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THE EGYPTIAN BILLON TETRADRACHM UNDER THE JULIO-CLAUDIAN EMPERORS – FIDUCIARY OR INTRINSIC?

INTRODUCTION

This article presents the results of the scientific investigation of twenty-six base silver tetradrachms of the mint of Alexandria issued under the emperors Tiberius (AD 14-37), Claudius (AD 41-54), and Nero (AD 54-68), and eight silver coins of Tyre, minted between 12 BC and AD 52. These analyses are part of a wider programme of investigations by the authors into the silver coinage of the Roman empire under the Julio-Claudian emperors.[1]

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[1] The authors would like to thank Christopher Howgego and the visitors of the Ashmolean Museum, Oxford, for kind permission to sample the relevant coins in the collection of the Heberden Coin Room, to Thomas Curtis of A.H. Baldwin & Sons, London, for assistance in locating many relevant pieces for purchase, and to private collectors, in particular Michel Prieur and Bruno van der Pluijm, for graciously permitting us to sample coins from their collections. Volker Heuchert, Arthur Houghton, Richard McAlee, and Michel Prieur were extremely helpful in providing additional data for weight standards, and without their assistance this paper would have been all the poorer. The support of Chris Somerfield of the School of Chemical, Environmental and Mining Engineering, Nottingham University, has been invaluable in allowing access to analytical equipment and deserves particular thanks. Justine Bayley and David Dungworth of the English Heritage

Analyses of Alexandrian tetradrachms of the Julio-Claudians have been published before, most comprehensively by D.R. Walker and C.E. King.[2] More recently a series of tetradrachms of Nero have been analysed by Oddone and Savio;[3] their work also presents an overview of earlier analyses. Indeed, more analysts have worked on Alexandrian coins than on any other Roman provincial silver coinage. In spite of this, it has proved far more difficult to obtain an accurate estimate of the silver content of these important issues. As the authors of this article have pointed out in work published elsewhere,[4] Walker's results for silver/copper alloys are generally unreliable because he analysed a point on the exterior of each coin only, and did not attempt to obtain a sample of the heart metal of the coin, where changes to the original alloy are likely to be smallest. The only analyst to have fully appreciated the problems involved in, and errors generated by, including the surfaces of the coins in any analysis is REECE, whose results for Alexandrian coinage remain among the most accurate of the previous studies. Other studies have placed undue significance on very slight variations in silver content detected, to the extent that variations of 1-2% (which fall well within the error limits of most instrumental analytical techniques and can be generated by real variations in the silver contents of – and within – individual coins) are seen as the result of fiscal policies. As will be demonstrated in this article, the metallurgy of, and technology used to produce, Alexandrian tetradrachms demands a strict sampling method in order to obtain reliable results.

In undertaking these analyses, we wanted to pursue a hypothesis, presented in BUTCHER 2004,[5] that there was a close relationship between the silver standards employed at Alexandria under the Julio-Claudian emperors on the one hand, and those used at Tyre and Antioch on the other, and that furthermore, Nero's reform of the denarius at Rome in AD 64 was connected with a change in the silver content of the Alexandrian tetradrachm. For this reason the Alexandrian tetradrachms were only one of several groups of Roman silver coins sampled.

The paper is divided into two parts. The first examines the results of analyses of Alexandrian tetradrachms and Tyrian silver, and the second considers the relationship of these coinages to each other, and their relationships to the tetradrachms of Antioch and the denarii of Rome.

Ancient Technology section generously permitted the use of the SEM in their laboratory. Thanks are of course also due to our funding bodies, The Leverhulme Trust (MP) (Grant No. RF&G/6/2002/0336) and the Faculty of Arts and Sciences Research Committee and the University Research Board of the American University of Beirut, Lebanon (KB).

2 D.R. WALKER/C.E. KING, Ptolemaic and Augustan Silver: The Evolution of the Tetradrachm of Roman Egypt, in: WALKER, pp. 139-159.

3 ODDONE/SAVIO; M. ODDONE/A. SAVIO, Ancora sul titolo del tetradrammo alessandrino di Nerone, NACQT 19, 1990, pp. 235-240.

4 See BUTCHER/PONTING.

5 BUTCHER 2004, pp. 253-254.

PART I: ANALYSES OF ALEXANDRIAN AND TYRIAN SILVER

The tetradrachm of Roman Egypt during the first three centuries of our era has long been considered special, though it has not necessarily been viewed as the most splendid of Roman provincial silver issues. For at least the first two centuries of Roman rule it enjoyed the dubious privilege of being the most debased silver coin in the Roman world. Unlike other tetradrachms circulating in the eastern Roman Empire, whose face values were reckoned at the equivalent of either three or four Roman imperial denarii apiece, the Alexandrian tetradrachm was valued at one denarius. The Alexandrian coinage does not appear to have circulated outside Egypt, and some scholars have seen the very baseness of this coinage as an explanation for its limited circulation. Although equivalent to a denarius, it contained much less silver; and consequently outside Egypt (where its value could be enforced in some way), the tetradrachm's high degree of overvaluation made it unacceptable. Indeed, in many discussions Alexandrian silver is described as a 'fiduciary' or 'token' coinage. It is either implicit or explicit in such discussions that Egyptian silver was very much the poor relation of the Roman imperial coinage, and that the Roman state profited from foisting such poor quality silver on the hapless Egyptians.

A desire by the Roman state to profit from the issue of overvalued provincial silver coins is normally considered sufficient to explain their silver content, and indeed profit from overvaluation is sometimes deemed sufficient to explain their issue as well. Walker's view, that provincial coinages were 'an instrument for the convenience of the state', and not something to 'satisfy the needs of the provincials',[6] is typical of prevailing attitudes. Explanations as to why particular silver standards were chosen are curiously lacking, even though the issuing authorities in the provinces often clung to the chosen standards for long periods of time. One striking aspect of our programme of analyses so far has been to note the remarkable stability over time of provincial silver standards,[7] and how small changes to the denarius rarely had any effect on this stability (one might have expected adjustments, if a constant rate of overvaluation and profit were to be maintained). However, as will be demonstrated, the major debasement of the denarius under Nero was accompanied by alterations to the provincial silver, and it is the nature of these changes that we seek to explore.

Walker was a great advocate of overvaluation and state profit, and his arguments have clearly convinced many, as they underpin much current thinking. He argued that by debasing the provincial coins considerably, the Roman state was able to acquire enormous revenues from their issue. Compared to Alexandrian or Syrian tetradrachms or Caesarean didrachms, the imperial denarius was a far superior coin by virtue of its silver content. As we will see, these arguments rest on rather poor factual foundations.

6 D.R. Walker, The Metrology of the Roman Silver Coinage, Part III. From Pertinax to Uranius Antoninus. BAR Suppl. Series 40 (Oxford 1978), p. 121.

7 K. Butcher/M. Ponting, Silver Standards at Caesarea in Cappadocia, Intern. Kolloquium zur kaiserzeitlichen Münzprägung Kleinasiens. Nomismata I (Milan 1997), pp. 167-171.

The coins analysed

Our programme of analyses is not as comprehensive as Walker's, and access to coins for sampling was much more restricted. It should also be noted that while the results of analyses of imperial denarii and Antiochene tetradrachms are discussed in the sections below, the details of these analyses will be published elsewhere.[8]

Alexandria

Tiberius

Obv. ΤΙΒΕΡΙΟΣ ΚΑΙΣΑΡ ΣΕΒΑΣΤΟΣ Laureate head of Tiberius right; date in field before bust.
Rev. ΘΕΟΣ ΣΕΒΑΣΤΟΣ Radiate head of Augustus right.

Year 7, AD 20/1
1. Sample A1, RPC 5089, MILNE 52 (*this coin*)
2. Sample A2, RPC 5089

Year 14, AD 27/28
3. Sample A3, RPC 5090 (*rev.* head of Augustus left), MILNE 53 (*this coin*)
4. Sample A4, RPC 5090 (*rev.* head of Augustus left), MILNE 54 (*this coin*)
5. Sample A5, RPC 5090 (*rev.* head of Augustus left), MILNE 55 (*this coin*)
6. Sample A6, RPC 5091 (*obv.* head of Tiberius left), MILNE 56 (*this coin*)

Year 19, AD 32/33
7. Sample A7, RPC 5094 (*rev.* head of Augustus left), MILNE 56*

Year 20, AD 33/34
8. Sample A8, RPC 5097 (*rev.* head of Augustus left), MILNE 57 (*this coin*)
9. Sample A9, RPC 5096 (*obv.* head of Tiberius right), MILNE 57a (*this coin*)

Claudius

Obv. ΤΙ ΚΛΑΥΔΙ ΚΑΙΣ ΣΕΒΑ ΓΕΡΜΑΝΙ ΑΥΤΟΚ Laureate head right; date before bust.
Rev. ΜΕΣΣΑΛΙΝΑ ΚΑΙΣ ΣΕΒΑΣ Messalina standing left.

Year 3, AD 42/43
10. Sample BW4, RPC 5131
11. Sample BW9, RPC 5131
12. Sample BW11, RPC 5131
13. Sample BW16, RPC 5131

Year 4, AD 43/44
14. Sample BW7, RPC 5145
15. Sample BW8, RPC 5145
16. Sample BW12, RPC 5145
17. Sample BW14, RPC 5145
18. Sample BW1, as RPC 5145

Note that BW1 appears to be an ancient forgery; or at least, lead has been substituted for the silver content.

8 For the denarii, see BUTCHER/PONTING.

Nero

Obv. ΝΕΡΩ ΚΛΑΥ ΚΑΙΣ ΣΕΒ ΓΕΡ Radiate head right.

Year 10, AD 63/64

Rev. ΑΥΤΟΚΡΑ Bust of Serapis right; date before bust. RPC 5274

19. Sample BW2
20. Sample BW6
21. Sample BW10
22. Sample BW17

Rev. ΠΟΠΠΑΙΑ ΣΕΒΑΣΤΗ Bust of Poppaea right; date before bust. RPC 5275

23. Sample BW3
24. Sample BW5
25. Sample BW13
26. Sample BW15

Tyre

Obv. Laureate head of Heracles right.
Rev. ΤΥΡΟΣ ΙΕΡΑΣ ΚΑΙ ΑΣΥΛΟΥ, eagle standing left on prow of galley, with palm on wing; in field before, date and inverted club; behind, KP and monogram.

27. Sample A35, RPC 4645, CRE 1495 (*this coin*). Tetradrachm, year 115 (12/11 BC)
28. Sample A37, RPC 4647, CRE 1496 (*this coin*). Tetradrachm, year 117 (10/9 BC).
29. Sample A36, RPC 4657. Tetradrachm, year 144 (AD 18/19)
30. Sample KB22, RPC 4657. Tetradrachm, year 144 (AD 18/19)
31. Sample KB23, RPC 4658. Tetradrachm, year 145 (AD 19/20)
32. Sample KB24, RPC 4693. Didrachm, year 159 (AD 33/4)
33. Sample A38, RPC 4665. Tetradrachm, year 161 (AD 35/6)
34. Sample A39, RPC 6476. Tetradrachm, year 177 (AD 51/2)

Results

Technical aspects of the Alexandrian coinage

The Roman mints disguised the production of increasingly base silver coins by artificially enhancing the silver content at the surface of the coin. This process entailed allowing the copper-rich phase at the surface of a coin blank to oxidize and then stripping out the copper oxide with organic acid, thereby creating a layer of almost pure silver that was subsequently compacted by striking.[9] However, this process relies on there being a continuous network of interconnecting silver-rich

9 See GITLER/PONTING. It should be noted that this process was not necessary for coinages over 90% pure silver (BUTCHER/PONTING), and therefore the Tyrian silver coins would not have been treated in this way (see below).

