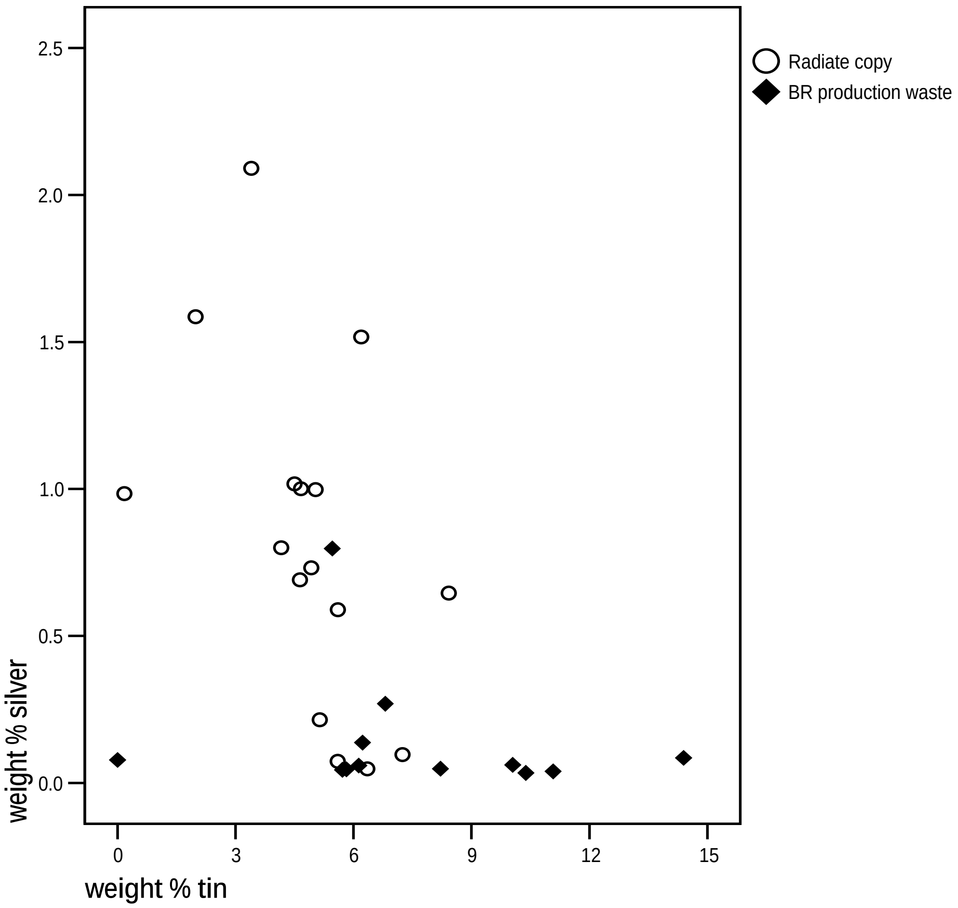

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Fig. 11. Scatterplot of silver against tin in radiate copy material

Interestingly, there is a weak correlation between the zinc and tin contents (coefficient of 0.5), which is nevertheless significant at the 0.05 level, and which therefore suggests that the tin and zinc were, on occasion added together. This is not surprising, especially given the fact that tin was frequently an (unexpected?) component of the orichalcum used for sestertii and dupondii (see Étienne and Rachet 1984) and the weaker correlation of tin with silver may reflect the fact that some of the tin in radiate copies came in as a contaminant in what was regarded as 'pure' orichalcum (see Dungworth 1996 for a discussion of the decline of zinc levels in sestertii and dupondii).

Clearly there is considerable variation in the major element compositions of the radiate copies, far more than would be expected in a single, cohesive coinage. However, similar variability has been noticed in other Roman issues and has been shown to be due to differences in alloying practice at different mints (Ponting, forthcoming; Cope 1974). By studying the data here four possible compositional groups could be identified and this was further refined by running a discriminant analysis (DA) on the data. The groups are defined in Table 4.

Table 4. Means and standard deviations of the four compositional groups (group 3 has only one member).

Group	Ag %	Pb %	Sn %	Zn %
1	1.1 (0.5)	4.8 (1.3)	4.5 (1.2)	1.2 (0.6)
2	0.1 (0.1)	5.8 (2.9)	6.5 (1.0)	2.8 (1.1)
3	1.0	1.2	0.2	0
4	0.2 (0.3)	8.9 (6.8)	7.3 (1.9)	0.4 (0.4)

The single coin in group 3 may well be an overstrike on an official radiate, or part of one, as the major element composition is consistent with this. Group 1 is defined by having both silver and zinc, whilst group 2 has no silver but higher zinc and tin. Group 4 has no silver or zinc but high tin and lead. However, none of these coins are linked in style or type to any other, suggesting that these groups relate either to workshops using particular alloy recipes over many dies or that these compositional groups are perhaps related to specific batches of metal rather than workshops and that several workshops had access to the same metal. Only further work will resolve this issue.

Comparing radiate copies and Carausian coins.

When the radiate copy analyses are compared with those for the Carausian coins the similarities are quite clear; the zinc contents across the Um A and 'C' mint issues of Carausius are the same as those of the radiate copies and is an important link between these two coinages (Fig 12).

The silver contents also overlap, although the silver contents of some of the London issues of Carausius and those of the overstruck Um B issues are up to twice as high as in the radiate copies. Similarly the tin contents also broadly overlap, although again the overstruck Um B issues of Carausius contain lower levels than the majority of the radiate issues. This suggests that the Um A and 'C' mint issues and some of the London issues of Carausius are compositionally identical to that of radiate copies (at least in the major element compositions).

