Recycling and Roman silver coinage

Recycling can sometimes be the 'elephant-in-the-room' when it comes to discussions of ancient metalworking economies. It can make explanations of how economies function difficult and introduces awkward potentials for variation and uncertainty. It can also have important implications for the interpretation of analytical data. In their seminal paper discussing Bronze Age metallurgy in southern Britain, Needham et al (1989) state that the early bronze age has often been regarded as the exemplar of a 'non-recycling economy' primarily because of the lack of finds of scrap-metal in the archaeological record and the assumption of a lack of recycling strategies that this then engenders (Ibid: 383-4);

"Recycling economies, when efficient, are by their nature invisible in archaeological terms………." (Ibid).

The article then goes on to present analytical evidence to support the view that recycling was in fact 'a normal and rapid concomitant of early metal use……' (Ibid). But while it may be possible to at least argue that during the earliest phases of metal use, re-cycling was perhaps not necessary because rich, easily smeltable ores were so readily available and metal supplies limited and easily controlled, such a naive view cannot be applied to the Roman world. Indeed, one of the great advantages of non-ferrous metals over most other materials, with the exception of glass, is the fact that artefacts that are broken or otherwise no longer of use can be melted down and re-made into something else. For Roman coinage, this characteristic would have been particularly useful, enabling frequent changes of both emperor and coin type without the need for large amounts of freshly mined metal and incurring the associated costs of smelting. Furthermore, it also means that objects already made of metals of the correct composition can be converted into coin relatively easily. For these reasons alone, it would seem very likely that the Roman State practiced bullion recycling on a large scale.

In terms of the sources of silver bullion that could be used for coinage, if recycling is accepted as a possibility, there are three main categories:

1. Freshly refined silver bullion from mines. This could be extracted from ores from a single mine or the combination of metal extracted from ores from several mines within an administrative region.
2. Recycled silver bullion from seized bullion/coins/artefacts - Booty from campaign etc. that was immediately sent to the mint to be turned into coin.
3. Recycled silver bullion from stored resources. The holdings of the Imperial treasury that itself could comprise of freshly extracted silver or booty/legacy bullion or both.

Indeed, there are a number of references to the Roman State Treasury or *aerarium populi Romani* or *Saturni* in the literary sources, for example; Ammianus Marcellinus, '*Rerum Gestarum*'; Cicero, '*For Marcus Fonteius', 'On Agrarian Law' etc.* (See Corbier, 1974). The treasury was located in the Temple of Saturn, below the Capitol, and it is well documented in epigraphic and textual sources that large amounts of booty were acquired by Roman generals and Emperors to supplement the other sources of Imperial income from taxation and other payments (Duncan-Jones, 1994: 3-10). Pliny tells of the contents of the *aerarium populi Romani* at different times to illustrate the growing wealth of Rome, referring to both gold and silver in ingots (*laterum*) and in coin (*numerato*) (*HN* xxxiii. 17). Some booty would have been sent directly to the Treasury, some would have been distributed amongst the troops, some directly enriched the generals and Imperial family or paid for grandiose building projects, but sooner or later most of it ended-up in the Imperial melting-pot, was re-alloyed and re-appeared as coin. There is even some suggestion of bullion being exchanged for coin directly at the mint, thereby suggesting the possibility of free-minting in the Roman world. This quote from Cicero is clearly alluding to such a situation:

'I have written to Philotimus about furnishing me with money for the journey, either from the Mint — for no one pays ready money now—or from your comrades the Oppii.' (Cic. *Att*. 8.7.3, 23, February 49 BC).

According to Harl (1996: 78), Augustus turned spoils taken in Spain, Illyricum and Egypt into coin worth over 1 million denarii and that booty remained the readiest source of new metal under the Flavians. Under Trajan the Imperial treasury was expanded by the booty from his Dacian wars and latterly by his campaigns against the Parthians (Ibid: 79; Duncan-Jones 1994:13). There are even reports of specific instances of recycling such as when Otho came to support Galba against Nero in AD 68 bringing with him gold and silver drinking-cups and tables for recycling into coin (Howgego 1990: 6). All of which suggests that a considerable proportion of Roman silver (and gold) coinage was made from recycled metal.

In addition to 'new' metal coming into the system as booty from campaigns outside the Empire, old coin would also have been re-cycled into 'new-coin' (Howgego 1995; 24). It is assumed that this was mainly done when changes were made to the weight and/or silver bullion content of the coinage, although the need for bullion to produce any substantial issue may have been met simply through coin coming into the treasury through the usual routes of taxation, indemnities or gifts (Howgego 1992; 4). Recall and de-monetization of coinage is rare in the Principate, with the removal of old coin under Trajan being perhaps the best known. Hoard evidence shows us that old coin circulated for considerable periods of time (Butcher and Ponting 2014: 709-728) and that Republican denarii made up a large proportion of the circulating medium until the reign of Trajan, when there was a concerted effort to remove the older Republican coins, as reported by Dio Cassius:

'He also caused all the money that was badly worn to be melted down' (Epitome of book 68.15, 3 1)

It is also perhaps of no surprise that the re-called coins would have been mostly made of un-alloyed silver (although reliable compositional data for Republican silver is hard to find), whereas Trajan's new denarii were alloyed with around 20% copper (Butcher and Ponting 2015: 427). Thus, there was clearly a profit to be made from doing this that would more than cover the cost of the re-call, melting, alloying and striking of the new coins.

This event was accompanied by a rare issue of copies of some Republican denarii, referred to as 'restored' issues (Mattingly and Sydenham 1926: 302-311), perhaps to acknowledge the removal of ‘money that was badly worn’ and its replacement by new, shiny coins struck in a debased alloy that was carefully disguised to look like fine-silver, but that also had a legend pertaining to Trajan. In order to do this, of course, it would have been necessary to melt the older, finer coins down and also possibly refine the metal to remove any added copper (such as would be present in the legionary denarii of Mark Antony, for example) before alloying the silver with copper to obtain the required fineness.

Evidence does exist, however, that shows that not all recycled bullion was melted down before being turned into new coin. Figure 1 shows a section cut through a denarius of Domitian struck after AD 85 (RICII: 162, no. 71/II^2: 288, no. 342). This coin was clearly made from folded-over silver sheet of the correct fineness (the silver content is 93%) and other examples of coin blanks made from folded sheet are known from the reign of Trajan.