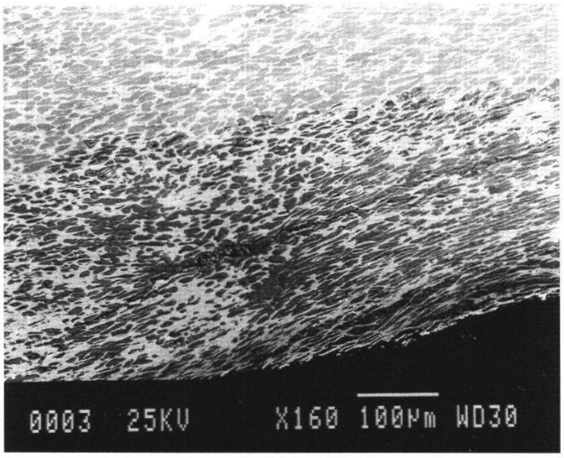

Fig. 1

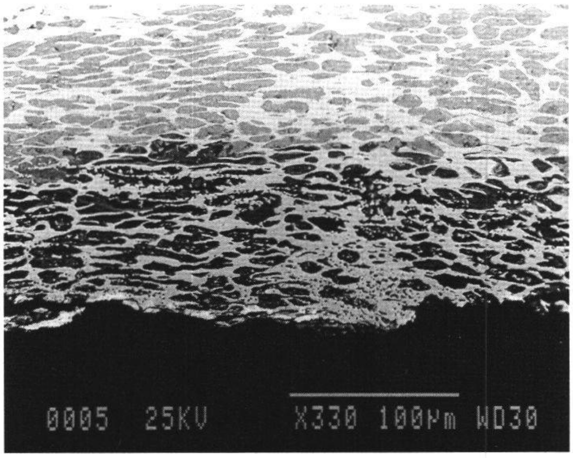

Fig. 2

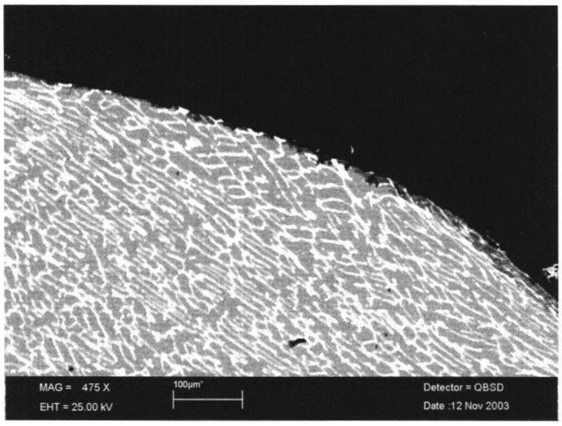

Fig. 3

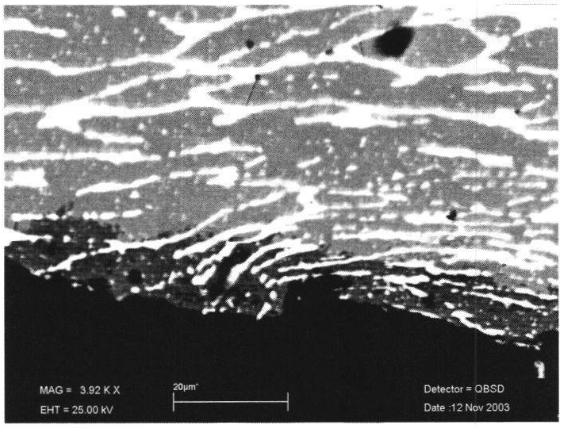

Fig. 4

Fig. 1. Back scattered electron (BSE) image of a section through a denarius of Geta (~ 50% silver). The surface of the coin is towards the bottom right (see text for explanation).
Fig. 2. BSE image of a section through the surface layers of the denarius of Geta. The surface is towards the bottom of the image (see text for explanation).
Fig. 3. BSE image of a section through an Alexandrian tetradrachm (BW2). The surface of the coin runs from top left down to bottom right of the image (see text for explanation).
Fig. 4. BSE image of the section of BW2, showing an area at the surface of the coin with the discontinuous silver phase spalling away (see text for explanation).

phase material that will remain after the copper-rich material has been oxidized and removed. When the silver content falls to such a level that there is no longer an adequate interconnecting system of silver-rich material within the coin blank, the silver-rich phase will merely spall away, leaving at best a patchy silver surface with areas of almost pure copper in between. This effect will also be further enhanced by corrosion processes. The scanning electron microscope (SEM) micrographs (figs. 1-4) illustrate how this spalling occurs by comparing the structure of a denarius of Geta (approximately 50% silver) with that of an Alexandrian tetradrachm of Nero (BW2 – 16.7% silver). Figure 1 shows an area towards the surface of the denarius: the dark areas are copper-rich material and the white areas are silver-rich material; the very dark areas are either oxidized copper or voids where copper-rich material has been oxidized and then leached out. The oxidized and leached zone can be clearly seen (bottom ¾ of the section). Figure 2 shows the edge of the same coin at higher magnification; the copper-rich phase has been oxidized to a depth of approximately 100 microns and much of this has been leached out leaving a sponge-like layer, part of which has been consolidated into an almost pure silver surface coating. The important thing here is that the silver-rich phase forms a self-supporting contiguous structure after the copper-rich material has been leached out. Figure 3 shows a view of the section of BW2 that is similar to Figure 1: the proportions of the two phases are notably different, with the dark, copper-rich phase being the most predominant in the baser coin. There is no leached zone; the bulk structure continuing unaltered to the coin's surface. However, at higher magnification (fig. 4) oxidized, copper-rich material (at least partially the result of natural corrosion processes) can be seen forming a layer about 10 microns thick with thin strands of silver within it. The silver strands are all that the silver-rich phase can form at this concentration and they do not form a contiguous structure, so that they have a tendency to break off together with the oxidized metal, leaving more copper-rich material exposed.

Whereas the alloy richer in silver will give falsely high silver content if an analysis is conducted on metal at either the coin's surface or within the leached zone, the surface of the baser alloy of the tetradrachm will be very heterogeneous. The latter will give readings higher in copper or silver depending on where on the coin the analysis was done, or from where a sample was taken: if a silver strand is hit, then the result will be erroneously high in silver; if the area is predominantly copper, then the result will reflect this, rather than the true, homogenized composition. Such results are apparent in Walker's data, which give silver contents varying from 9% to 20.5% silver (SD 4.12) for Nero's tenth year and similarly high standard deviations for subsequent and preceding years. Generally speaking, however, Walker's averages for the Alexandrian tetradrachms of Claudius and Nero are unexpectedly close to the ICP results (his surface technique usually gives silver readings that are significantly higher because of blanching[10]). Nevertheless, even when reasonably large areas of internal metal are exposed and analysed the inherent heterogeneity is sufficient to give misleading results: three areas approximately 2mm square were analysed along the section of BW2 and gave silver contents of 15.3%, 17.5% and 14.4% by energy dispersive analysis (EDS) and serve to illustrate how heterogeneous these coins can be.

A preliminary examination of the data seems to suggest that the spalling occurs when the silver content falls below about 25%: the tetradrachms of Tiberius with an average silver content of 25.2% tend to retain convincing silver surfaces; whereas those of Claudius with an average of 23% silver do not. The effect of a reduction of a mere two percent is surprising and is not supported by the phase diagram, yet this conclusion is apparently supported by comparing our results with those of

[10] See K. Butcher/M. Ponting, Rome and the East. Production of Roman Provincial Coinage from Caesarea in Cappadocia under Vespasian, AD 69-79, Oxford Journal of Archaeology 14/1, (Oxford 1995), pp. 63-79 for a discussion of this.

Walker: Figure 5 compares analyses of coins of Tiberius (A3, A4, A5, A6 and A7) analysed by Walker with our ICP-AES results for the same specimens. Walker's X-ray fluorescence (XRF) results range from 35.5% to 40% for the four tetradrachms of year 14 that we analysed; our results range from 23.7% to 25.6%. The discrepancy between Walker's results and ours is typical of coins with a substantial surface-enriched layer of silver. There is an average difference of 13% and it should also be noted that the ICP-AES data are rather more consistent.

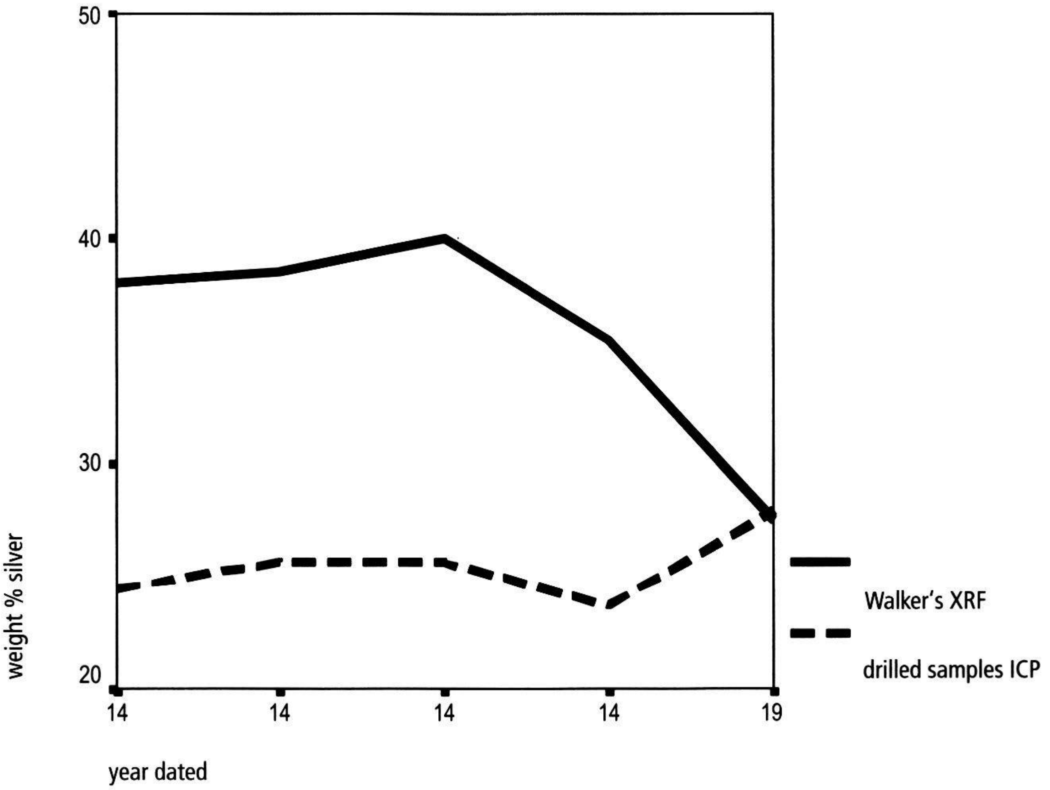

Fig. 5. Comparison of the silver contents of tetradrachms of Tiberius analysed by XRF and by ICP (same coins).

However, further scrutiny of the data clearly shows that the observed difference in the quality and durability of the blanched surfaces is not due to differences in the bulk silver content. The single coin of Tiberius' 19th year (A7) has a silver content of 27.9% according to the bulk ICP-AES analysis and so should have a similarly robust silvered surface to the other Tiberian tetradrachms, yet Walker's surface analysis of the same coin is in very close agreement at 27.5% (*fig. 5*). This suggests that blanks containing over 25% silver will still suffer from spalling (indeed, spalling can be a problem with alloys of up to 40% silver). The determining factor in this process is in fact not so much the silver content as the cooling rate of the cast blanks, which in antiquity was probably a function of the mould material. When cooling is rapid, as it will be in a stone or clay mould, the copper-rich material will solidify first, forming dendrites growing into the liquid from the mould wall. This usually results in a tendency for a thin copper-rich surface to form, which is rapidly oxidized, causing the blank to come out of the mould with a black coating of copper oxide. However, under conditions of particularly rapid cooling, pressure can build up when the liquid silver-rich phase rushes into the gaps between the copper-rich dendrites and is squeezed out onto the surface.[11] This inverse – or dendritic – segregation will result in a blank having a thin silver surface when it leaves the mould and this will enhance any subsequent blanching process by preventing spalling and producing a particularly robust silver surface. This is the most likely explanation for the silver surfaces of the tetradrachms of Tiberius' 14th year and the reason for the particularly rapid cooling must be down to a change in mould material. The sort of temperature gradient required to produce dendritic segregation would have to be considerable and would be best explained by a change from stone to bronze moulds.

Clearly this change was, for whatever reason, short lived, and the spalling of the silver surfaces reappears in year 19 to continue throughout the series as we have seen. Analytically, the effects of the loss of the silver-rich surface through spalling (whether immediately after striking or through corrosion) means that Walker's surface XRF results are more reliable for base Alexandrian coins than for other Roman silver issues, although, for the reasons discussed above, the variability is unacceptably high. Reece's volumetric and gravimetric analyses of Alexandrian tetradrachms, which involved the filing away of the silvered surfaces, are the most reliable of the earlier analyses, and his comparison of filed and unfiled samples serves to illustrate the problem with Walker's approach (and, indeed, any surface technique). Some coins have unfiled and filed portions giving very similar results, others show a predictably higher silver content in the unfiled portion whilst still other coins reveal that an unfiled portion can also yield a result that is actually lower in silver than the filed portion! All this serves to reinforce the authors' contention that it is only ever possible to gain a reliable estimate of the silver content of ancient silver coins by analysing a sample that has come from well beneath the surface.