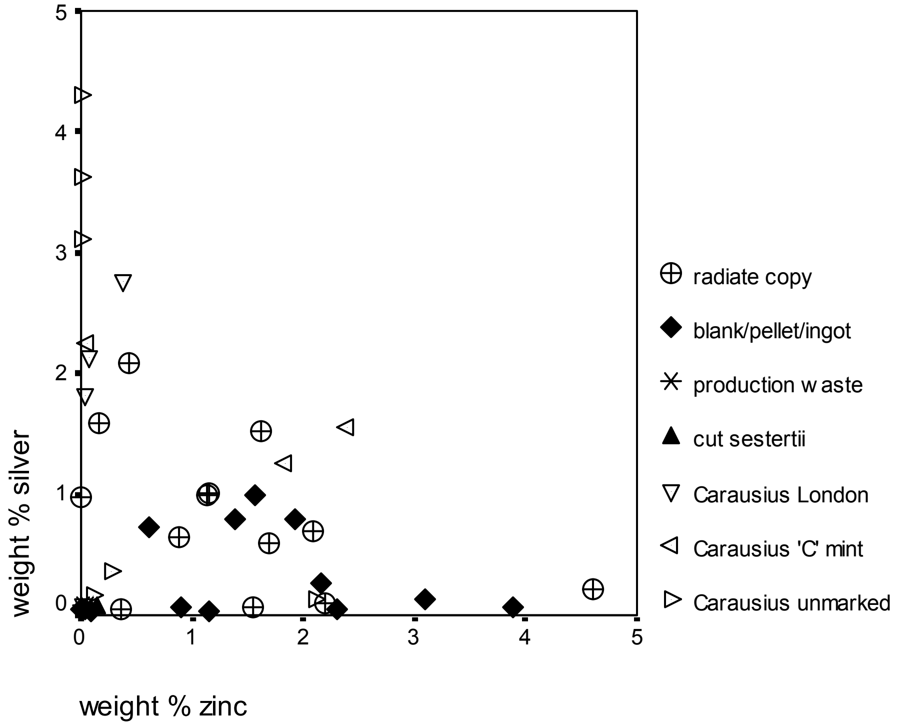


Fig. 12. Scatterplot of silver and zinc contents for radiate copies and Carausian coins (the production waste and one cut sestertius have negligible silver or zinc and so are obscured at the origin, the remaining cut sestertii have zinc contents of over 11% and are not included on this graph)

Bi-variate scatterplots of pairs of trace elements for the Carausian issues and the radiate copies reveal no strong structure, which also suggests that the metal used for both came from what was essentially the same circulation pool. Multivariate statistical analysis revealed some structure not revealed by the bi-variate approach, although it still does not completely separate the Carausian issues from the radiate copies. The plot of the first two principal components (log transformed) resulting from the analysis of all the trace elements in the Carausian coins and the radiate copies (Fig. 13) shows a main cluster of all material with six outliers; these are the orichalcum raw material including one of the cut sestertii and the sections of bar and rod (35 and 32). Given that most of the trace elements in the orichalcum would have originated in the copper used to make the orichalcum, it seems likely that the orichalcum has a different origin from the bulk of the metal used to make both radiate copies and the coins of Carausius. The other outliers are the blank and pellet from Great Dunham (33 and 34), which also have an atypical major element composition, and the three Carausian coins of Um B, already identified as overstrikes on continental issues.

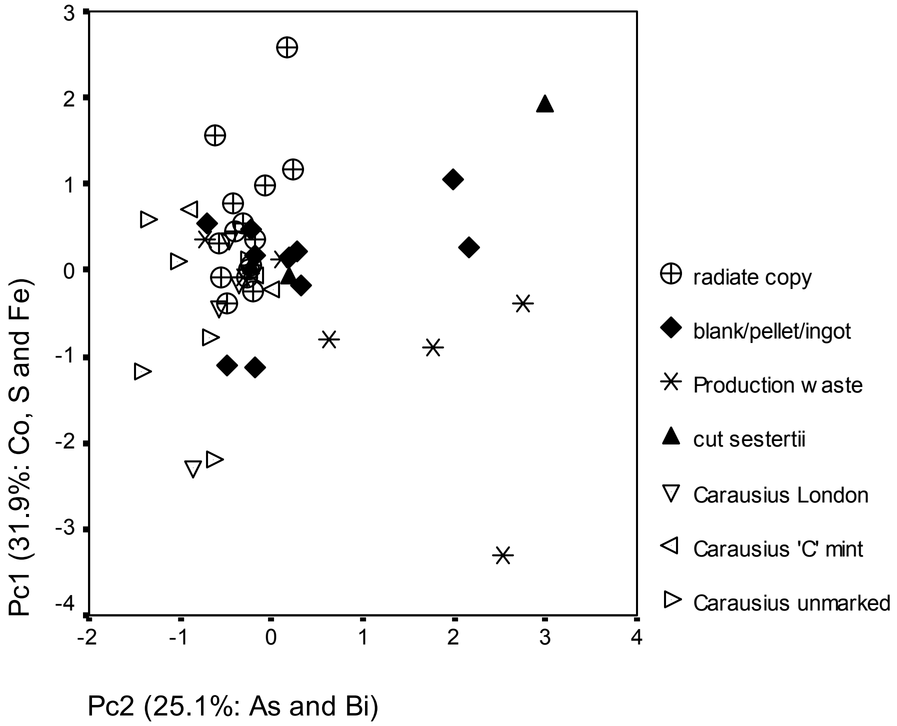


Fig. 13. Principal component plot of radiate copies and Carausian coins. Elements listed on the axes are only those that contribute to the data structure.