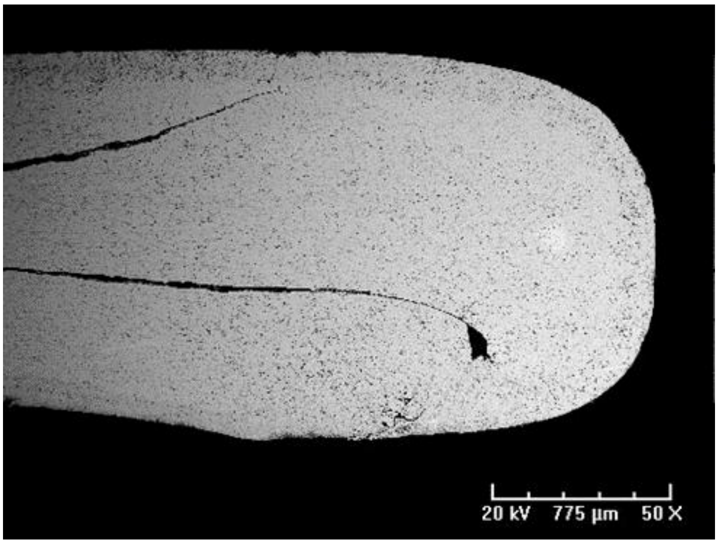

Figure 1. Scanning electron microscope image of a section from a Denarius of Domitian, issued after AD 85 (93% silver bullion). Flan produced from a single sheet of metal, folded over on itself and hammered.

So it appears that the Roman mint was able to screen bullion used for re-cycling to some extent, enabling metal of the right fineness to be turned into coin directly, thereby avoiding the expense of refining and re-alloying. This should come as no surprise since touchstones are known to have been used to assess the fineness of silver coin since at least the sixth century BC and with an accuracy of up to 2% in skilled hands (Wälchli 1981). Furthermore, what we know of the composition of Roman silver plate (and indeed silver plate from elsewhere) indicates that, like most Republican and Julio-Claudian denarii, it was usually made of fine silver (Hughes and Hall 1979; Lang and Hughes 2016). After Nero's reform, therefore, most re-cycling of earlier coin or plate would have had to involve melting and alloying with copper. This is clearly indicated by the microstructures observed in the coins when sectioned (Fig. 2). These show classic dendritic-eutectic structures that are diagnostic of casting and, incidentally, also indicate that these coins were not hot-struck, or at least not heated above the re-crystallisation temperature of the alloy, which is around 400 C depending on the exact composition (Butcher and Ponting 2014: 146).

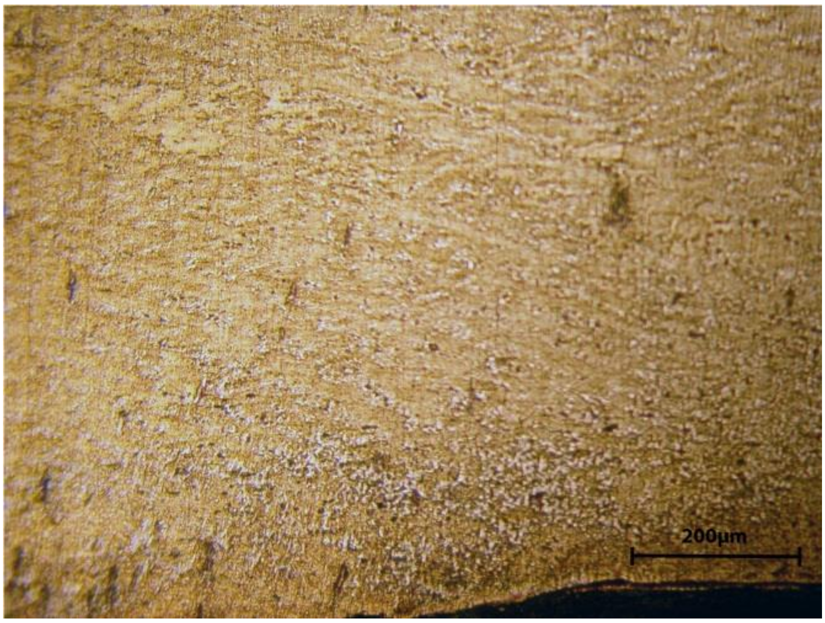

Figure 2. Photomicrograph of a section taken from a denarius of Otho (94% silver) showing deformed dendritic structure indicative of casting and cold-striking.

Much of the later recycled silver coin, however, and certainly that struck from Nero's reform onwards, must have been put through a complex two stage refining process to ensure the purity of the metal sent to the mint for alloying. To do this, the silver-alloy coin would have been melted with a large amount of lead in the process known as liquation. Archaeological evidence for the process is scarce for the Roman period, although Craddock reports liquation debris being found at Corinth in third century contexts and related specifically to the re-cycling of base-silver coins as well as reports of similar debris being found at Hengistbury Head in Dorset and Silchester in Hampshire (Craddock

1995: 232). The process of liquation would sequester the silver from the copper to form a lead-silver alloy and this would then be subjected to cupellation, the process by which pure silver is separated from lead by enhanced oxidation. This is essentially the same process that was used to extract silver from lead smelted from argentiferous lead ores such as galena (Ibid: 221).

The probable use of this sort of refining process will have implications for the analysis of these coins, especially the use of lead isotope measurements as the basis for provenance studies, since the isotopic signature of the refined silver will be that of the lead used in refining rather than the lead in the original ore. Nevertheless, to gain some understanding of Roman silver re-cycling we must turn to the coins themselves and the metal from which they were made.

The analyses of examples of the fine silver coinages of Julio-Claudians present a good overview of the chemical types of silver bullion that were circulating during the early Principate. The analyses are of samples drilled from the core of each coin and measured by inductively-coupled plasma atomic emission spectrometry (ICP-AES), they are published in Butcher and Ponting (2014). Figure 3 shows the gold and bismuth concentrations in the coins, scaled as if both these elements are solely associated with the silver. This is something that only becomes important once the silver is alloyed with copper to allow direct comparison between trace elements in un-alloyed silver with those in alloyed silver (see Butcher and Ponting 2014 for a discussion of the analytical methodology).