Analytical methods

The analytical procedure adopted here was to take a sample by collecting the turnings from a hole made by an 8 mm diameter drill, penetrating the coin for approximately 1.5 cm (the length of the drill). The first two millimetres or so of metal turnings were always discarded to prevent contamination of the samples by unrepresentative surface material. The drill size is sufficiently large to cut through many phases at once and also cuts through over half the diameter of the coin, thereby extracting

[11] See J. Campbell, Castings (Oxford 1991), p. 155 for a detailed description. Recent experimental work by L. Beck/S. Bosonnet/S. Réveillon/D. Eliot/F. Pilon, Silver surface enrichment of silver-copper alloys: a limitation for the analysis of ancient silver coins by surface techniques, Nuclear Instruments and Methods in Physics Research B 226, 2004, pp. 153-162, has produced a similar effect in silver buttons with a silver content of between 15 and 20%. However, the buttons were not cast in a mould, but air-cooled and produced only a thin silver layer (<40 m) which is, by itself, insufficient to result in the effects observed here.

a homogenized and largely representative sample of approximately 25 mg whilst causing minimum damage to the coin. The samples were then weighed into glass vials and dissolved in acids according to the method described in GITLER/PONTING.[12] The analysis was by inductively coupled atomic emission spectrometry (ICP-AES) following the methodology set out in Ponting and Somerfield.[13] Scanning electron microscopy with energy dispersive analysis (SEM-EDS) was conducted on cut half-coins mounted in epoxy resin and polished to a mirror-like finish. EDS analysis was conducted on the mounted sections at an accelerating voltage of 25 kV, counting for 100 sec. with a count rate of 2000 cps on cobalt metal. Primary standards were pure elements which were calibrated on specially prepared silver/copper alloys as secondary standards.

Silver standards at Alexandria

Walker, having argued that other provincial silver coinages were overvalued against the denarius, had difficulty explaining the apparent undervaluation of the Tiberian tetradrachm. He obtained a mean of 30.6%, which, when compared to his results for Tiberian denarii, indicated that the tetradrachm contained 10% more silver. Because of this he suggested that the equation of 1 tetradrachm = 1 denarius was impossible in this period.[14] Oddone and Savio analysed a single Tiberian tetradrachm in its entirety, by neutron activation, and obtained a result of 22.5% elemental silver.[15] Our results (*fig. 6*) suggest a mean bullion content of 25.6%, essentially 1 part silver to 3 parts copper, and this is the standard proposed many years ago by Milne.[16] This means that compared to a pure silver bullion denarius of Tiberius weighing about 3.7 g, a tetradrachm contained about 3.4 g of silver (see below), and was therefore overvalued against the denarius by about 8%. Walker's results also seemed to indicate that tetradrachms of Tiberius' 14th year (AD 27/28) were struck on a higher standard of 40% and that this was possibly an abortive attempt to return to the previous Cleopatran standard.[17] Our analyses clearly show that this was not the case; Walker's higher figures for this year being due to changes in the method of blank production, as discussed above.

12 GITLER/PONTING, pp. 17-18.

13 M. PONTING/C. SOMERFIELD, The Analysis of Ancient Silver Alloys by Inductively Coupled Plasma Atomic Spectrometry (forthcoming).

14 WALKER, p. 155.

15 ODDONE/SAVIO, p. 143.

16 MILNE, p. xliii. Note that all of our calculations for silver content are based on what we have designated bullion – silver plus lead, gold and bismuth – rather than pure elemental silver, which would have been unobtainable in antiquity (on this, see BUTCHER/PONTING).

17 WALKER, p. 152.

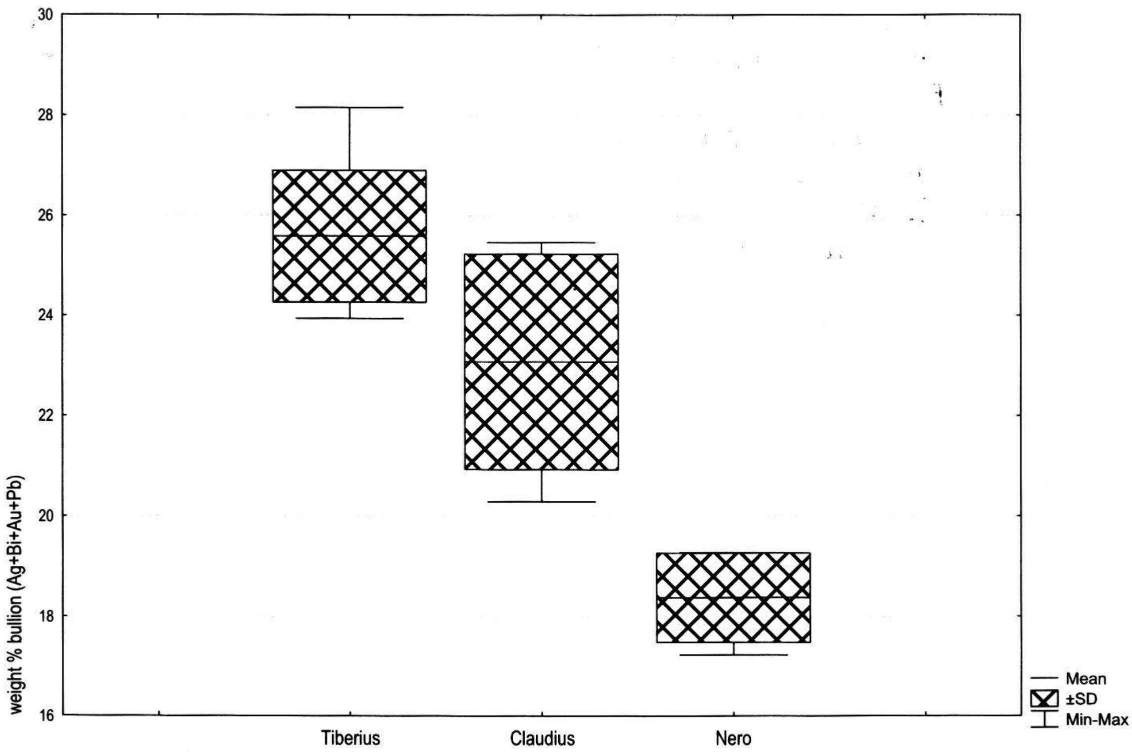

Fig. 6. Box and whisker plot showing the silver bullion contents of Alexandrian tetradrachms. The mean values are indicated by the central black line and the boxes represent plus or minus the standard deviation of the mean. The whiskers represent the maximum and minimum values measured.

It would appear that overall the Claudian coins were issued on a slightly lower standard than those of Tiberius, with a bullion content of about 23.4% (a lead forgery will be discussed below and is omitted from this average). Though real, this is a very minor difference, and it would not be misleading to claim that the standard of about ¼ silver was maintained under Claudius. Reece obtained a slightly higher mean of 24.83% for seven tetradrachms of Claudius, of years 2-6.

One tetradrachm of Claudius (BW1) was found to contain virtually no silver (0.1%) but 20.2% lead and 7.9% tin. The coin is therefore likely to be a forgery, although it is a curious coincidence that the amount of lead added is close to the amount of silver in the regular issues. However, the amount of tin is consistent with Roman bronzes and similar levels of lead are often found in castings of similar date.[18]

Walker reported that the Claudian standard continued until Nero's regnal year 4 (AD 57/58) when a further debasement occurred.[19] We have not analysed any coins of Nero's early regnal years, and cannot comment on exactly when this debasement took place, but a lowering of the silver content had certainly occurred

18 P.T. Craddock, Three Thousand Years of Copper Alloys: From the Bronze Age to the Industrial Revolution, in: P. England/L. van Zelst (eds.), Application of Science in Examination of Works of Art (Boston 1985), pp. 59-67, esp. p. 61.

19 Walker, p. 154.

by his regnal year 10 (AD 63/64, which more or less coincides with the debasement of the denarius at Rome). Oddone and Savio's neutron activation results for four tetradrachms of years 4, 5 and 9 seem to suggest that the Claudian standard had already been abandoned early in the reign, although it should be noted that they also analysed a single tetradrachm of Claudius and obtained an elemental silver content of 15.0%, rather lower than any of our samples.[20] Therefore it is possible that the early Neronian coinage was struck to a higher standard than the coinage of year 10; without further analyses we cannot be certain.

The eight silver coins of Nero of year 10 analysed here give a mean bullion content of 18.4%, and 17.9% for elemental silver. Allowing for experimental error and variations in the samples, this is close to 1 part silver to 5 parts copper (17.5% or $^{1}/_{6}$ silver) suggested by Walker and King.[21]

Oddone and Savio analysed three coins of year 10, obtaining a slightly lower mean of 16.0% for elemental silver, but this is not significant. They have suggested that the silver content of the Alexandrian coinage was lowered afterwards, between AD 64 and 66, by about 18%, in line with Nero's lowering of the silver content of the denarius,[22] and that there were minor fluctuations in the silver content between 64 and the end of Nero's reign. There seems to be too much variation in their results for individual coins to be certain of such conclusions, and the coincidence of the percentage of debasement of tetradrachm and denarius will not hold, as the post-reform Neronian denarius was much baser than the 93% they cite.[23] Clearly more analyses of tetradrachms issued in Nero's later years would be desirable, but we see nothing in the data from earlier analyses to persuade us of the case for any further debasements in Nero's reign. In particular, the results obtained by REECE for nine coins of years 13 and 14 (respectively means of 18.2% and 17.7% for elemental silver) speak against it. We would suggest that a standard of roughly $^{1}/_{6}$ silver was established at some point in or before year 10 and maintained thereafter.

The Neronian debasement seems to have been accompanied by a rise in tetradrachm production.[24] It has been proposed that this enlarged production was the result of recycling old Ptolemaic silver, replacing each Ptolemaic tetradrachm with a debased Neronian one, and sending the silver thus recouped from the process to Rome, to help cover Nero's financial problems.[25] Certainly the reign of Nero seems to have been a watershed in the hoards of Alexandrian tetradrachms, so that Ptolemaic and pre-Neronian coins are rarely encountered thereafter.[26]

Analyses of Alexandrian tetradrachms issued under later emperors suggests that the Neronian standard remained in use for many decades,[27] although we have

20 ODDONE/SAVIO, p. 142.
21 *Supra*, n. 2.
22 ODDONE/SAVIO, p. 149.
23 *Ibid.*, p. 149.
24 E. CHRISTIANSEN, The Roman Coins of Alexandria I (Aarhus 1988), pp. 103-104.
25 *Ibid.*, pp. 105-106, 109; *Id.*, Nero's Alexandrian Coinage Revisited, *XAPAKTHP*, Essays offered to Mando Oeconomidou (Athens 1996), pp. 92-96.
26 E. CHRISTIANSEN, The Roman Coins of Alexandria (30 BC to AD 296). An Inventory of Hoards, Coin Hoards 7 (London 1985), pp. 77-140; *Id.* (*supra*, n. 24), p. 105.
27 MILNE, p. xliii; WALKER, p. 154.

not undertaken analyses of these later coins to confirm that this is so. Four tetradrachms of Vespasian, of his regnal years 1 and 2, were analysed by REECE. These had a mean elemental silver content of 17.5%.

The silver standard at Tyre

The Tyrian silver was very pure and its production did not require any blanching of the blanks prior to striking. It is important to note, however, that the coins were not pure silver bullion. Our results are remarkably consistent, giving a mean fineness of 97% silver bullion (compared to 94.6% for elemental silver cited by Walker).[28] The alloy was clearly carefully controlled, with the deliberate addition of some 3% copper, and with no variation in fineness between the earliest and latest specimens.