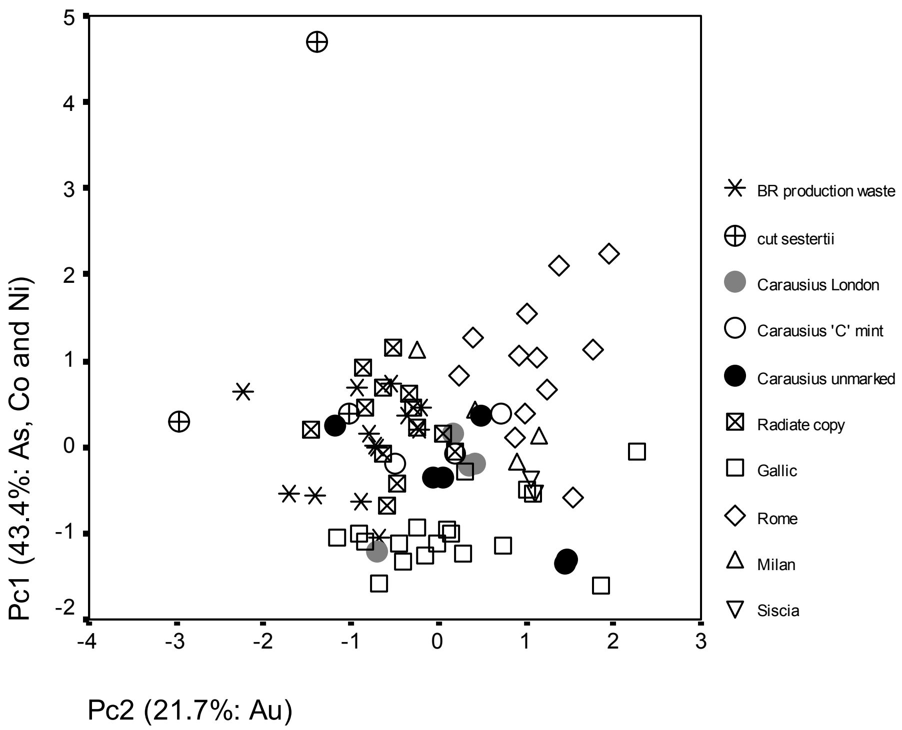


Fig. 14. Principal component plot of radiate copies, Carausian issues and Continental issues of the Gallic and Central Empire (Wallbottle hoard, unpublished data). Elements listed on the axes are only those that contribute to the data structure.

If the trace element compositions of the radiate copies and the Carausian coins are compared with that of the contemporary continental issues (of both the Gallic and central empires) the similarity between the compositions of the radiate copies and the issues of Carausius are quite clear, sitting between the issues of the central and Gallic empires (Fig.14). This reinforces the similarities between Carausian coins and BRs already noted above.

Results and discussion of Constantinian copies

The second stage of the project involved the investigation of the chemical compositions of a group of irregular copies of Constantinian coins (wolf and twins type). The coins analysed came from a small group of die-linked coins from various sites in Britain and the aim was to link the die linked groups to any compositional groups identified. The analytical data are given in Table 7.

Five die-linked groups were selected, plus one un-linked coin. The linked groups were mostly pairs with one group of three and all links were on both obverse and reverse, with the exception of group 5, which was linked by the obverse die only (Fig 15).

Group 5 is clearly defined by having considerably lower lead content (Fig 16) and other elements clearly mark these two coins as both compositionally the same as each other and different from the rest of the coins analysed.

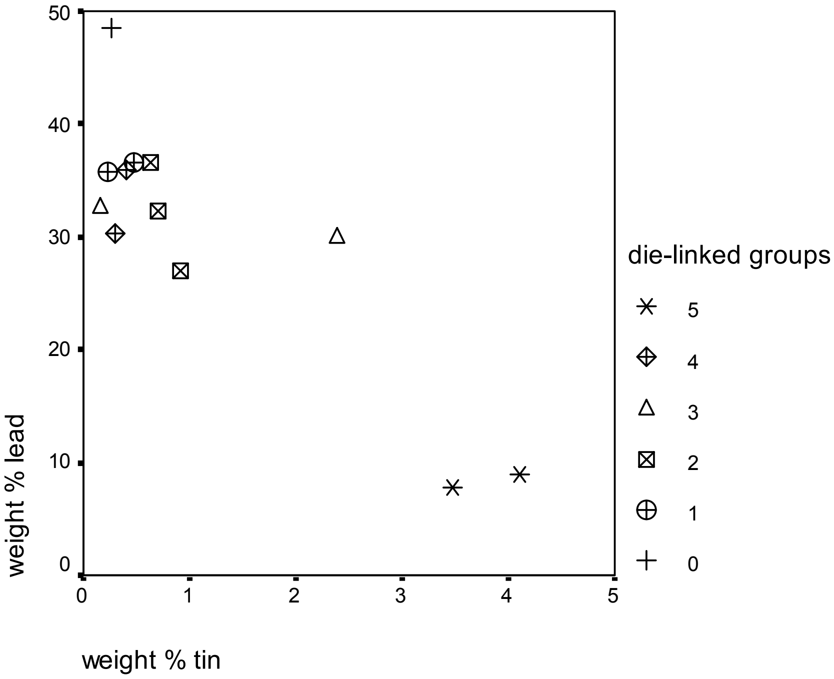
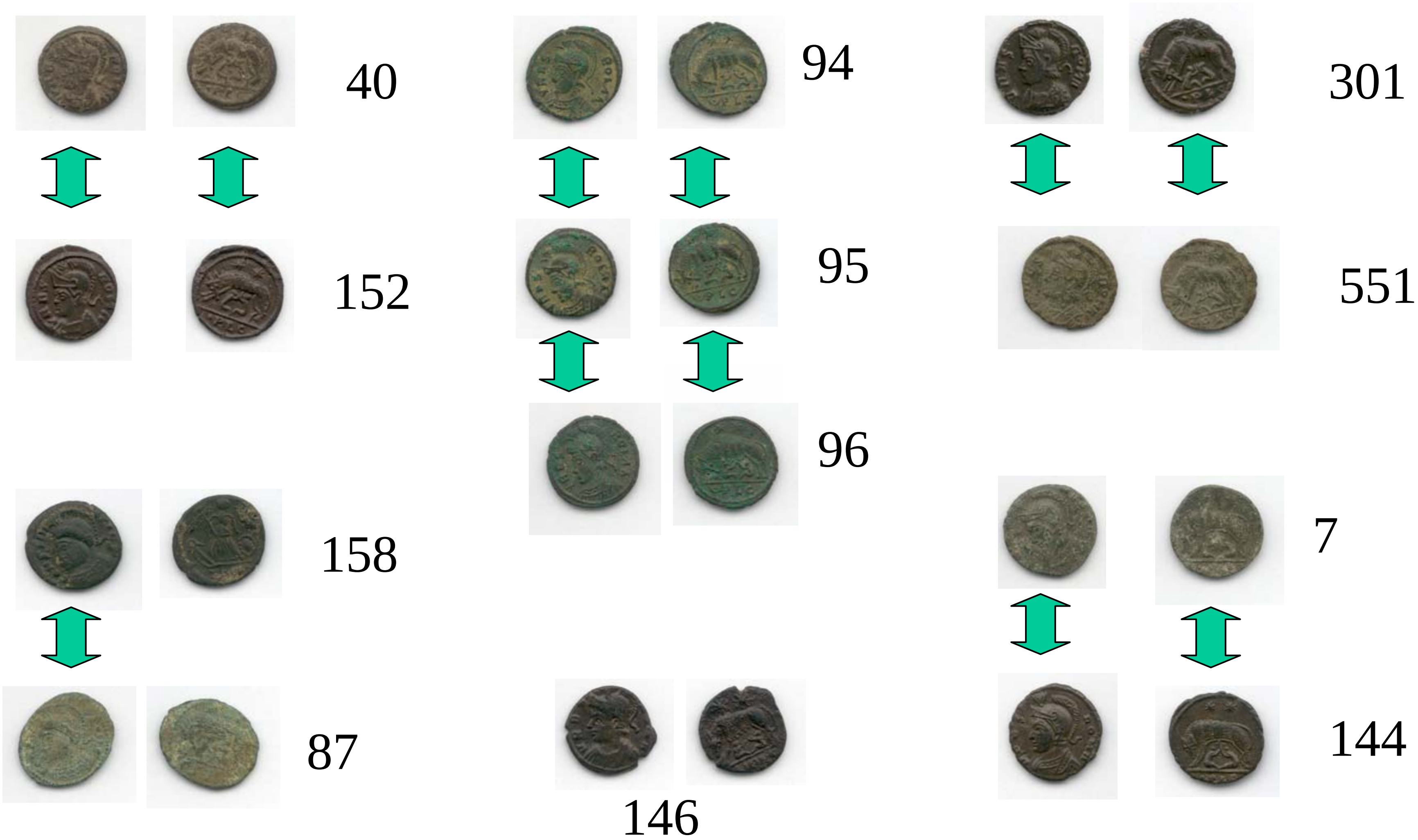