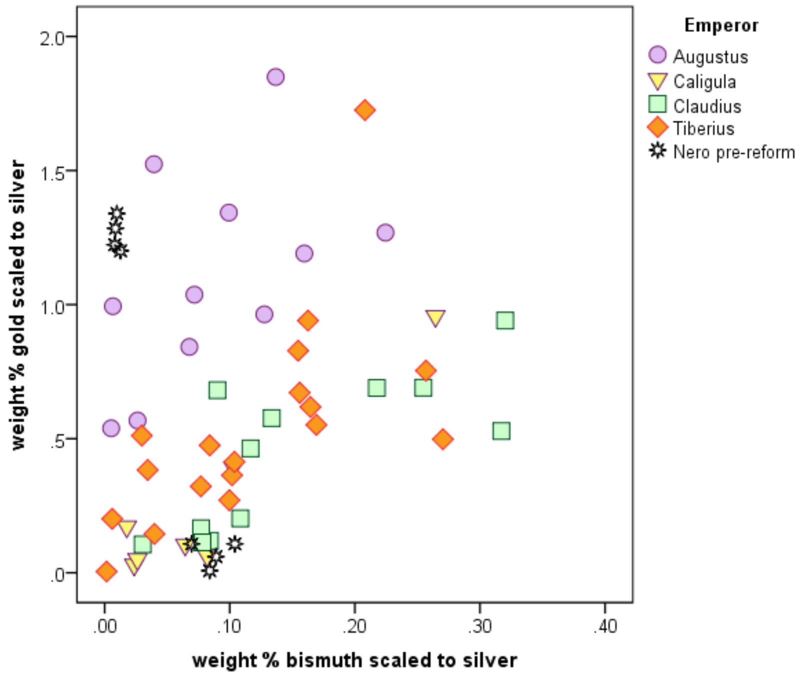

Figure 3. Plot of gold against bismuth for Julio-Claudian denarii. The two groups of Nero's pre-reform denarii are the oak-wreath type (>1% gold) and the figurative types.

Gold and bismuth are the two main trace elements found in silver ores that pass through the smelting and refining processes little changed, and so serve to characterise silver from different ore types (Craddock 1995: 212).

What the plot shows here is a continuum of composition, suggesting gradual change in the levels of gold and bismuth over the 50 years or so covered by the sample. The most likely explanation for these changing levels is that they represent gradual changes in the silver being used to make the coins and sometimes these can be linked to specific types of ore:

- Silver containing relatively high levels of gold with moderate to high levels of bismuth is characteristic of Augustan denarii; silver with these characteristics is typical of metal extracted from Southern Spanish sources (but not exclusively).
- This changes during the reign of Tiberius to silver containing lower levels of gold and higher levels of bismuth; this may suggest mixing of low gold and high gold metal. The higher bismuth levels are consistent with silver extracted from argentiferous galena ores such as those in the Massif Central region of France. Indeed, two denarii of Augustus that were

analysed have lead isotope ratios consistent with this (Butcher and Ponting 2014: 177) suggesting the use of Gallic bullion or possibly Gallic lead used to recycle older bullion.

- There is also a group of coins made of silver containing very little gold (<0.25%) and low levels of bismuth (<0.1%), metal that is quite distinct from the other two types and must be indicative of metal from a different ore type, possibly from the so-called 'dry-ores' or even native silver. Both of these possible sources would have been extremely rare by the first century (Craddock 1995: 212) and so the presence of this chemical signature may indicate the recycling of much older silver from booty or that had been stored in the treasury.

It is also significant that the two main pre-reform issues of Nero (denarii with Oak wreath and Figurative reverses respectively) form two very different and discrete compositional groups; one high-gold and low bismuth (oak wreath), the other low gold and moderate bismuth (figurative). It seems likely that these represent two issues struck from fresh metal from two different sources (Butcher and Ponting 2014; 196-198).

After this period, however, the picture gets increasingly complicated. Figure 4 shows examples of denarii struck as part of Nero's reformed coinage and how the majority of these cluster mid-way between the high and low gold types of the earlier issues and look as if they could be made from a mixture of the silver containing high levels of gold and moderate levels of bismuth mixed with the silver containing low levels of gold.

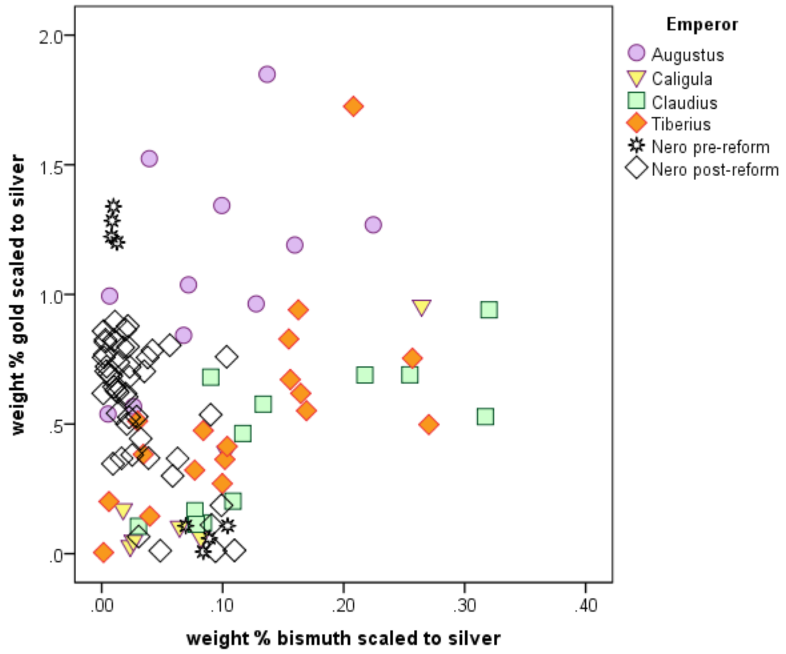

Figure 4. Plot of gold and bismuth values for Julio-Claudian denarii including denarii issued after the reform of Nero in AD 63/4.

Lead isotope ratios were measured from only four post-reform denarii of Nero, however, the results are reasonably consistent with the lead isotope measurements of galena ores from France. As can be seen in Figure 5, it is not a perfect fit with the Gallic field (calculated at 95% confidence), but it is a better fit than any of the other potential sources, clustering around 2.09 208/206 Pb and 0.85 207/206 Pb (Figure 5). Their location on the plot, however, is also mid-way between the two main Spanish fields, perhaps suggesting a mix of predominantly Spanish metal, and the orientation of the group is more consistent with that of the Spanish fields than the French. A mixed Spanish origin rather than a French origin would of course be consistent with the gold and bismuth data already mentioned.