The pattern of production at Alexandria

Apart from the silver and copper in the alloy, we were also able to quantify a number of minor and trace elements present in the metal of the coins.[29] These contaminants are associated with the copper or silver ores from which the constituent

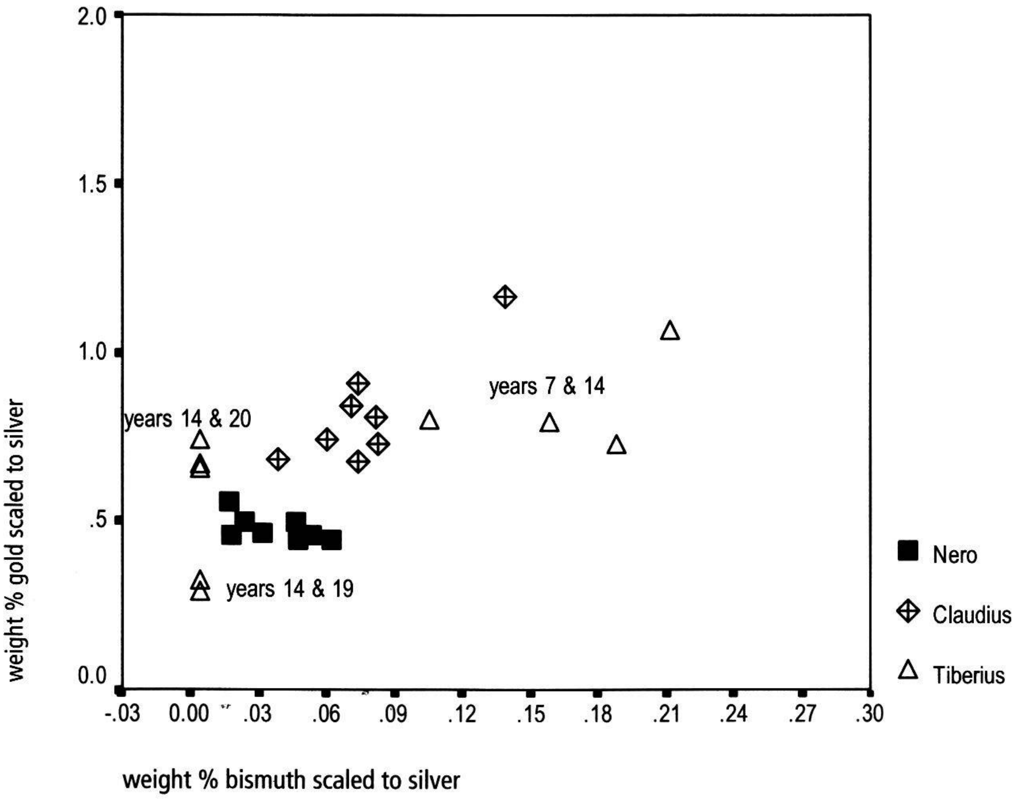

Fig. 7. Scatter-plot showing the gold and bismuth contents scaled to silver according to the issuing emperor. The annotations refer to the years of Tiberius' reign.

28 WALKER, p. 58.

29 Details of the trace elements of Tyrian silver will be dealt with in a forthcoming paper on the Syrian silver coinages of the Julio-Claudians.

metals were smelted, or from the refining process used to purify the silver. The minor elements present are gold, lead and bismuth, with traces of arsenic, cobalt, iron, manganese, nickel, antimony, tin, zinc and chromium. The variations in the amounts of these elements in the coins have provided information related to the pattern of production of Alexandrian coins that has not previously been observed.

Gold and bismuth are elements that are carried through from the silver ore into the metal and can therefore be used to characterise silver bullion. Figure 7 shows a scatter-plot of these elements recalculated as a percentage of the silver only; the structure in the data is readily apparent with the coins clustering into four groups defined by the issuing emperor. However, the tetradrachms of Tiberius form two groups: one high in bismuth and gold, the other low in bismuth and gold; and these appear to be related to the date of issue. The high-bismuth, high-gold coins are years 7 and 14; the low-bismuth, low-gold coins are years 14, 19 and 20. This suggests that there was a change in the source/s of silver bullion used to produce the tetradrachms of Tiberius in AD 27/28 and serves to reinforce the suggestion that important changes occurred in the way tetradrachms were produced during this year. The silver used in the coins of Claudius is again chemically distinct from that used to produce the coins of Tiberius, whilst that of Nero's year 10 tetradrachms is distinct from all earlier issues. There is no suggestion of re-cycling within this chronology, although obviously refining and re-alloying earlier Ptolemaic issues can not be ruled out. What does seem apparent is that the silver for the coins of each of the four groups is chemically distinct and must represent four distinct

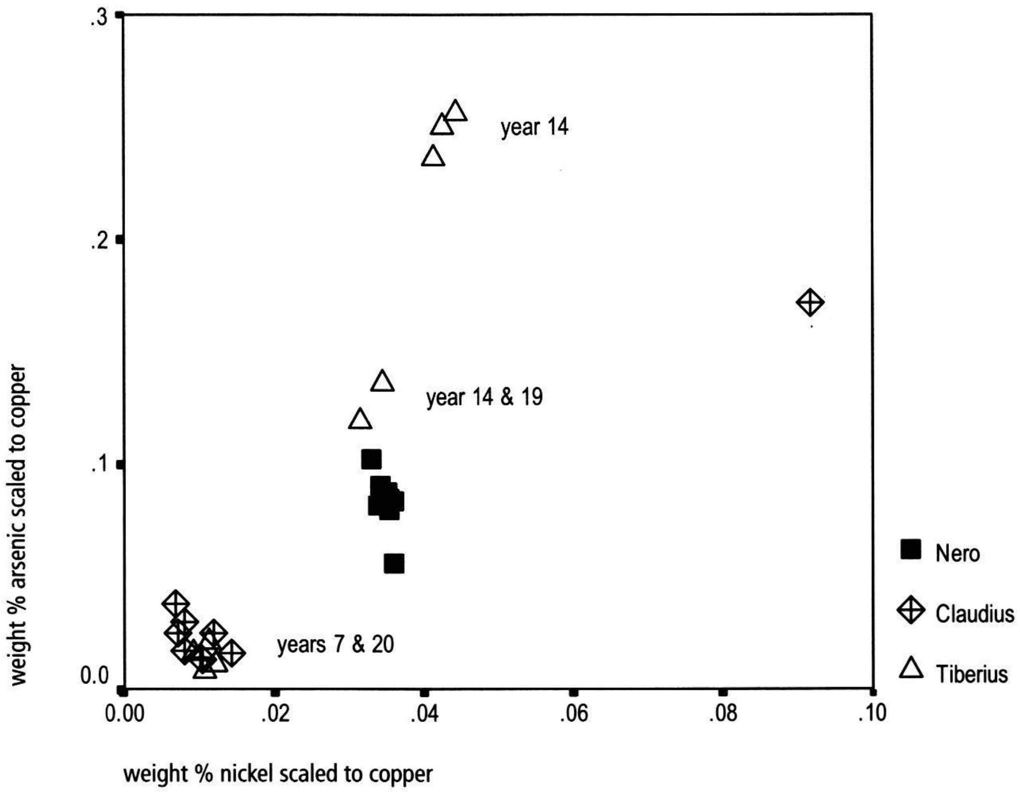

Fig. 8. Scatter-plot showing the arsenic and nickel contents scaled to copper according to the issuing emperor. The annotations refer to the years of Tiberius' reign.

procurements of bullion for AD 20-AD 27/28, AD 27/28-AD 34, AD 42-AD 44 and for AD 63/64. This would seem to suggest that bullion supply was episodic rather than a continuous trickle.

The trace elements associated with the copper in the alloy, especially nickel, also group the coins in curious ways. Figure 8 shows the nickel and arsenic concentrations and groupings are readily apparent, but these groupings are different to those found when the gold and bismuth are plotted. Here the issues of Tiberius for years 7 and 20 group with the issues of Claudius, whilst one of Tiberius' year 14 and one of year 19 fall close by Nero's year 10 and the rest of Tiberius' year 14 form a separate high-arsenic group. The discrete groupings indicate three chemically distinct copper sources being used at different times, with some being reused at later dates, unlike the silver sources. Because the groupings for the copper are quite different to those of the silver this suggests that the two metals must have been brought independently to the mint for alloying. The apparent continuity of the same Tiberian copper source/s under Claudius shows a continuity of base metal procurement that is not evident for silver bullion; this indicates that silver and copper were procured independently from each other, as well as by different methods, and that it was not simply a case of melting down old coins to make new blanks.

PART II: ALEXANDRIA, TYRE, ANTIOCH, AND ROME

The limits of precision

It cannot be stressed too strongly that the figures we have cited for fineness are not absolute, and that for all instrumental analytical techniques a small margin of error of up to 2% is unavoidable because of the heterogeneity of the alloys and the way the figures are calculated by the machine. It is crucial that this be borne in mind when comparing one coinage with another. Thus the figure of 25.6% for Alexandrian tetradrachms of Tiberius does not mean that 25.6% was *exactly* the standard of fineness used, but that the standard falls within a maximum range of 23.6%-27.6%, with a strong likelihood that it falls close to 25.6% (the median value is 25.8%). Similarly the Alexandrian coinage of Claudius falls within the 21.4%-25.4% range, and therefore the range overlaps with the fineness of tetradrachms of Tiberius. Not so the tetradrachms of Nero, whose fineness must fall in the 16.4%-20.4% range. The Neronian tetradrachms are clearly significantly different (*fig. 9*).

This range of possibilities has some effect on any calculation of silver content (*fig. 10*). If one compares the mean silver content of Alexandrian tetradrachms of Tiberius with the mean for Claudius there is a difference in fineness of 2.2%, and it would thus appear that the Claudian coins were overvalued against the Tiberian ones by about 9%. However, comparing the Tiberian mean with the highest value for Claudius narrows the gap to 0.6% overvaluation – effectively no overvaluation at all. Neither figure should be regarded as correct. The minor variations in fineness of the individual coins, and the limits of analytical precision, combine to make it impossible to calculate the degree of overvaluation precisely. To put the figures just quoted in perspective: there is a difference of 0.53 g-0.54 g of silver between

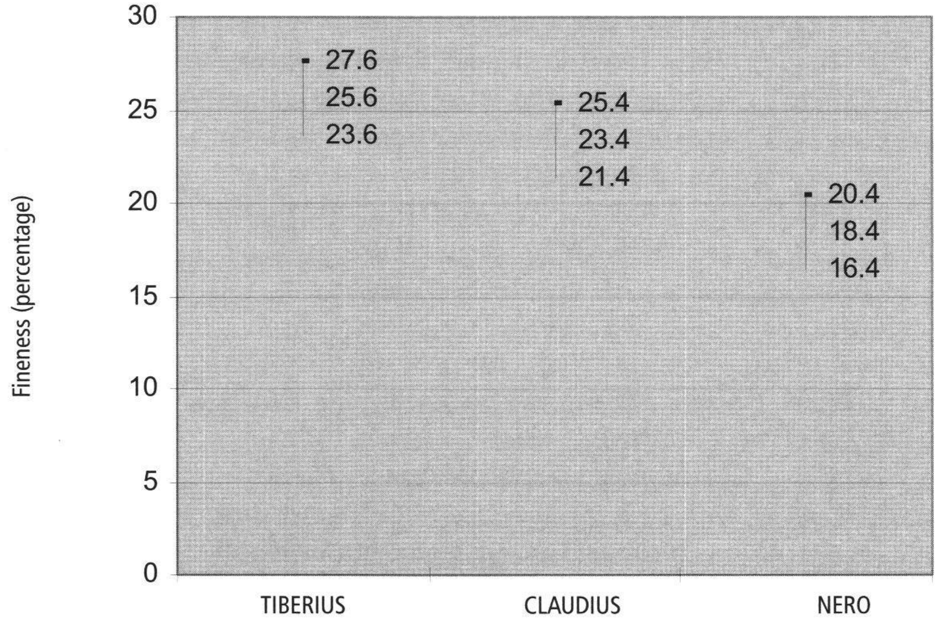

Fig. 9. Fineness of Alexandrian tetradrachms, allowing for a 2% margin of error.

the minimum and maximum percentages of silver for the tetradrachms of Tiberius, Claudius and Nero respectively. If one were calculating the overvaluation of the minimum figure against the maximum for each coinage, we would obtain figures of 17% overvaluation for Tiberius; 19% for Claudius; and 24% for Nero.

Ruler	*At minimum %*	*At mean %*	*At maximum %*
Tiberius	3.13 g	3.40 g	3.67 g
Claudius	2.84 g	3.11 g	3.38 g
Nero	2.18 g	2.45 g	2.71 g

Fig. 10. Range of grammes of silver contained in Alexandrian tetradrachms of Tiberius, Claudius and Nero, assuming a tetradrachm weight of 13.3 g (see below).

It is therefore possible to talk in terms of the tetradrachm fineness of Tiberius and Claudius as being intended to represent more or less the same standard, even if there really is a slight difference in fineness (three out of eight of the coins of Claudius analysed fall below the lowest value for Tiberius). If one calculates the fineness using the median value rather than the mean, the fineness of the Tiberian tetradrachms is 25.8%, and that for Claudius 23.9% – a difference of 1.9%. In this case the Claudian coins would still be overvalued against the Tiberian ones by only 8 or 9%.

The Claudian tetradrachms may well have been slightly more debased than the Tiberian ones, but the difference would have been impossible to detect in antiquity. The results for Nero, however, fall outside the margins of error for the other two, and the standard ought to be regarded as different. In terms of overvaluation, the mean Neronian weight of silver is overvalued against the Tiberian mean by 39%, and against the Claudian by 27% – both far more significant differences than the overvaluation of the Claudian tetradrachms against the Tiberian (8 or 9%). This difference ought to have been detectable in antiquity.