Fig. 16. Scatterplot of lead against tin for Constantianian copies.

Discriminant analysis using all elements successfully attributed all the coins to their die-linked groups. However, the group centroids of groups 0 (the single un-linked coin), 1 and 2, and 3 and 4 are very close (Fig. 17), suggesting that these five groups can be condensed down to two.

Fig. 15. Die-linked Constantinian copies



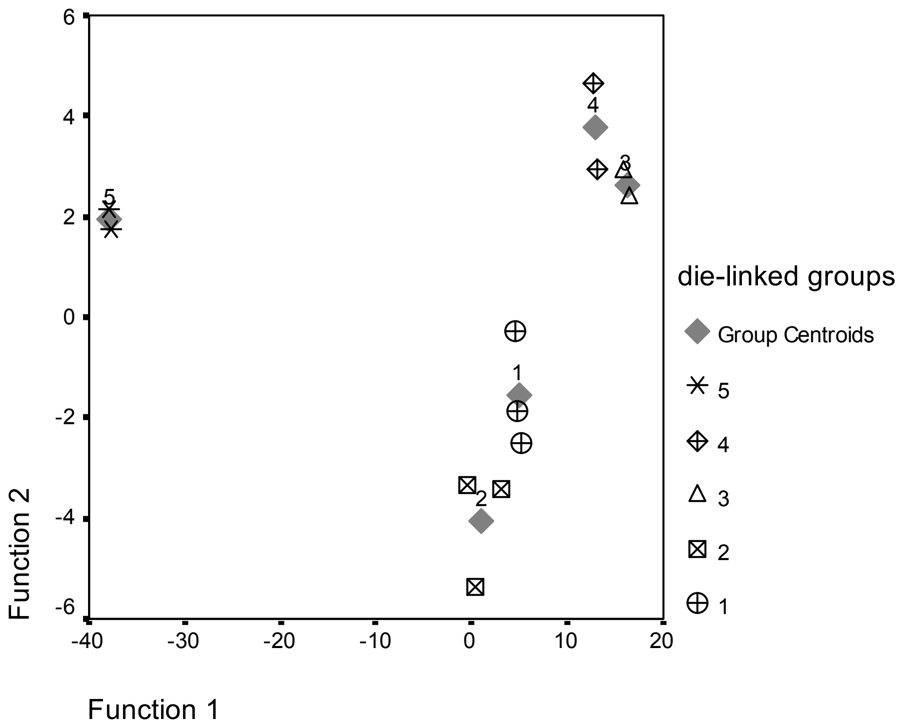


Fig. 17. Canonical discriminant functions plot for die-linked Constantinian copies.

When this is done the three groups have well separated group centroids (Fig. 18). Group 5 (now group 3) remains well separated and distinct as a visual assessment of the data can tell, but the un-linked coin (ABM 146) is now in group 1, which also includes the original groups 1 and 2. Group 2 now combines die-linked groups 3 and 4.