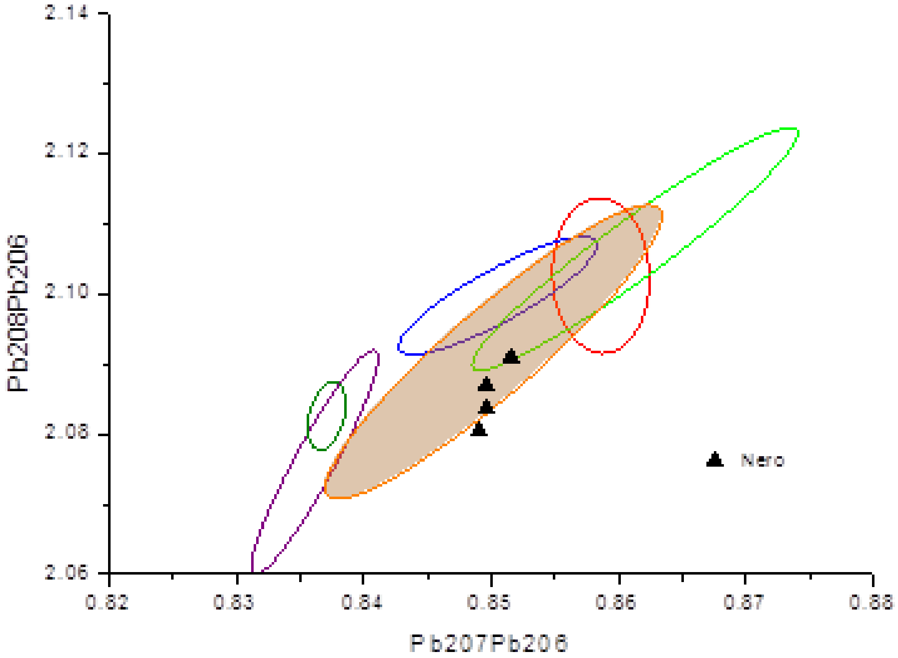

Figure 5. Lead isotope fields for Rio Tinto (red), Sierra Demanda (blue), Cartagena ingots (dark green), Cartagena/Almagrera/Cabo de Gata (purple), Southern Sardinia (light green) and the Massif Central region of France (orange) with the isotope signatures of the four post-reform denarii of Nero analysed.

The spread of lead isotope data for a sample of Republican silver denarii (Fig. 6) shows how this might work if coins from different issues made of Spanish and Sardinian silver were recalled and recycled together. The range of isotopic compositions produced by mixing metal from these sources can be seen along the mixing-line; the differing proportions and effects of small amounts of silver from other sources accounting for the scattering that is apparent. The off-set of the earlier issues from the Cartagena ellipse (less than 2.08 208/206 Pb and around 0.835 207/206 Pb) probably indicates the use of silver from the Aegean region, although the ellipse for this region has not been included.

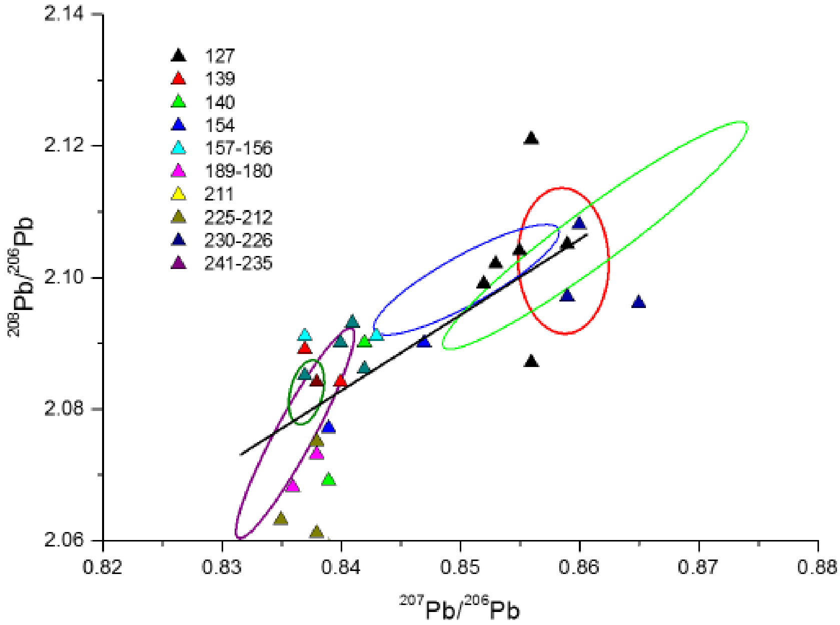

Figure 6. Lead isotope fields for Rio Tinto (red), Sierra Demanda (blue), Cartagena ingots (dark green), Cartagena/Almagrera/Cabo de Gata (purple), Southern Sardinia (light green) with examples of Republican denarii. The dates are years BC. (data from Holstein et al 2000).

The plot in Figure 7 shows the gold and bismuth compositions of a sample of Roman silver denarii issued during the Civil War of AD 68/69. The similarity with the plot of the same elements in Julio-Claudian denarii is very apparent but the plot is now diagnostic of the products of different mints. Here the silver bullion used by the mint in Rome has gold values of around 0.75% and bismuth at less than 0.05%, whereas the denarii struck in Gaul and Hispania generally have less gold and more bismuth, suggesting continued use of the same resources in Gaul and Hispania for some Civil War issues, but also a growing reliance on re-cycled bullion first identified during Nero's reform.