Weight standards

There is another problem confronting anyone who wishes to compare the silver content of one coinage with that of another: how does one calculate the target average weight for an issue? Silver content is fineness plus weight. Since we do not know what the original weight standards were, we are forced to rely on the evidence of the coins themselves. The weights of individual specimens often vary greatly, and a large sample is often necessary to draw statistically valid conclusions. However, as with the silver content, one might ask what an acceptable margin of error was for those issuing the coins. It was presumably very difficult and laborious to measure minute differences in weight in antiquity, particularly with heavier coins such as tetradrachms. We may be able to notice a difference between coins of 13.25 g and 13.30 g, but we cannot be certain that people in antiquity would have been able to measure such a difference – or even that they would have attempted to do so. Thus the mints may have 'stretched' the amount of bullion from time to time, not by lowering the fineness, but by squeezing a few extra coins out of a given weight of alloy, and this would have passed unnoticed. But the weight differences between mints may also reflect small variations in standard sets of weights being used in different locations, or even different weight systems, with the result that the official weight for a tetradrachm at mint A might have been very slightly different from that at mint B, even though they were intended to be the same. If the coins did not normally circulate together, their weights might never have been compared for differences. It might be argued that the difference would become apparent when one mint was discovered to be operating at a loss compared with the other, but a rational economic argument of this sort supposes that production costs were the same in both locations and that such information was regularly exchanged between minting authorities.

The weights of surviving Egyptian tetradrachms of the Julio-Claudians are very erratic, ranging from less than 10 g to more than 14 g, and it is very difficult to find well-preserved specimens that are not corroded, even for the very common issues of Nero. Where they can be found, well-preserved specimens of Nero's coinage from years 10 to 14 tend to cluster in the 12.8 g to 13.8 g range. The same appears to be the case for Tiberius and Claudius. Using a sample of 139 well-preserved specimens of Nero's tetradrachm coinage, years 10-14,[30] we obtained a mean weight of 13.23 g

[30] The coins in question are all 'good very fine' to 'extremely fine' condition. The sources for the data are: A. Geissen, Katalog alexandrinischer Kaisermünzen der Sammlung des Instituts für Altertumskunde der Universität zu Köln, Band I. Augustus – Trajan (Opladen 1974); S. Bakhoum, SNG France 4. Alexandrie I: Auguste – Trajan (Zurich 1998); with additional specimens derived from sales catalogues. We would like to thank Volker Heuchert of the Ashmolean Museum, Oxford, for helping us in our quest for suitable specimens.

(almost identical to Walker's mean of 13.22 g), but the greatest concentration of weights falls somewhat higher, between 13.30 g and 13.39 g (*fig. 11*). The median is 13.26 g; the mode (the most-commonly occurring weight) is 13.36 g.

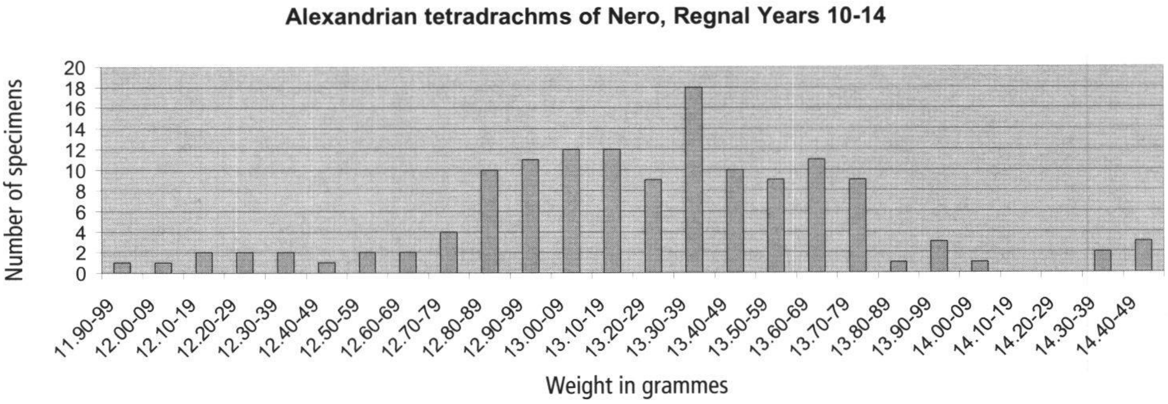

Fig. 11. Weights of 139 well-preserved Neronian tetradrachms of Alexandria. Mean = 13.23 g; median = 13.26 g; mode = 13.36 g.

There is much uncertainty when dealing with the average weights of coins about whether one should use the mean, median or mode to discover the 'true' target weight for striking a particular issue. In many cases the difference is not great; in the case of the weights of Nero's Alexandrian tetradrachms of years 10-14 the difference between mean and mode is 0.13 g, and between mean and median 0.03 g. When one calculates the weight of silver contained in the coins using the three different averages the differences remain extremely small (*fig. 12*). It may be questioned whether the Roman mints were capable of distinguishing such tiny differences, so that to all intents and purposes the mean, median and mode are the same in the case of the Alexandrian tetradrachms. Given the concentration of weights between 13.30 and 13.39 g and a mode of 13.36 g, it would not seem too imprudent to round the figure off to 13.3 g, which is also the mid point of the greatest concentration between 12.8 and 13.8 g.[31] Whichever method for calculating the average one adopts, the margins of error for weight standards are very small, and it is the margin of error for fineness that has a far greater impact on the likely weight of silver in the coins.

31 Duncan-Jones, p. 234, proposes an even higher target weight of 13.45 g for the Alexandrian tetradrachm from Tiberius to Nero, but this is based on the assumption that the standard used is the Roman pound rather than an Egyptian standard (p. 232), and it is not derived from the actual weights of coins. Nevertheless 13.45 g is not far from our proposed average of 13.3 g and the possibility that the standard used is the Roman pound cannot be dismissed. If so, Alexandria was striking tetradrachms at 24 to the pound, assuming a Roman pound of 322.8 g; see *ibid.*, pp. 221, 225.

Ruler	*Fineness*	*Weight of silver using mean weight*	*Weight of silver using median weight*	*Weight of silver using mode weight*	*Weight of silver using rounded weight, 13.3 g*
Tiberius	25.6%	3.38 g	3.39 g	3.42 g	3.40 g
Claudius	23.4%	3.10 g	3.10 g	3.13 g	3.11 g
Nero	18.4%	2.43 g	2.44 g	2.46 g	2.45 g

Fig. 12. Finenesses and weights of silver in Alexandrian tetradrachms, taking our mean average fineness for each ruler and calculating the weight of silver using mean, median and mode weights, as well as our 'rounded' weight of 13.3 g. As can be seen, the differences between the four methods of rendering the average weight are extremely small.

The relationship of the Alexandrian tetradrachm to other coinages

Metrological writers of the second century AD confirm the existence of an 'Alexandrian' or 'Egyptian' or 'Ptolemaic' talent, worth a quarter of an 'Attic' talent but containing the same divisions and denominations.[32] The Attic drachm was considered equivalent to a denarius, and therefore an Attic tetradrachm was worth four denarii. An Attic tetradrachm was also worth four Alexandrian tetradrachms. These statements, when added to other data from Egypt, present a good case for the Alexandrian tetradrachm's equivalence with the denarius.

Tetradrachms worth four denarii were issued in the neighbouring province of Syria. Until the reign of Nero the nearest major tetradrachm mint to Alexandria was Tyre, which produced a distinctive coinage modelled on earlier silver issued by the Ptolemies. Tyrian tetradrachms seem to have circulated all over the southern Levant, in the regions formerly controlled by the Ptolemies prior to the Seleucid conquest at the end of the third century BC. Metrological writers confirm that the Attic and Tyrian talents were equivalent in value, and so the Tyrian tetradrachm was worth four denarii and four Alexandrian tetradrachms.[33]

Alexandria and Tyre

As stated in the introduction, one of the purposes of performing these analyses was to test a hypothesis set out in Butcher 2004, that there was a logical relationship between the fineness of the Alexandrian tetradrachm and those of Tyre and Antioch. It has been proposed that initially, under Tiberius and Claudius, the point of reference was the tetradrachm of Tyre (so that an Alexandrian tetradrachm contained a quarter of the silver in a Tyrian tetradrachm), but that under Nero the point of reference switched to the tetradrachm of Antioch. The Tyrian tetradrachms and the Antiochene tetradrachms of Nero were produced at different finenesses (*pace* BUTCHER 1996)[34]: but both seem to have been valued at four denarii.[35]

32 J.R. MELVILLE JONES, Testimonia Numaria. Greek and Latin Texts Concerning Ancient Greek Coinage (London 1993), p. 403.

33 *Ibid.*, p. 403; F. HULTSCH, Metrologicorum Scriptorum Reliquae I (Leipzig 1864), pp. 301-302.

34 BUTCHER 1996, p. 105.

35 BUTCHER 2004, pp. 184, 200.

Our analyses of the Tyrian silver coinage suggest a silver bullion content of 97.0%. A quarter of this would be about 24.3%, which is close enough to the silver standards we obtained for Alexandrian tetradrachms of Tiberius and Claudius to suggest an equivalence. For the average weight of the Tyrian tetradrachms, the same problems arise as for the Alexandrian tetradrachms. Walker gives a mean of 13.99 g (s.d. 0.36) for 22 coins ranging in date from 64/63 BC to AD 55/56.[36] Data for the tetradrachms issued under the Julio-Claudian emperors suggests a very slightly higher weight for these; in the region of 14.1 g (*fig. 13*).[37]

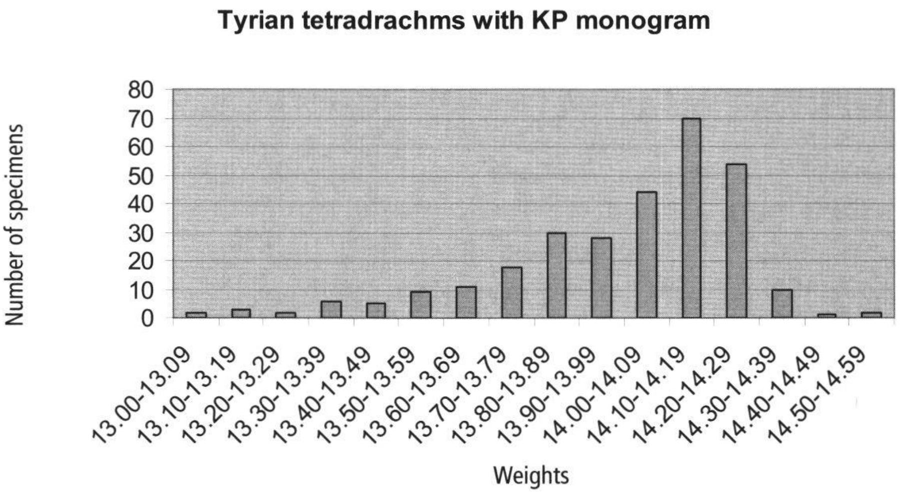

Fig. 13. Weights of Tyrian tetradrachms with the monogram KP, issued under the Julio-Claudian emperors, using a sample of 298 coins. Mean = 13.99 g; median = 14.05 g; mode = 14.16 g. Three outliers, weighing 11.76, 14.72, and 14.91 g, are excluded from the above chart but included in calculations of mean and median.

If the weight of the Alexandrian tetradrachm is taken to be 13.3 g, then the weight of silver in the Tiberian issues is 3.4 g. At 14.1 g the Tyrian tetradrachm contained about 13.7 g of silver, so a quarter of this would be 3.42 g; essentially identical to the mean silver content obtained for the Alexandrian tetradrachms of Tiberius (*figs. 14, 15*).

Coinage	*Fineness*	*Weight of silver*
Tiberius, Alexandria	25.6%	3.4 g
Tyre	97%	3.42 g

Fig. 14. Comparison of tetradrachms of Tyre with those of Alexandria under Tiberius, assuming the Alexandrian weight to be 13.3 g and the Tyrian weight 14.1 g, and that the Alexandrian tetradrachm is worth a quarter of the Tyrian (i.e. the Tyrian tetradrachm is worth four Attic drachms, the Alexandrian one Attic drachm).

36 He does not give a 'corrected mean weight', based on a larger data set of better-preserved examples, and instead relies only on the coins used for his analyses, which in many cases included worn specimens.

37 We are grateful to Arthur Houghton for generously providing us with the data on 298 Tyrian tetradrachms with the KP monogram.