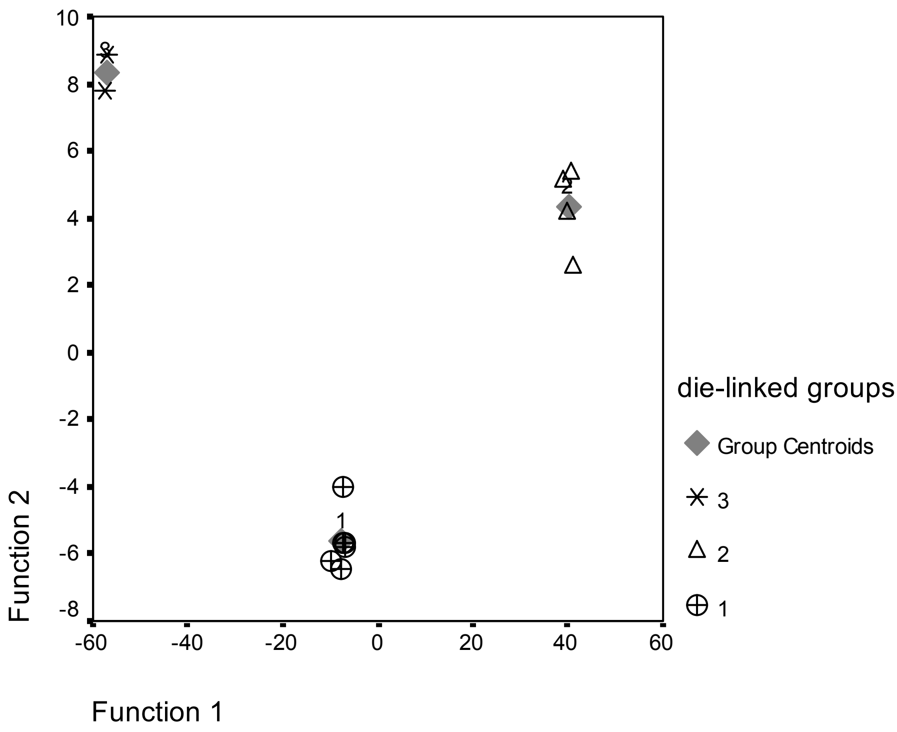


Fig. 18. Canonical discriminant functions for die-linked groups based on three groups.

Results and discussion of copies of the FEL. TEMP. REPARATIO (FTR) issues

The ten coins from Piercebridge that were chosen for analysis were of a variety of copying styles, from very good copies (1734) to very small, poor copies (2522.16). The analysis showed all except one of these coins to be made of highly-leaded low-tin bronze with no silver or zinc (the full results are given in Table 7). The exception was an illegible piece (2522.074) that had been identified by the numismatist as a FTR copy but which, on analysis, was shown to be an orichalcum pellet relating to radiate copy manufacture. Indeed, closer examination revealed a chop-mark on the side showing that it was chopped from a cast rod of metal as was common for radiate copies and their raw materials (see above). Obviously this piece could not be included in any further statistical analysis and so was excluded from the data set.

The data from the remaining nine coins were reviewed element by element, but no obvious structure was apparent. The data were then subjected to a principal components analysis using all the variables after log transformation. The scatterplot of the first two components (Fig. 19) shows two possible groups and two outliers (1919 and 2522.012). However, currently there is no stylistic or metrological criterion defining either group; copies of all qualities are spread across both groups. However, the identification of structure in the chemistry of what is otherwise a stylistically diverse and unstructured group suggests that a larger study in collaboration with a numismatist specialising in these issues could yield useful results similar to those demonstrated for the Constantinian copies.

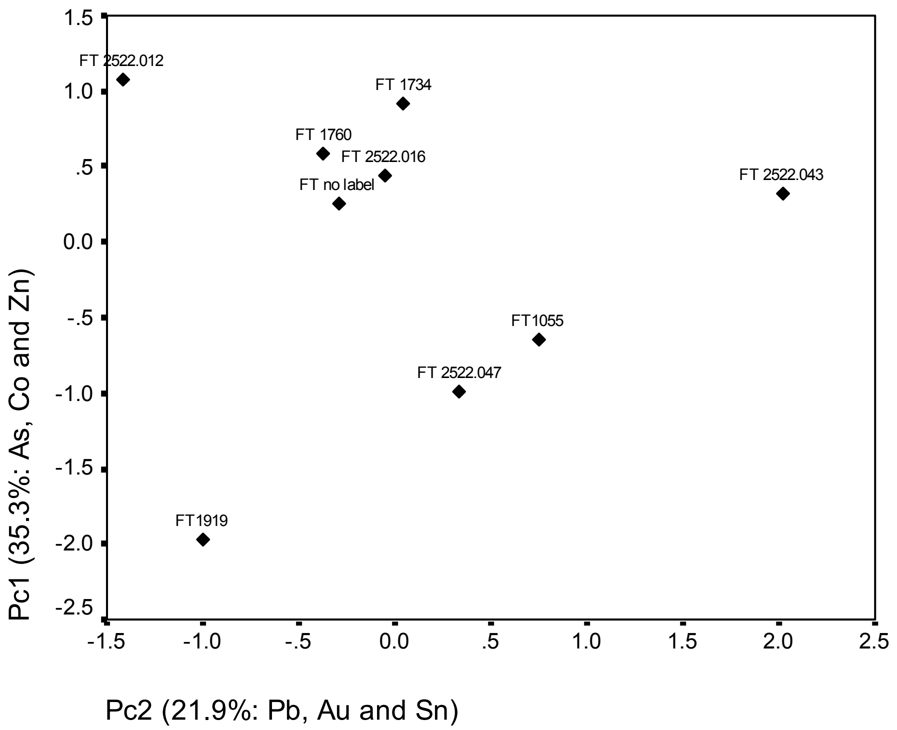


Fig 19. Principal component plot of FTR copies. Elements listed on the axes are only those that contribute to the data structure.

Conclusion

This project has only scraped the surface of the potential for chemical analysis to address some of the important questions surrounding the endemic copying of base metal coins in Roman Britain.

Radiate copies were made of an alloy of variable composition, yet one where the economic components (silver, zinc and tin) were controlled to maintain a certain intrinsic value. The use of orichalcum (through re-cycling worn sestertii and dupondii issued some 100 or 150 years earlier) as a raw material for radiate copies is an intriguing phenomenon. According to Abdy (2003), the re-cycling of orichalcum coin seems to have given the metal an ‘added value’, one which no doubt was reflected in its use in radiate copy production. Thus any attempt to calculate the ratio of values between metals purely on the basis of elemental composition is going to be overly simplistic, yet such attempts can begin to help in an understanding of the manufacture of radiate copies. Clearly these coins were made to a standard defined by both the economic and social value of the components.