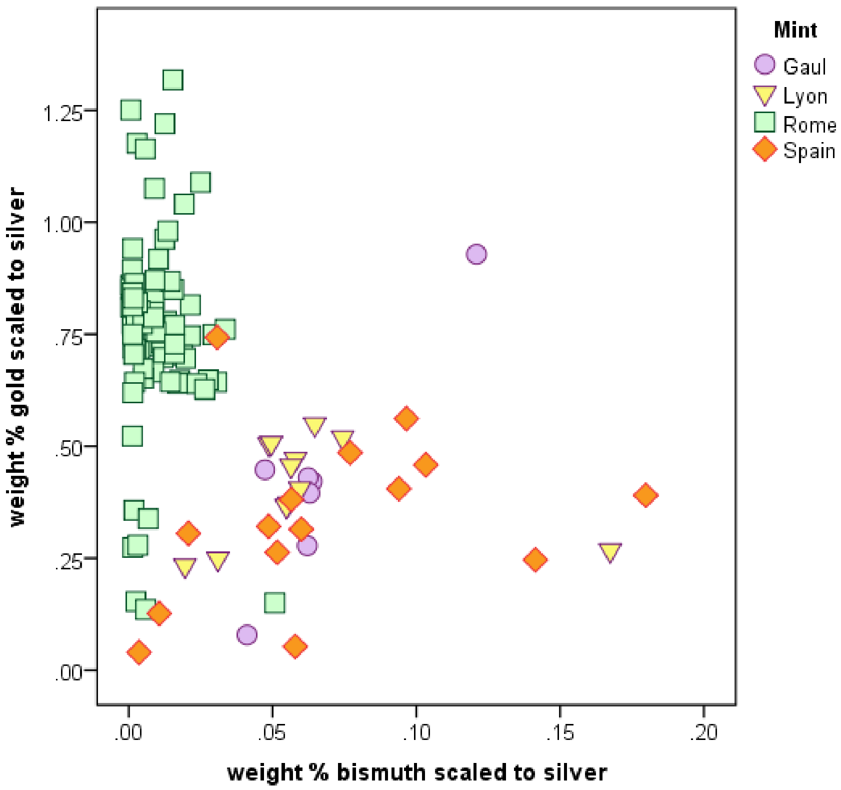

Figure 7. Plot of gold and bismuth values for examples of the denarii of the Civil War (from Butcher and Ponting 2014).

Under the Flavians (Fig. 8) a second compositional group appears, characterised by lower gold and higher bismuth (gold/bismuth values of 0.75/<0.05 and 0.5/0.08 respectively) this second compositional group continues into the reign of Nerva and Trajan's early issues (0.5/>0.1). Gradually the gold levels drop and the levels of bismuth rise, suggesting dilution of the old high gold/moderate bismuth metal over a period of less than 50 years with new metal; the dilution of re-cycled metal of predominantly Spanish origin with metal from new sources lower in gold and higher in bismuth.

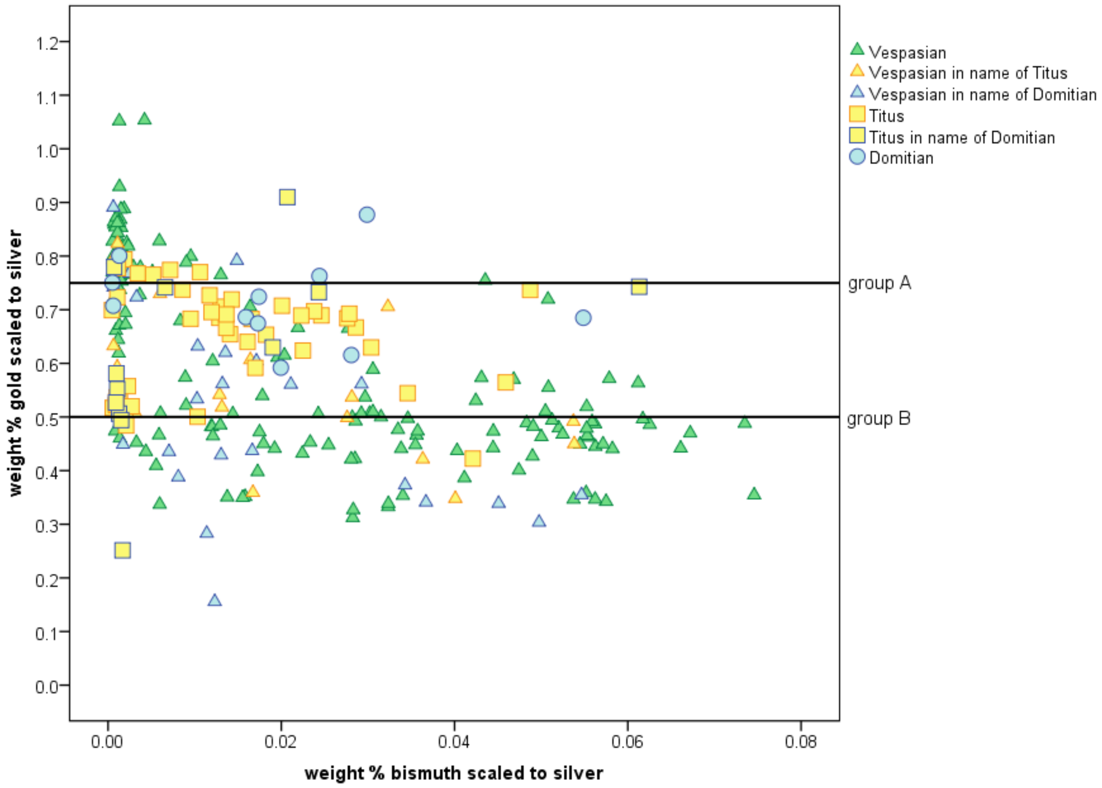

Figure 8. Plot of gold and bismuth values for examples of the denarii of the Flavian dynasty (from Butcher and Ponting 2014).

The lead isotopes, however, appear to tell a different story. Returning to the Civil War period (Figure. 7) the coins struck in Rome exhibit what has been interpreted as a 'mixed' metal compositional profile, whereas those coins stylistically attributed to mints in Hispania and in Gaul (either specifically Lugdunum-Lyon or more generally within the province of Gaul) are clearly chemically different from those struck in Rome, generally containing less gold and more bismuth. The lead isotope analyses of a sub-set of the same coins, however, only succeeds in separating a small proportion of the coins from a generally homogenous group that clusters around 2.09 208 /206 Pb and 0.85 207/206 Pb (Figs. 9 and 10). Closer inspection, however, shows that the small group of denarii with different lead isotope ratios are also those Civil War denarii known to have been struck in Hispania. Furthermore, the lead isotopes allow the metal from which these denarii were made to be attributed to ore fields in Northern Spain and in the Rio Tinto region (Fig. 10). Most of the coins struck in both Rome and the Western mints (those in Hispania and Gaul) and that the gold and bismuth levels separate into different groups are all found to have virtually identical lead isotope signatures. In other words, lead isotope ratios cannot be used to distinguish between the coins struck in the mint of Rome and those struck at mints in Gaul and some of those attributed to mints in Hispania, whereas differences in the levels of gold and bismuth clearly do.