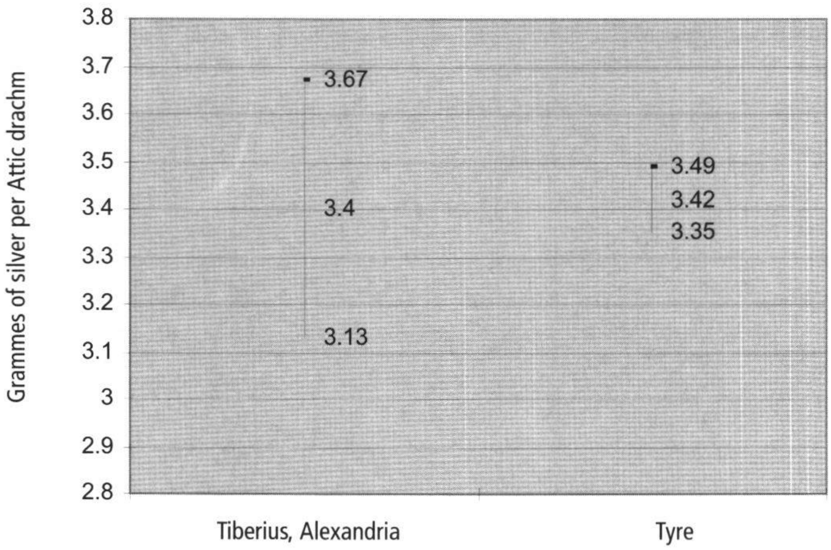

Fig. 15. Range of finenesses for tetradrachms of Tyre and Alexandrian tetradrachms of Tiberius, assuming a 2% margin of error around the mean value and that the Alexandrian tetradrachm is worth a quarter of the Tyrian (i.e. the Tyrian tetradrachm is worth four Attic drachms, the Alexandrian one Attic drachm). The Tyrian range of fineness sits comfortably within the range for Alexandria.

This would appear to confirm the proposition that the Alexandrian tetradrachm of Tiberius contained a quarter of the silver found in the Tyrian tetradrachm. The slight decline in silver content of the Alexandrian tetradrachm under Claudius would have seen the Egyptian coinage overvalued against the Tyrian (using our mean values, we arrive at a figure of about 10%, but as stated above, this counts as a low percentage and may not be particularly significant, given the margins of error).

Alexandria and Antioch

The Neronian tetradrachms of Alexandria were clearly overvalued against the Tyrian tetradrachm (by about 40%), but production of Tyrian silver came to an end in the reign of Nero (the latest known is dated to AD 65/66).[38] Levantine hoards from the reign of Nero show that tetradrachms of Antioch began to replace the Tyrian coins in the southern Levant, and within a few decades the Tyrian silver had been removed from circulation entirely.[39] In northern Syria, Neronian silver also seems to have replaced earlier Julio-Claudian coinages of Antioch. As in Egypt, the reign of Nero marks a watershed in the hoarding patterns of silver coins in Syria, with pre-Neronian coins almost never occurring in hoards of later times.

[38] RPC I, 4706; see also B.L. Levy, Tyrian Shekels: The Myth of the Jerusalem Mint, SAN, Journal of the Society for Ancient Numismatics XIX/2, 1995, pp. 33-36.

[39] Butcher 1996, pp. 104-106; Butcher 2004, pp. 180-181, 184, 239-240.

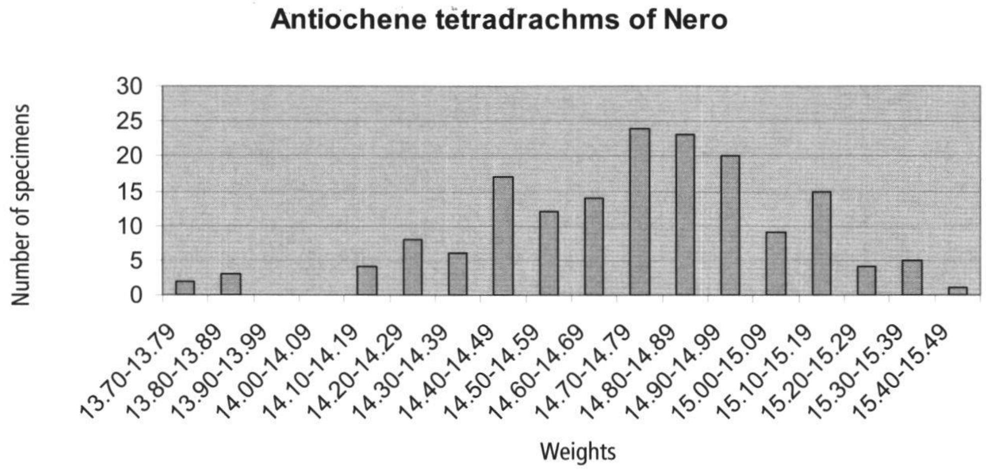

Fig. 16. Weights of 167 Neronian tetradrachms of Antioch, AD 59/60-68. One unusually light specimen weighing 13.25 g has not been included on this chart. Mean = 14.72 g; median = 14.76 g; mode = 14.8 g.

The Neronian tetradrachms of Antioch, issued in large quantities from AD 59/60 (Nero's regnal year 6), weighed about 14.8 g[40] and were therefore heavier than the Tyrian or Alexandrian coins (*fig. 16*). They were baser than the Tyrian, however, with a mean silver bullion content of 70.1% (based on a sample of 28 coins). This standard of fineness had been in use at Antioch from at least the 40s BC (analyses to be published elsewhere), and was therefore not an innovation of the reign of Nero. But prior to the reign of Nero the Antiochene tetradrachms did not circulate in the southern Levant, where Tyrian silver was predominant.[41] Before Nero, the Antiochene and Tyrian tetradrachms seem to have made up two separate pools of circulation in the province of Syria, the former in the North and the latter in the South. Nero's reign witnessed the unification of these two pools under a single standard: that of Antioch.

The Neronian Antiochene tetradrachm contained a mean of about 10.36 g of silver[42] against the Tyrian's 13.7 g and, had the Tyrian coins remained in circulation, the Antiochene tetradrachms would have been overvalued against the Tyrian by about 32%, which is significant. Some transitional hoards have mixed Tyrian and Neronian Antiochene silver,[43] suggesting that this difference did not always matter all that much to hoarders, but presumably it mattered to the issuing authorities,

40 Rounded weight based on a sample of 168 coins in 'good very fine' to 'extremely fine' condition (see *fig. 16*). The authors would like to thank Michel Prieur for generous permission to use data from his extensive database of Syrian tetradrachms, and Richard McAlee for his kind help in providing additional material.

41 BUTCHER 1996, p. 104; see the list of hoards in BUTCHER 2004, pp. 270-272.

42 Walker's 'corrected mean weight' for the Syrian tetradrachm of Nero from regnal years 8 to 10 produced an average of 14.66 g (WALKER, p. 66). For what it is worth, this is very close to 22 to the Roman pound (22.02), assuming the weight of the pound to be 322.8 g, see DUNCAN-JONES, pp. 221, 225. Our mean weight of 14.8 g is also tolerably close to 22 to a pound at 322.8 g (21.8).

43 BUTCHER 2004, p. 272.

because no major provincial silver coinages were issued at such a high fineness as the Tyrian ever again.

The removal of Tyrian tetradrachms from circulation, and their replacement by Antiochene ones, was a major event in the monetary economy of Syria, and we propose that the Alexandrian tetradrachm was adjusted as part of the same programme of reform. At 18.4% pure, an Alexandrian tetradrachm of Nero's year 10 contains 2.5 g of silver, which is fairly close to a quarter of the silver contained in the Antiochene tetradrachm (2.6 g; *see fig. 17*). This might suggest that the Alexandrian tetradrachm was overvalued against the Antiochene by 6%, but such a difference is not very significant and one might question whether the authorities responsible for producing the coins were capable of making such a fine distinction. In any case the range of values for Antioch, when allowance is made for a 2% margin of error, sits within the range for Alexandria under Nero, and both are markedly different from Tyre (*fig. 18*). It is quite possible that the silver content of the Alexandrian tetradrachm and the Antiochene drachm were intended to be identical, so that the Alexandrian tetradrachm went from containing a quarter of the silver of a Tyrian tetradrachm under Tiberius and Claudius to a quarter of an Antiochene tetradrachm under Nero. This would support the scheme outlined previously by one of the authors.[44]

Coinage	*Fineness*	*Weight of silver*
Nero, Alexandria	18.4%	2.5 g
Nero, Antioch	70.1%	2.6 g

Fig. 17. Comparison of Antiochene tetradrachms of Nero, AD 59/60-68, with Neronian tetradrachms of Alexandria, AD 63/64, assuming that the Alexandrian tetradrachm is worth a quarter of the Antiochene.

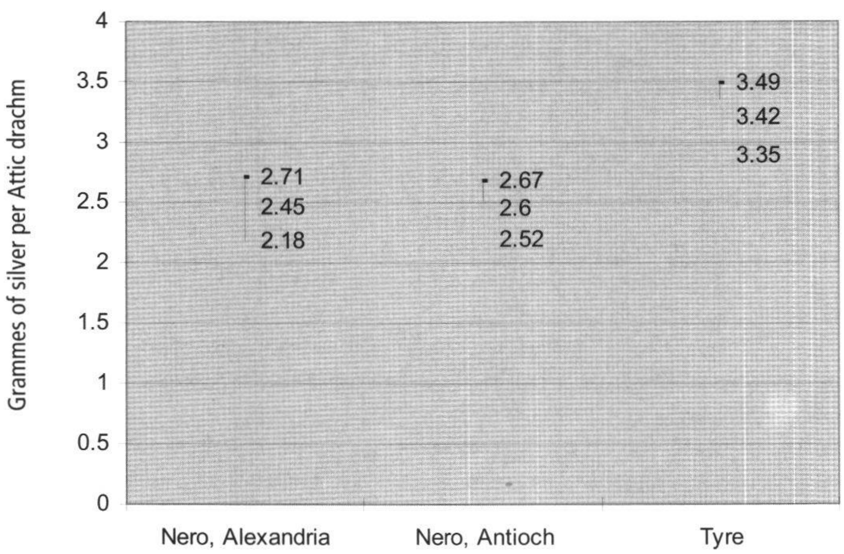

Fig. 18. Grammes of silver per 'Attic' drachm/denarius for Alexandria and Antioch under Nero, and the Tyrian tetradrachm, assuming a 2% margin of error about the mean value. It can be seen that the range for Antioch (2.52 g-2.67 g of silver) fits within the range for Alexandria, but that the range for Tyre is quite different from both.

44 *Ibid.*, p. 254.

To sum up: the Tiberian coins of Alexandria were issued at a quarter the silver content of the tetradrachms of Tyre. But by AD 63/64 the relationship had changed. Tyrian tetradrachm production was coming to an end and the coins were then removed from circulation and replaced by baser Antiochene ones. The silver content of the Alexandrian tetradrachm was adjusted to take account of this new situation, to a quarter of the Antiochene tetradrachm. Precisely when this change took place cannot be determined, and a broader sample of Nero's Alexandrian coinage needs to be analysed to enable us to trace the history of this reform.

Alexandria and Rome

What prompted these changes to the Egyptian and Syrian coinages? An answer may lie in the Neronian reform of the denarius. From Augustus to Claudius the denarius was very pure, but it was not issued in large quantities after the reign of Tiberius. As noted above, the Alexandrian tetradrachms of Tiberius contained slightly less silver than contemporary denarii. But the degree of overvaluation against the denarius was small (perhaps 8%); certainly it was less than the degree to which the post-reform Neronian denarius was overvalued against the issues of Nero's predecessors (30% or more). In AD 64 Nero reduced the silver content of the denarius to 80%,[45] and also reduced its weight. This change had a profound effect on the pattern of denarius hoarding across the empire and within two or three decades pre-64 denarii had largely disappeared from circulation. This debasement may also mark the point at which the denarius began to circulate in Syria (there being very little evidence for it in earlier times;[46] denarii are thought to have been excluded from Egypt at all times).[47]

The Neronian reform of the denarius is usually explained simply in terms of Nero's financial difficulties: the emperor needed to raise revenues, and consequently debased the coinage. While we do not intend to challenge this view here, we would like to propose that the fineness and weight of the new denarius were chosen for a reason: compatibility with the major eastern silver issues. The debasements of the Egyptian, Syrian and denarius coinages may well have been prompted by the Roman state's desire to raise money. Our aim here, however, is to show that by the reign of Nero a system of interlocking standards had been chosen for the principal silver coinages of the Roman Empire. Because these three different coinages do

45 BUTCHER/PONTING. Our mean fineness, when outliers (the result of sampling errors) are removed, is 80.3%.

46 BUTCHER 2004, pp. 192-195. Note however that there is some evidence for Republican denarii and denarii of Augustus circulating in the south alongside Tyrian tetradrachms (*ibid.*, p. 193). Tyrian tetradrachms were only about 8% overvalued against pre-Neronian denarii, which might explain the latter's presence there. There is no evidence for denarii circulating alongside the baser Antiochene tetradrachms of the north until after the Neronian reform (*ibid.*, p. 195). This might suggest that for practical purposes the silver content of the pre-Neronian denarius and Tyrian drachm were regarded as equivalent, but no such equivalence existed between the pre-Neronian denarii and pre-Neronian tetradrachms of Antioch.