It is now clear that Carausius’ early coins grew out of the pre-existing tradition of radiate copies. Furthermore, it is clear that not only the so-called ‘semi-official’ issues contain zinc, but also some of the more acceptably ‘official’ issues of the ‘C’ mint. This now casts doubt on the ‘semi-official’ status of that group and suggests that these pieces are Carausius’ first attempt at coin production. The use of orichalcum as an economic component of parts of Carausius’ coinage is a significant departure from normal Roman coin manufacture and seems to represent a uniquely British solution to the problem of maintaining a set intrinsic value to a coinage.

Trace element composition has been shown to correlate well with die-linked groups of Constantinian copies. Furthermore, the chemistry seems to be able to link across the die-linked groups and thereby offers the potential of establishing workshop groups that were each using a series of die-types. This could offer an important insight into how the workshops producing copies were organised and how they operated. By extension, the analysis of the FTR copies from Piercebridge has demonstrated that chemical groups can be established where die-links cannot and therefore can offer an alternative method for investigating the production of these copies, possibly leading to establishing chemical signatures for specific regional workshops.

Appendix 1

The bulk chemical analysis techniques that were used for this project were ICP-AES and ED-XRF. Two techniques were used because together they provide an additional check on major element composition alongside certified standard reference materials. Additionally, because aqua regia (a mixture of nitric and hydrochloric acids) was used to dissolve the drilled samples, any significant amounts of silver present in the solutions would precipitate out of solution and therefore not be measured. The chlorine in the aqua regia will combine with any silver present to form silver chloride, a sparingly soluble salt. Experiments have shown that a maximum of 5 ppm of silver will remain in solution, a concentration that corresponds to about 0.5% in the solid sample (Ponting, unpublished data). Consequently all silver concentrations over 0.5% were measured by ED-XRF only.

The ICP-AES instrument used was a Perkin Elmer Optima DV3300 in the School of Chemical, Environmental and Mining Engineering at Nottingham University. The instrument was calibrated using two matrix matched solutions made-up from commercial single element ICP standards and a matrix matched blank. Major and minor elements were bracketed between the two standards and trace elements were measured on a single point calibration to avoid curvature. The acids used were 'primar' trace analysis grade and the water was Fluka ultra-pure. A matrix matched quality control solution containing moderate levels of the elements sought was run every ten samples to monitor instrumental drift and a standard reference metal (SRM) (Bundesanstalt für materialprüfung nr. 211) was included at the beginning and end of the batch. Relative accuracy, based on the two analyses of 211at the beginning and at the end of the analysis (Table 5), is better than 7% for all major and minor elements with the exception of nickel (15.5% at 0.122%). The relative accuracy of the trace elements is better than 30%, again with the poorer values occurring when the concentrations approach the limits of detection (i.e. arsenic with 26% error on a certified value of 0.033%). Instrumental precision (coefficient of variation across three replicate analyses of the same sample) is generally better than 3%, whilst analytical precision (coefficient of variation of two analyses of the same SRM across all analyses) is generally better than 3% for major, minor and trace elements over all analyses with the exception of sulphur and bismuth, which are poor because the certified values are close to the limit of detection (LOD).

Table 5. Values and statistics for standard reference metal BAM211 and instrumental limit of detection (LOD) calculated as 3σ.

	Ag	As	Cu	Fe	Mn	Ni	Pb	Sb	Sn	Zn	S	Bi
211a	0.058	0.024	88.75	0.101	0.0021	0.102	0.77	0.034	10.22	0.54	0.0234	0.0019
211b	0.060	0.025	89.54	0.104	0.0020	0.105	0.78	0.034	10.60	0.55	0.0184	0.0026
Cert	0.059	0.033	87.71	0.110	0.002	0.122	0.74	0.033	10.60	0.56	0.0211	0.0020
LOD	0.001	0.003	0.005	0.0001	0.00003	0.0002	0.001	0.002	0.001	0.0004	0.008	0.001
Mean	0.059	0.024	89.15	0.102	0.002	0.103	0.773	0.034	10.412	0.544	0.021	0.002
St Dev	0.00	0.00	0.56	0.00	0.00	0.00	0.00	0.00	0.27	0.01	0.00	0.00
error	0.38	26.06	-1.64	6.82	-8.46	15.53	-4.40	-3.51	1.77	2.87	0.96	-11.71
precision	2.6	2.9	0.6	1.8	2.5	2.0	0.6	0.4	2.6	1.7	17.1	22.0

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Table 6. ICP-AES data for Carausian coins and radiate copy material