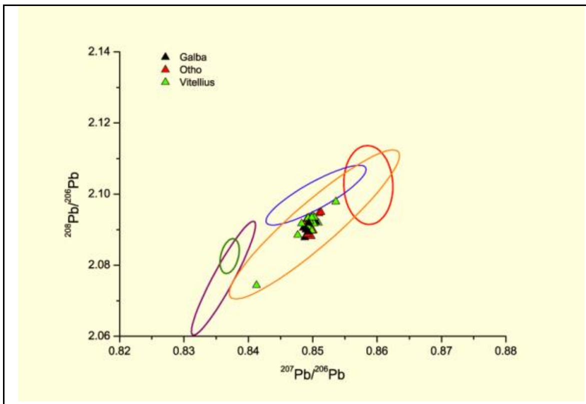

Figure 9. Lead isotope plot of denarii struck in Rome.

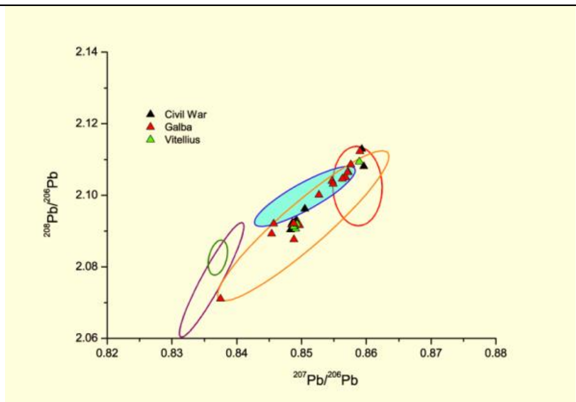

Figure 10. Lead isotope plot of Civil War denarii struck in Western mints.

This group of homogenous lead isotope metal is a good example of re-cycled silver bullion that has been refined through the addition of lead from a different source to that from which the silver was originally extracted. Both Rome and the Gallic mints (Lugdunum or wherever) were relying on re-cycled bullion, whereas many of the issues struck in Hispania (at a mint generally accepted as being the city of Tarraco, modern Tarragona in Northern Spain, close to one of the mining areas identified) appear to be using freshly produced Spanish silver. Refining would of course have been necessary when refining Nero's reformed denarii, which were struck on 80% and 90% silver bullion standards.

Support for the idea of recycled and refined silver having the lead isotope signature of the lead metal added during refining is found in the published lead isotope values for lead water pipe from Pompeii (Boni et al. 2000). Here the lead isotope ratios of Pompeian lead water pipes are very similar to those of the majority of the Civil War denarii analysed here and are explained as being the result of the mixing and re-cycling of lead.

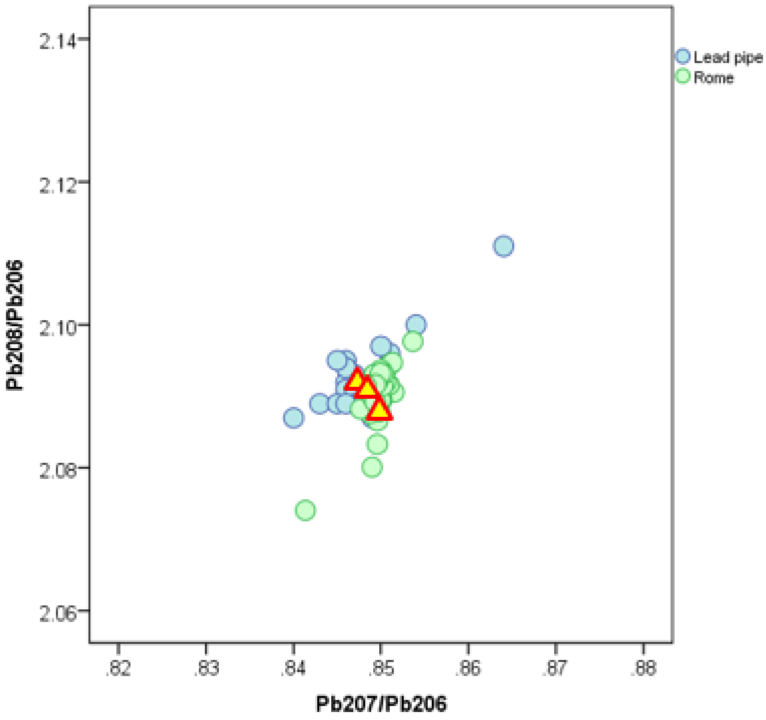

Figure 11. Lead isotope plot showing ratios for lead pipe from Pompeii and Civil War denarii struck in Rome, with three analyses of radiates of Gordian III, also struck in Rome – yellow triangles (Pompeii data from Boni et al. 2000).

Indeed, identical lead isotope signatures are found for Roman silver coins from the mid-third century (radiates of Gordian III) (Fig. 11), suggesting that recycling and refining became the normal way of obtaining silver bullion for coinage for the Roman State.

Where lead isotopes may retain their usefulness in the provenancing of silver-alloys is where coin or bullion from a single identifiable source is recycled without refining. This seems to be the case with some issues where the isotopic characteristics of Spanish and/or Sardinian silver appear out of nowhere in metal with trace elements that differ from the recycled norm, suggesting some mixing sufficient to change the trace element concentrations, but not involving the addition of lead, thereby retaining a diagnostic lead isotope signature. Alternatively, a completely new isotopic signature can appear alongside completely new trace element concentrations indicating a completely new source, be that fresh or recycled.

The former is what appears to happen around the time of Trajan's reform, with a Sardinian signature appearing accompanied by a significant change in gold and bismuth concentrations that also rule out Hispanic or Gallic sources that might otherwise be easier alternatives to Sardinia.