47 But see DUNCAN-JONES, pp. 90-91 for an alternative view.

not appear to have circulated alongside each other, at least not initially, we might suppose that the systematic changes were indeed prompted by fiscal considerations rather than a simple desire for integration.

The weight of the post-reform Neronian denarius deserves careful study. Walker obtained a mean weight of 3.18 g for 24 Neronian post-reform denarii.[48] Curiously he did not attempt to calculate a 'corrected mean weight' using a larger sample of well-preserved coins, as he did with most other issues;[49] had he done so, he might well have obtained a quite different result. Other studies have indicated much higher weights: 3.5 g[50] and 3.41 g (RIC I, p. 141). Duncan-Jones reports a target weight of 3.36 g, based on a standard of 96 denarii to the Roman pound, where the Roman pound is taken to be 322.8 g.[51] Walker's low figure is almost certainly the result of including worn coins in his sample and, as can be seen from Figure 19, there are very few well-preserved denarii that fall below 3.2 g in weight. Using a sample of 50 post-reform denarii in what numismatists would term 'good very fine' or 'extremely fine' condition, we obtained a mean weight of 3.38 g, and a median of 3.43 g – again a minor difference between the two (0.05 g).[52] However, it should be noted that the greatest concentration is between 3.35 and 3.54 g (*fig. 19*), which could suggest a slightly higher target average weight of 3.45 g (the mode is 3.46 g). An average weight of 3.45 g would produce a silver content of 2.8 g at 80%. Overall, a figure of 2.8 g of silver per denarius seems reasonable, erring perhaps on the high side of caution.[53]

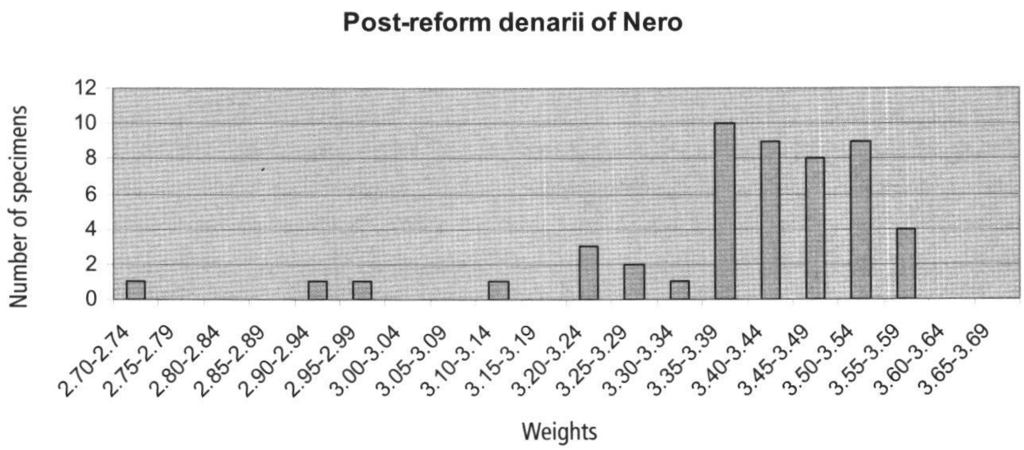

Fig. 19. Weights of 50 specimens of Nero's post-reform denarii. Mean = 3.38 g; median = 3.43 g; mode = 3.46 g.

48 Walker, p. 18.
49 *Ibid.*, p. 17.
50 D.W. Mac Dowall, The Western Coinages of Nero, ANSNNM 161 (New York 1979), p. 142.
51 Duncan-Jones, pp. 221, 225.
52 The data were drawn exclusively from sales catalogues.
53 A weight of 3.45 g would mean that Nero's denarii were struck at 93 or 94 to the pound rather than 96, assuming a pound of 322.8 g.

What, then, was the relationship between the post-reform Neronian denarius and the Alexandrian tetradrachms of Nero? Using our data, and assuming a weight of silver per denarius of 2.8 g and employing a 2% margin of error about the mean, we can see that the range for the amount of silver in the denarius falls slightly above that of the Alexandrian and Antiochene ranges (*fig. 20*). The difference between the mean for the denarius and the Alexandrian tetradrachm suggests a rate of overvaluation of the Egyptian coinage of 13%, and between the denarius and the Antiochene tetradrachm of 7%. Indeed, our mean values suggest a greater difference between the denarius and the Egyptian coinage than the mean values of either Walker or Duncan-Jones (*figs. 21, 22*).

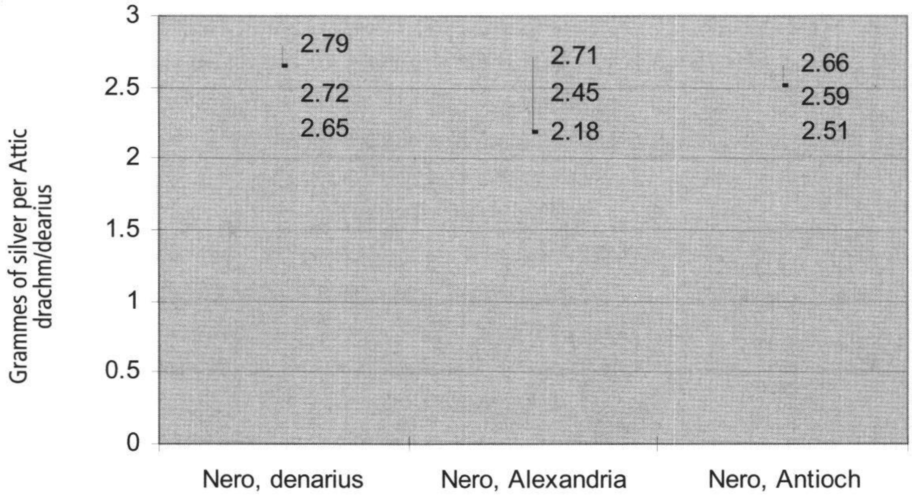

Fig. 20. Range of values for Nero's post-reform denarii, his Alexandrian tetradrachms and his Antiochene tetradrachms, assuming a 2% margin of error about the mean fineness and an Antiochene tetradrachm valued at 4 denarii.

Authority	*Denarius*		*Alexandrian tetradrachm*	
	Reported Weight	*Weight of silver at 80%*	*Reported Weight*	*Weight of silver at 18.4%*
WALKER	3.18	2.54	13.22	2.43
DUNCAN-JONES	3.36	2.69	13.45	2.47
BUTCHER/PONTING	3.45	2.76	13.30	2.45

Fig. 21. Possible weights of silver in Nero's post-reform denarius set against possible weights of silver in the Alexandrian tetradrachm of Nero's regnal year 10.

Authority	*Overvaluation*
WALKER	4.5%
DUNCAN-JONES	8.9%
BUTCHER/PONTING	13%

Fig. 22. Some possible rates of overvaluation of the Alexandrian tetradrachm against the post-reform denarius of Nero. Walker's figures are unlikely to be correct (see text).

There is a negligible difference between the weight of silver in the Alexandrian tetradrachm in the results reported by Walker, Duncan-Jones and ourselves, and we can be fairly confident that the average silver content of Nero's Alexandrian tetradrachms is about 2.45 g. Given the margins of error for finenesses, it would be futile to calculate an exact percentage of overvaluation of Nero's Alexandrian coinage against his post-reform denarii, but we can suggest some parameters. The degree of overvaluation is unlikely to have been greater than the difference between the highest figure for the denarius (Butcher/Ponting) and the lowest figure for the Alexandrian tetradrachm (Walker). If, at the most extreme, the denarius is considered to contain 2.8 g of silver (assuming our maximum average weight of 3.45 g), and the tetradrachm 2.45 g (assuming Walker's weight of 13.22 g), then the highest degree of overvaluation for the tetradrachm is 13.5% – considerably less than the 37% proposed by Walker and King.[54] It would mean that for every nine tetradrachms issued a 'profit' of one denarius was made. But using the smallest difference (ignoring Walker's figure of 3.18 g for the denarius and instead using Duncan-Jones's denarius of 3.36 g set against Walker's tetradrachm value of 3.22 g), one denarius was recouped for every 10 tetradrachms. If Duncan-Jones is correct about a target weight of 3.36 g for the post-reform Neronian denarius, and this is set against our Alexandrian tetradrachm weight of 13.3 g, the overvaluation is 9% (one denarius's worth of silver per 11 tetradrachms). None of these figures are intended to be regarded as absolute, but they give some impression of the likely range of 'profit' if differential overvaluation were a factor (although this ignores the value of the copper in the tetradrachm, which was considerably more than the copper in a denarius).

It would seem, then, that the case for some sort of overvaluation of the Egyptian tetradrachm against the post-reform Neronian denarius can be made, albeit with reservations. A figure of around 10% seems plausible, though it may have been less. But it is far from clear whether this can be regarded as 'profit'. 'Profit' would suppose that production costs at Alexandria were identical to production costs at Rome. If silver was only marginally more expensive in Egypt than at the imperial mint in Rome, then the 'profit margin' might have been considerably smaller, or even non-existent. If the mint found itself competing for silver with the public, who were prepared to pay more for silver than the mint was, the mint could debase the coinage a little to help finance a higher purchasing price (an expedient employed by European mints in the Renaissance). Alternatively, if the mint at Rome was subsidized by the state, and the Egyptian mint not, that alone could explain the difference. Perhaps the seigniorage levied on provincial silver helped subsidize the Roman mint. We cannot claim to know these factors, but it is clear that there are numerous alternative explanations for the small differences other than simple profiteering. We would suggest that the significance of apparent 'overvaluation' and 'profit' be treated more cautiously than is often the case.

The percentages of overvaluation of provincial coinages against Julio-Claudian denarii are listed in Figure 23. This may give us some indication of the degree of

[54] *Supra*, n. 2, p. 156.

difference, or overvaluation, that was tolerable, and what was not. After Nero's reforms, the earlier coins were removed from circulation – suggesting that if the new coins were overvalued against the old by 30% or more, the continued circulation of the old was unacceptable. But smaller degrees of overvaluation may have been tolerated. As stressed before, these values should not be considered precise, and a large part of some differences listed in Figure 23 may be generated by the variation in the analytical results. For example, if the fineness of the Neronian tetradrachm of Alexandria is raised by 1% to 19.4% rather than 18.4%, the degree of overvaluation against the post-reform denarius is 7% – the same as the Antiochene coinage. With base silver coinages like the Alexandrian, 'overvaluations' of 10% or so fall within the margin of error for fineness.

Against denarii of Tiberius-Claudius:		
Coinage	*Grammes of silver*	*Overvaluation*
Tiberius, Alexandria	0.2	8%
Tyre	0.2	8%
Claudius, Alexandria	0.49	19%
Nero, post-reform denarius	0.84	34%
Nero, Alexandria	1.15	51%
Nero, Antioch	1.01	43%
Against post-reform denarii of Nero:		
Nero, Alexandria	0.31	13%
Nero, Antioch	0.17	7%

Fig. 23. Difference in grammes of silver, and percentage of overvaluation, of provincial coinages against denarii, using our mean weights of silver per issue. For reference, the overvaluation of the Neronian post-reform denarius against the earlier denarii (here considered to weigh 3.7 g) is included.