Sample	Ag	As	Au	Co	Cu	Fe	Mn	Ni	Pb	Sb	Sn	Zn	S	Cr	Bi
Carausian coins															
846 Car	0.37	0.036	0.0035	0.0010	77.0	0.044	0.00024	0.029	19.65	0.090	2.31	0.264	0.220	0.0003	0.0003
2071 Car	0.13	0.062	0.0025	0.0021	74.6	0.182	0.00084	0.018	20.34	0.109	2.38	2.11	0.057	0.0003	0.0003
1633 Car	0.17	0.066	0.0489	0.0007	83.5	0.050	0.00018	0.026	10.12	0.150	5.62	0.104	0.153	0.0005	0.0003
1937 Car	3.11	0.024	0.0242	0.0003	95.6	0.130	0.00010	0.028	0.58	0.064	0.45	0.004	0.005	0.0004	0.0004
2316 Car	3.62	0.057	0.0176	0.0003	95.6	0.043	0.00098	0.020	0.36	0.118	0.13	0.006	0.017	0.0004	0.0021
1575 Car	4.30	0.051	0.0257	0.0001	94.9	0.010	0.00021	0.024	0.60	0.073	0.02	0.002	0.005	0.0003	0.0093
2210 Car	1.56	0.052	0.0098	0.0022	86.9	0.115	0.00028	0.021	3.39	0.090	5.39	2.39	0.070	0.0002	0.0030
2757 Car	1.26	0.045	0.0082	0.0013	91.7	0.167	0.00020	0.018	0.56	0.107	4.19	1.84	0.131	0.0006	0.0004
730 Car	2.26	0.070	0.0177	0.0019	91.2	0.111	0.00009	0.027	3.11	0.098	3.02	0.046	0.022	0.0003	0.0044
1779 Car	0.08	0.041	0.0023	0.0001	96.8	0.005	0.00010	0.021	2.13	0.102	0.77	0.011	0.004	0.0004	0.0013
690 Car	2.76	0.071	0.0181	0.0012	92.8	0.020	0.00065	0.021	1.59	0.124	2.11	0.377	0.068	0.0012	0.0033
2016 Car	2.14	0.052	0.0157	0.0010	93.2	0.175	0.00094	0.022	2.25	0.091	1.92	0.075	0.029	0.0004	0.0023
1700 Car	1.82	0.055	0.0143	0.0010	93.8	0.065	0.00051	0.021	2.34	0.095	1.70	0.041	0.020	0.0004	0.0010
Radiate copy material															
13 cut sest #9	0.05	0.048	0.0005	0.0012	83.9	0.136	0.00095	0.016	1.13	0.158	3.21	11.32	0.037	0.0004	0.0003
14 m. sest #38	0.07	0.328	0.0012	0.5507	72.9	0.611	0.00059	0.054	4.53	0.229	9.22	11.45	0.041	0.0006	0.0503
15 cut sest #8	0.06	0.075	0.0022	0.0012	76.2	0.034	0.00002	0.022	19.53	0.121	3.69	0.145	0.116	0.0003	0.0039
1 tree	0.01	0.013	0.0005	0.0062	68.0	0.056	0.00243	0.064	0.03	0.004	0.01	31.79	0.012	0.0010	0.0003
2 gate	0.04	0.093	0.0011	0.0008	81.6	0.231	0.00046	0.043	0.66	0.015	0.12	17.07	0.047	0.0009	0.0514
3 lump	0.08	0.315	0.0009	0.0010	75.1	0.489	0.00023	0.050	4.27	0.064	2.07	17.38	0.042	0.0004	0.1396
4 lump	0.08	0.502	0.0005	0.0001	99.2	0.003	0.00002	0.026	0.03	0.026	0.00	0.010	0.004	0.0004	0.0825
5 drip	0.09	0.053	0.0022	0.0006	67.5	0.055	0.00035	0.022	17.54	0.215	14.39	0.051	0.064	0.0006	0.0004
6 bar	0.04	0.043	0.0010	0.0040	85.0	0.187	0.00028	0.100	3.46	0.035	11.08	0.083	0.019	0.0003	0.0026
7 rod	0.03	0.033	0.0005	0.0027	87.9	0.074	0.00046	0.017	0.24	0.083	10.38	1.16	0.072	0.0004	0.0003
8 ingot	0.80	0.073	0.0062	0.0016	86.9	0.145	0.00019	0.024	4.48	0.107	5.46	1.93	0.033	0.0006	0.0026
9 blank 36	0.14	0.062	0.0025	0.0013	85.7	0.382	0.00018	0.020	4.20	0.092	6.23	3.10	0.032	0.0003	0.0023
10 blank 3	1.00	0.063	0.0077	0.0015	87.5	0.343	0.00006	0.022	4.71	0.110	4.67	1.57	0.050	0.0003	0.0050
11 BR10	0.21	0.060	0.0035	0.0021	83.2	0.280	0.00014	0.022	6.26	0.112	5.14	4.60	0.051	0.0006	0.0004
12 BR	0.73	0.061	0.0087	0.0004	85.1	0.265	0.00107	0.018	8.15	0.120	4.93	0.614	0.049	0.0010	0.0005
16 BR 8a	0.07	0.069	0.0071	0.0026	88.5	0.212	0.00073	0.024	3.76	0.151	5.60	1.55	0.070	0.0010	0.0019
17 BR7a	1.52	0.073	0.0098	0.0016	84.8	0.441	0.00072	0.022	5.12	0.119	6.20	1.62	0.060	0.0006	0.0004
18 BR9a	1.02	0.059	0.0105	0.0014	87.7	0.188	0.00036	0.021	5.14	0.114	4.50	1.15	0.067	0.0004	0.0030
19 BR12a	0.69	0.065	0.0073	0.0019	88.3	0.359	0.00031	0.023	3.68	0.107	4.64	2.09	0.058	0.0004	0.0004
20 BR13a	0.98	0.047	0.0106	0.0004	96.7	0.691	0.00496	0.016	1.23	0.100	0.17	0.0003	0.019	0.0006	0.0032
21 BR15	0.65	0.031	0.0129	0.0020	85.5	0.408	0.00135	0.020	3.84	0.127	8.42	0.874	0.152	0.0019	0.0039
22 blank	0.06	0.038	0.0013	0.0006	87.4	0.113	0.00045	0.018	1.30	0.097	10.05	0.892	0.030	0.0007	0.0019
23 blank	0.05	0.051	0.0044	0.0015	81.0	0.105	0.00013	0.020	8.08	0.109	8.21	2.30	0.042	0.0005	0.0017
24 blank	0.27	0.126	0.0040	0.0019	88.3	0.203	0.00037	0.018	1.97	0.099	6.81	2.15	0.045	0.0007	0.0001
25 bar	0.80	0.059	0.0081	0.0014	87.9	0.240	0.00018	0.022	5.23	0.104	4.17	1.38	0.043	0.0004	0.0016
26 bar	0.06	0.060	0.0027	0.0022	78.6	0.189	0.00016	0.026	10.83	0.123	6.13	3.88	0.050	0.0004	0.0038
27 BRr1	0.59	0.060	0.0071	0.0026	86.6	1.385	0.00060	0.022	3.87	0.116	5.61	1.69	0.046	0.0011	0.0035
28 BRr2	1.00	0.056	0.0087	0.0015	87.7	0.188	0.00007	0.024	4.69	0.098	5.04	1.14	0.049	0.0005	0.0004
29 BRr3	2.09	0.063	0.0200	0.0633	89.0	0.354	0.00556	0.017	4.20	0.138	3.40	0.427	0.180	0.0030	0.0043
30 BRr4	1.59	0.060	0.0126	0.0011	92.4	0.048	0.00018	0.021	3.51	0.104	1.99	0.168	0.049	0.0005	0.0043
31 BRwa3	0.10	0.040	0.0025	0.0010	84.4	0.186	0.00037	0.018	5.75	0.075	7.24	2.19	0.036	0.0006	0.0003
32 E pellet	0.07	0.232	0.0015	0.0018	71.0	0.782	0.00009	0.067	4.45	0.173	4.85	18.24	0.026	0.0004	0.0665
33 GD blank	0.05	0.045	0.0018	0.0010	79.1	0.018	0.00037	0.018	14.82	0.090	5.82	0.028	0.018	0.0003	0.0020
34 GD pellet	0.04	0.042	0.0019	0.0003	77.0	0.016	0.00024	0.018	17.02	0.081	5.72	0.005	0.025	0.0004	0.0015
35 Tac. blank	0.14	0.297	0.0018	0.0281	75.7	0.658	0.00139	0.198	3.92	0.179	2.82	15.98	0.038	0.0004	0.0057
744 BR	0.05	0.051	0.0018	0.0014	85.3	0.046	0.00010	0.021	7.69	0.130	6.35	0.368	0.028	0.0003	0.0003