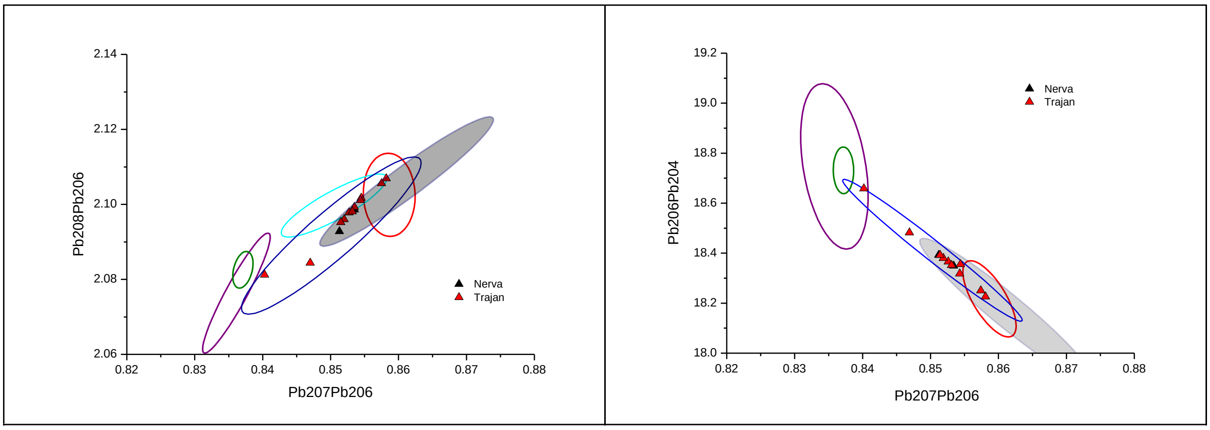

Figure 12. Lead isotope fields for Rio Tinto (red), Sierra Demanda (light blue), Cartagena ingots (dark green), Cartagena/Almagrera/Cabo de Gata (purple), Sardinia (grey fill) and Massif Central (blue) with denarii of Nerva and Trajan.

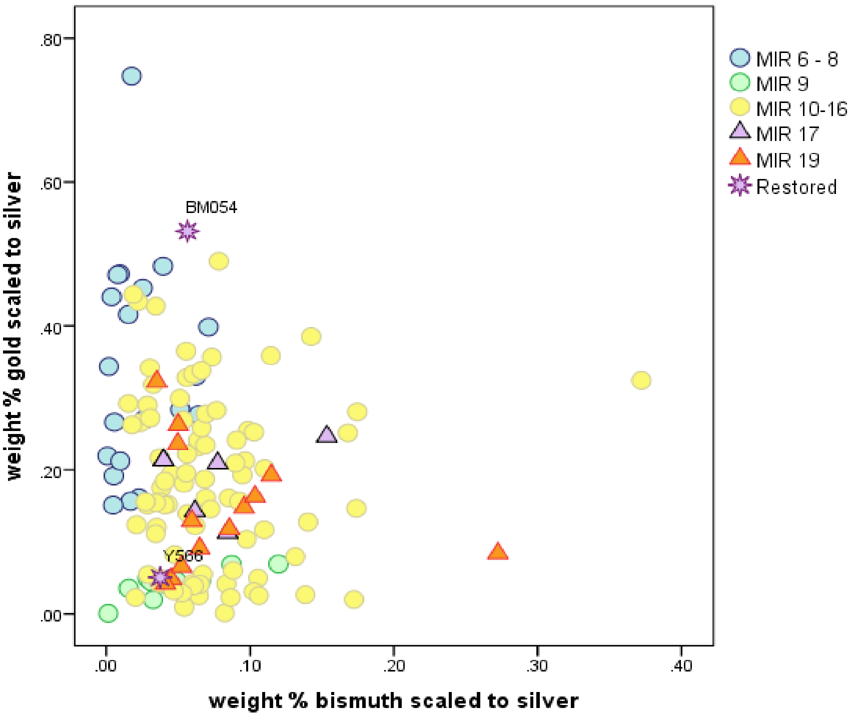

Figure 13. Plot of gold and bismuth values for Trajan's denarii. The MIR numbers refer to the different issues of Trajan's post-reform coinage.

The problem with Sardinia as a silver source in the early second century has been that most scholars believe that Sardinia's silver resources had been largely worked-out by the first century BC (Healy 1978; 56), although more recent work now presents evidence for at least the mining of lead in the reign of Hadrian (Hanel and Morstadt 2014: 221). Regardless of whether silver was being extracted from Sardinian sources in the early second century or not, this does not rule-out the possibility of coins made of Sardinian metal from an earlier date being recycled as part of Trajan's major reform. Indeed, the recycling of older coin as part of Trajan's reform has already been mentioned as one of the few occasions where there is documentary evidence for the calling-in and recycling of old coinage.

The two restored denarii of Trajan that have been analysed (Butcher and Ponting, forthcoming) have gold and bismuth levels consistent with re-cycled metal; one with high gold suggestive of Spanish sources (BM054) and the other (Y566) falling in the low gold, low bismuth region that first appears in the denarii of Caligula and Claudius, fifty years earlier and then again under Domitian (Butcher and Ponting 2014: 405).

The documentary sources say that Trajan's reform involved the 'melting down' of old coins. This is significant since the gold and bismuth values of Trajan's denarii determined by analysis show a distinct change from the purely 'mixed' signature observed in denarii from immediately after Nero's reform and through the Flavian period (which Harl reports relied heavily on re-cycled metal) to a silver composition that has significantly lower levels of gold and higher levels of bismuth. This latter signature is generally thought to indicate a shift to the use of silver bullion originally extracted from galena ores. The chemical analysis therefore shows two things; that the metal used for the bulk of Trajan's reformed coinage is different to that used for the coinages of the previous century and, secondly that the admittedly tenuous evidence of only two of the restored issues suggests that these could well have been made from directly recycled silver.

If it is accepted that this recycling simply involved the re-melting and alloying of earlier fine silver coins that did not require re-refining with the attendant addition of re-cycled lead, then lead isotope measurements of the coins may be able to supply further information.