CONCLUSIONS

A possible history of the Alexandrian tetradrachm under the Julio-Claudian emperors can be reconstructed as follows: under Tiberius the denomination was first struck with a silver content equal to one Attic drachm, or a quarter of a Tyrian tetradrachm. The silver content of the Tyrian tetradrachm was fairly close to the silver contained in four denarii, but not identical.[55] So too the silver in an Alexandrian tetradrachm was fairly close to the silver in a denarius. But under Nero the silver content of the denarius was reduced dramatically, and other silver coinages followed suit, if they had not already done so. If the denarius was still considered to be the equivalent

55 The presence of Republican and Augustan denarii in some hoards of Tyrian tetradrachms (BUTCHER 2004, p. 193) might be seen as confirming the compatibility of the two coinages. See above, n. 46.

of an Attic drachm, this presumably meant that the Attic standard was now redefined at a much lower fineness. The Tyrian tetradrachm, which had been issued on the old Attic standard, was now undervalued against the denarius; and instead of being debased, it was discontinued. The baser Antiochene tetradrachm, which had circulated in the North since the first century BC, was already on or close to the new standard, and it became the point of reference against which the Alexandrian tetradrachm would be measured. The Antiochene tetradrachm replaced the Tyrian, and the Alexandrian tetradrachm was now issued at a silver content equivalent to an Antiochene drachm. The silver content of the Antiochene tetradrachm was fairly close to the silver in four Neronian post-reform denarii, and the content of the Alexandrian tetradrachm was not far off the silver in one denarius. In this way a close relationship between the Roman, Syrian and Egyptian coinages was maintained. The new standards chosen were not arbitrary, but were intended to relate to one another, perhaps using a new, reduced Attic standard as the bench mark. Whether these sweeping debasements also helped alleviate Nero's alleged financial difficulties is not a subject we can pursue here. But it is clear that the argument which posits that provincial silver was generally much more debased than the denarius, and that overvaluation was used to keep Alexandrian silver in Egypt, cannot stand. The Neronian debasement at Rome in AD 64 brought the denarius into close equivalence with the Antiochene tetradrachm, and the fineness of the Alexandrian tetradrachm was adjusted accordingly. To write of the denarius being brought into equivalence might seem provocative, given that we are used to assuming that the denarius was the measure by which all other silver coinages in the Roman empire were judged, yet of the three standards discussed, Nero's denarius fineness was probably the last to be instituted, and at least one of the three (the Antiochene) had been established long before Nero.[56] The 80% fine silver standard chosen for Nero's post-reform denarii can also be found in other provincial silver coinage of the Julio-Claudian period, antedating his reform.[57] Whoever was responsible for defining the new denarius standard may have had the provincial silver coinage in mind when devising its weight and fineness.

We therefore propose that the Neronian debasements of the denarius and the Alexandrian tetradrachm were connected in a rational and logical way, and that none of the changes to the various silver coinages that took place during his reign were independent of one another. Whether or not one accepts the suggestion that the denarius was influenced by eastern silver standards, the claim that the Alexandrian tetradrachm of Nero was 'a purely token currency'[58] must be rejected. Something other than silver content must have prevented the export of the Egyptian silver coins. The most likely alternative is custom: that Alexandrian tetradrachms did

56 Our analyses of denarii suggest that Nero may have raised the silver content to 90% at the very end of his reign. Under these circumstances the Alexandrian tetradrachm would have been overvalued by about 27%; but the 90% standard was not maintained, and by Vespasian's reign it had returned to 80%. We have not yet analysed any provincial silver of the period AD 68-69 to see if there were any adjustments to their silver contents.

57 We will be publishing the results of these analyses elsewhere.

58 Walker, p. 140.

not normally circulate outside Egypt because they were not legal tender in other provinces. They are certainly recognisably different from other silver coinages.

To produce the Alexandrian tetradrachms necessitated the use of a particularly base alloy, with all the concomitant problems that entailed. It would seem that maintaining the traditional denomination was more important than trying to make the coinage appear to be of good silver (for which a finer alloy would have been necessary, meaning either a higher silver content or a smaller tetradrachm). But in recognising the poor quality of the alloy we cannot ignore its intrinsic value. We might then ask: if the poorest quality silver coinage of the Julio-Claudians was almost as 'intrinsically' valuable as the denarius, what of the other provincial silver coinages traditionally considered to be highly 'profitable' enterprises for the Roman state? Clearly, after the Neronian denarius reform the silver content of the Syrian tetradrachm was more or less equivalent to the content of four denarii. It would appear that other provincial silver coinages produced under the Julio-Claudians, such as the silver cistophori of Asia, were issued at 80% fine – the standard chosen for Nero's denarii.[59] Numismatists should perhaps prepare themselves to be relieved of the illusion that the monetary policies of the Julio-Claudians were based to any significant degree on massive overvaluation of provincial silver against the denarius, and the rich profits to be reaped from such ruthless manipulation.

Zusammenfassung

Neue Metallanalysen und metrologische Untersuchungen erlauben wichtige Einblicke in die Entwicklung der Tetradrachmenprägung in Syrien und Ägypten, mit weit reichenden Konsequenzen auf die Denarprägung in julisch-claudischer Zeit.

Die alexandrinischen Tetradrachmen wurden unter Tiberius zunächst mit dem Silbergehalt einer attischen Drachme oder einem Viertel der Tetradrachmen von Tyros ausgegeben, was ungefähr einem römischen Denar entspricht. Unter Nero wurde der Silbergehalt des Denars stark reduziert; andere Silberprägungen folgten, falls sie nicht bereits zuvor einen geringeren Feingehalt aufgewiesen hatten.

Die Silbermünzen von Tyros, die dem alten attischen Standard entsprachen, waren nun gegenüber dem Denar plötzlich stark unterbewertet. Statt sie nun ebenfalls mit einem geringeren Silberanteil auszuprägen, stellte man die Herstellung der Tetradrachmen von Tyros ganz ein.

Jene von Antiochia hingegen, die seit dem 1. Jahrhundert v. Chr. in Nordsyrien zirkulierten, enthielten seit je her weniger Silber als die Münzen von Tyros und entsprachen somit bereits einigermassen dem Standard, den Nero nun für die Denarprägung einführte. Die Antiochener Silbermünzen verdrängten folgerichtig jene aus Tyros und bildeten nun den Massstab, nach dem sich auch die alexandrinischen Münzen ausrichteten: Der Silbergehalt der Tetradrachmen von Alexandria entsprach mehr oder weniger einer Drachme (bzw. dem Viertel einer Tetra-

[59] See n. 57.

drachme) von Antiochia, und somit auch ungefähr dem Feingehalt eines Denars (nach der neronischen Reform). Auf diese Weise konnte die enge Beziehung zwischen der römischen, syrischen und ägyptischen Silberprägung auch nach der neronischen Reform beibehalten werden.

Ob diese komplexen und differenzierten Eingriffe in das monetäre Gefüge unterschiedlicher Gegenden auch die oft zitierten wirtschaftlichen Probleme Neros lösen konnten, sei dahingestellt. Aber die Untersuchungen belegen klar, dass die Silberprägung in den Provinzen keineswegs generell geringerhaltig war als der Denar. Die Vorstellung, dass die alexandrinischen Tetradrachmen stark überbewertet gewesen seien und nur aus diesem Grund ausschliesslich in Ägypten zirkulierten, trifft also nicht zu. Im Gegenteil: Offensichtlich wurde der Denar durch die neronische Verringerung des Feingehaltes im Jahre 64 der Drachme von Antiochia angepasst, und der Silbergehalt der alexandrinischen Tetradrachmen wurde entsprechend geändert. Die Vorstellung, dass der Denar einer nahöstlichen Münze angepasst wurde, mag überraschen, da der Denar üblicherweise als Massstab für alle gleichzeitigen Silbermünzen gilt. Doch die neronische Denarreform war wahrscheinlich die jüngste der angesprochenen Änderungen; der Standard der Tetradrachmen von Antiochia hatte jedenfalls bereits lange vor Nero existiert.

Insgesamt wird deutlich, dass die Feingehaltsverringerung des Denars und der alexandrinischen Tetradrachme unter Nero auf logische Weise verbunden sind. Auch alle anderen Veränderungen in den unterschiedlichen Silberprägungen in jenen Jahren geschahen nicht unabhängig, sondern es beginnt sich ein System von sorgfältig aufeinander abgestimmten Münzeinheiten mit klar definierten Silbergehalten abzuzeichnen. Dies widerspricht allerdings diametral der gängigen Idee, dass silberhaltige Provinzialprägungen generell überbewertet und somit eine für Rom höchst profitable Massnahme gewesen seien.

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sample	*emperor*	*arsenic*	*gold*	*copper*	*iron*	*nickel*	*lead*	*antimony*	*tin*	*zinc*	*cobalt*	*bismuth*	*silver*	*bullion*
LOD		0.03	0.002	0.01	0.0006	0.002	0.008	0.024	0.0135	0.004	0.001	0.006	0.01	
Alexandria														
A1	Tiberius	<0.03	.190	73.2	.005	.009	.107	<0.024	<0.014	.0052	<0.001	.050	26.4	26.7
A2	Tiberius	<0.03	.255	75.4	.006	.008	.096	<0.024	<0.014	.0094	<0.001	.051	24.1	24.5
A3	Tiberius	.177	.194	75.0	.006	.031	.142	<0.024	<0.014	.0127	.0035	.026	24.4	24.7
A4	Tiberius	.189	.189	73.7	.005	.033	.176	.063	<0.014	.0129	.0082	<0.006	25.6	26.0
A5	Tiberius	.185	.201	73.8	.002	.031	.118	.025	<0.014	<0.004	.0120	.041	25.6	25.9
A6	Tiberius	.103	.075	75.8	.011	.026	.168	<0.024	<0.014	<0.004	.0589	<0.006	23.7	23.9
A7	Tiberius	.085	.078	71.7	.003	.023	.211	<0.024	<0.014	<0.004	.0154	<0.006	27.9	28.2
A8	Tiberius	<0.03	.160	75.4	.008	.008	.226	<0.024	<0.014	<0.004	<0.001	<0.006	24.1	24.5
A9	Tiberius	<0.03	.166	74.1	.004	.007	.177	.028	<0.014	<0.004	<0.001	<0.006	25.5	25.8
BW4	Claudius	<0.03	.233	79.6	.004	.009	.095	<0.024	<0.014	.0062	<0.001	.028	20.0	20.3
BW9	Claudius	.029	.175	75.9	<0.0006	.005	.238	.031	<0.014	<0.004	<0.001	.014	23.6	24.0
BW11	Claudius	<0.03	.204	74.5	.003	.006	.080	<0.024	.002	.0057	<0.001	.021	25.2	25.5
BW16	Claudius	<0.03	.169	74.6	.005	.005	.254	<0.024	<0.014	<0.004	<0.001	.010	24.9	25.4
BW1	Claudius	.122	.005	71.5	.022	.066	20.164	.089	7.923	.0222	.0139	<0.006	0.1	20.3
BW7	Claudius	<0.03	.169	76.2	.003	.008	.367	.025	<0.014	<0.004	<0.001	.019	23.2	23.7
BW8	Claudius	<0.03	.184	79.3	.003	.011	.271	<0.024	<0.014	<0.004	<0.001	.015	20.2	20.7
BW12	Claudius	<0.03	.188	77.2	.001	.008	.264	<0.024	<0.014	<0.004	<0.001	.016	22.3	22.8
BW14	Claudius	<0.03	.167	74.9	.001	.006	.310	.016	<0.014	<0.004	<0.001	.018	24.6	25.1
BW2	Nero	.066	.083	82.6	.017	.029	.397	.031	<0.014	<0.004	.0051	.008	16.7	17.2
BW3	Nero	.066	.084	80.9	.008	.027	.391	.035	<0.014	<0.004	.0031	<0.006	18.5	18.9
BW5	Nero	.046	.094	82.6	.019	.030	.283	<0.024	<0.014	<0.004	.0044	<0.006	16.9	17.3
BW6	Nero	.071	.085	80.9	.012	.028	.443	.035	.038	<0.004	.0041	.006	18.3	18.9
BW10	Nero	.073	.083	80.7	.009	.028	.445	.035	.003	.0053	.0028	.012	18.6	19.1
BW13	Nero	.069	.084	82.3	.018	.030	.394	.037	.045	<0.004	.0057	.004	17.0	17.5
BW15	Nero	.083	.084	81.0	.009	.027	.397	.024	<0.014	<0.004	.0029	.010	18.4	18.9
BW17	Nero	.068	.084	80.6	.005	.029	.338	.022	<0.014	<0.004	.0012	.009	18.8	19.3
Tyre														
A39		.038	.797	2.96	.025	<0.002	.094	<0.024	<0.014	<0.004	.4024	.036	95.6	96.5
KB23		<0.03	.742	2.97	.006	<0.002	.265	.059	<0.014	<0.004	.3484	.047	95.5	96.6
A37		<0.03	.407	2.29	.002	<0.002	.586	<0.024	<0.014	<0.004	.0924	.027	96.6	97.6
KB22		<0.03	.838	3.11	.003	<0.002	.230	<0.024	<0.014	<0.004	.1093	.045	95.7	96.8
A35		<0.03	.417	2.91	.005	<0.002	.535	<0.024	<0.014	<0.004	.1080	.026	96.0	97.0
A36		<0.03	.790	2.81	.002	<0.002	.391	<0.024	<0.014	<0.004	<0.001	.040	96.0	97.2
KB24		<0.03	.486	2.00	.003	.545	<0.008	<0.024	<0.014	<0.004	<0.001	.019	96.9	97.4
A38		<0.03	.739	2.73	.008	<0.002	.394	<0.024	<0.014	<0.004	.2721	.034	95.8	97.0

Table 1. Chemical compositions of Alexandrian and Tyrian silver coins. The limits of detection of the instrument (LOD) are calculated as 30 (standard deviation of the mean blank determination). (< means a value of less than the stated figure).