Table 7. ICP-AES data for Constantinian copies and FTR copies.

Sample	Ag	As	Au	Co	Cu	Fe	Mn	Ni	Pb	Sb	Sn	Zn	S	Cr	Bi
Constantinian copies															
ABM146	0.12	0.045	0.0082	0.0003	50.9	0.001	0.00044	0.022	48.58	0.043	0.26	0.0002	0.004	0.0003	0.0039
ABM144	0.17	0.055	0.0088	0.0002	69.0	0.001	0.00018	0.029	30.33	0.052	0.31	0.0002	0.004	0.0003	0.0003
ABM7	0.16	0.043	0.0132	0.0002	63.3	0.013	0.00006	0.025	35.97	0.040	0.40	0.0002	0.004	0.0004	0.0003
ABM152	0.08	0.025	0.0104	0.0001	63.8	0.004	0.00085	0.019	35.77	0.030	0.23	0.0002	0.005	0.0004	0.0004
ABM40	0.16	0.033	0.0092	0.0002	62.6	0.007	0.00028	0.018	36.60	0.040	0.48	0.008	0.004	0.0003	0.0003
ABM301	0.13	0.061	0.0092	0.0001	66.9	0.001	0.00007	0.027	32.66	0.043	0.16	0.001	0.006	0.0006	0.0004
ABM551	0.15	0.042	0.0093	0.0004	67.4	0.008	0.00150	0.022	29.95	0.060	2.38	0.003	0.007	0.0008	0.0018
ABM87	0.19	0.062	0.0128	0.0017	86.3	0.125	0.00026	0.028	8.92	0.097	4.10	0.162	0.018	0.0004	0.0023
ABMC158	0.17	0.062	0.0140	0.0015	88.1	0.073	0.00015	0.029	7.85	0.091	3.47	0.131	0.022	0.0003	0.0004
Easton 94	0.11	0.036	0.0056	0.0001	62.6	0.002	0.00020	0.024	36.52	0.046	0.63	0.0002	0.021	0.0004	0.0003
Easton 95	0.08	0.057	0.0070	0.0002	71.9	0.002	0.00034	0.024	26.96	0.051	0.92	0.001	0.005	0.0003	0.0003
Easton 96	0.10	0.047	0.0065	0.0001	66.8	0.002	0.00045	0.022	32.27	0.043	0.71	0.0003	0.005	0.0005	0.0004
FTR copies															
FT 1734	0.20	0.118	0.0113	0.0038	74.7	0.050	0.00195	0.037	23.30	0.077	1.46	0.015	0.025	0.0004	0.0027
FT 1760	0.16	0.103	0.0119	0.0022	79.6	0.041	0.00050	0.038	18.23	0.068	1.66	0.003	0.028	0.0004	0.0042
FT 2522.012	0.08	0.116	0.0119	0.0040	86.8	0.058	0.00033	0.042	10.49	0.084	2.08	0.259	0.012	0.0005	0.0004
FT 2522.016	0.08	0.094	0.0093	0.0010	78.6	0.027	0.00047	0.038	18.85	0.031	2.09	0.072	0.068	0.0009	0.0009
FT 2522.043	0.17	0.097	0.0068	0.0018	65.1	0.037	0.00048	0.032	33.56	0.058	0.67	0.014	0.254	0.0007	0.0004
FT 2522.047	0.09	0.065	0.0102	0.0007	76.3	0.013	0.00021	0.033	22.89	0.026	0.56	0.0002	0.025	0.0004	0.0003
FT 2522.074	0.05	0.219	0.0089	0.0017	76.5	0.878	0.00043	0.016	1.44	0.044	1.56	19.24	0.021	0.0003	0.0003
FT no label	0.10	0.119	0.0113	0.0023	78.8	0.006	0.00018	0.041	19.42	0.079	1.44	0.007	0.018	0.0004	0.0003
FT1055	0.16	0.081	0.0083	0.0016	66.7	0.007	0.00012	0.033	32.03	0.055	0.95	0.0002	0.004	0.0004	0.0025
FT1919	0.08	0.028	0.0103	0.00005	82.5	0.017	0.00072	0.016	16.25	0.023	1.12	0.0002	0.009	0.0003	0.0007