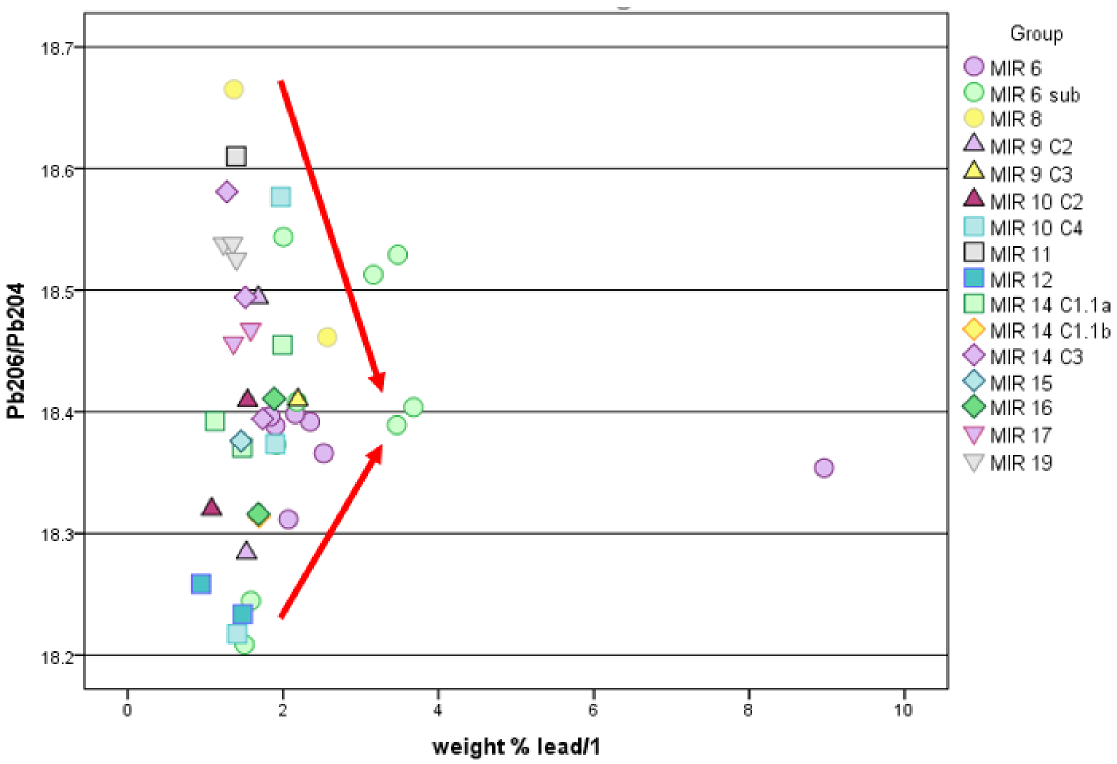

Figure 13. Plot of 206 Pb/204 Pb against lead concentration for Trajan's denarii.

The approach used for the investigation of lead isotope data from copper-alloys devised by Pollard and Bray (2014) suggests a different and potentially useful way of looking at lead isotope data from non-ferrous metals but relies on the lead abundancies to be quite variable. Plotting the lead abundances against the lead isotope ratios for the sample of Trajan's denarii (Fig. 13) shows a possible peak at 18.4, using the 206/204 Pb ratio as representative of all the ratios measured, with end-members at about 18.2 and 18.7 respectively, suggesting that the main contributors to Trajan's denarii would have had ratios close to these values. Unfortunately, the range of lead levels is rather limited, making the interpretation based on this method at best tentative. If, however, the kernel density estimates (KDE) are calculated for the lead isotope data for those regions that can be reasonably expected to be potential ore sources for Trajan's denarii on the basis of trace element data and archaeological research, the tentative end members in figure 13 correspond to the KDE peaks for Sardinian galena sources at 18.2 and Romanian galena sources at 18.7, with the peak for Trajan's denarii directly in-between them at 18.4. It should also be noted that important Bulgarian and Serbian sources may also contribute to the higher end members, but better data are yet needed.

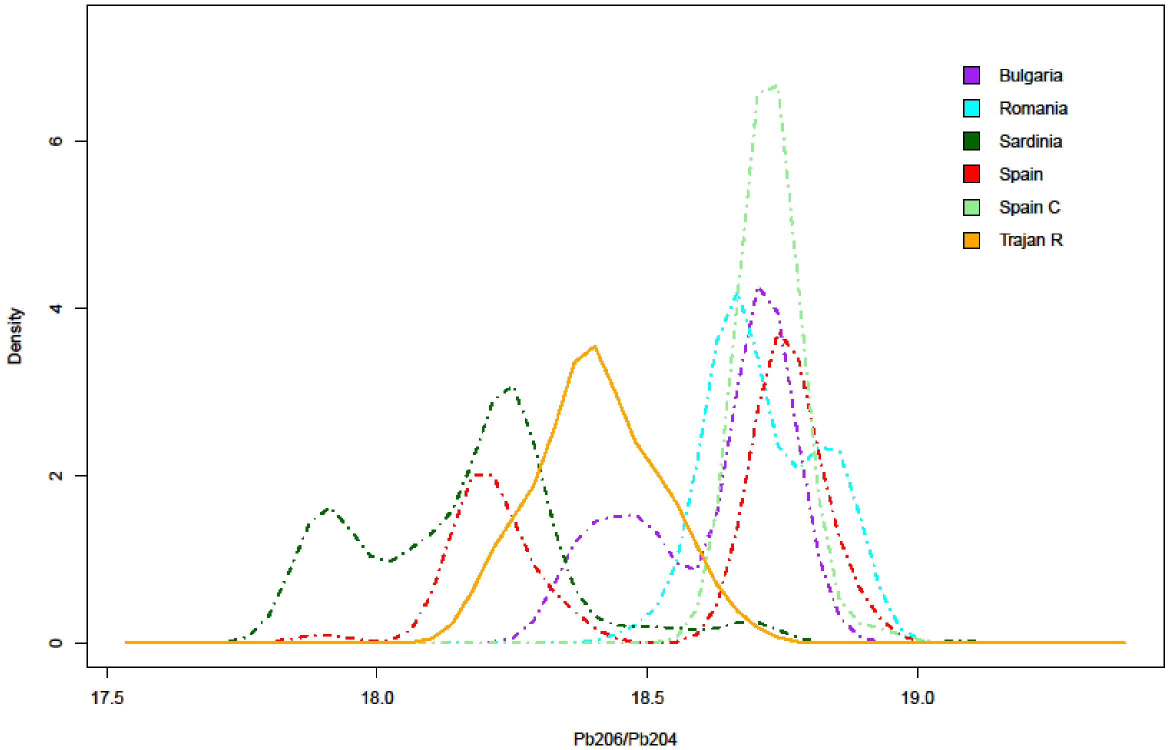

Figure 14. Kernel density plot of 206 Pb/204 Pb for Trajan's denarii compared with reference sets for selected ore deposits.

These same peaks can be seen in this pair of conventional lead isotope plots (Figs. 15 and 16) where KD contours have been added to the four lead isotope data sets. Sardinian sources peak at 18.2 and Romanian at 18.7, almost in the same location as the Bulgarian sources, but some separation is seen in the other plot, underlying the importance of taking all data into consideration.

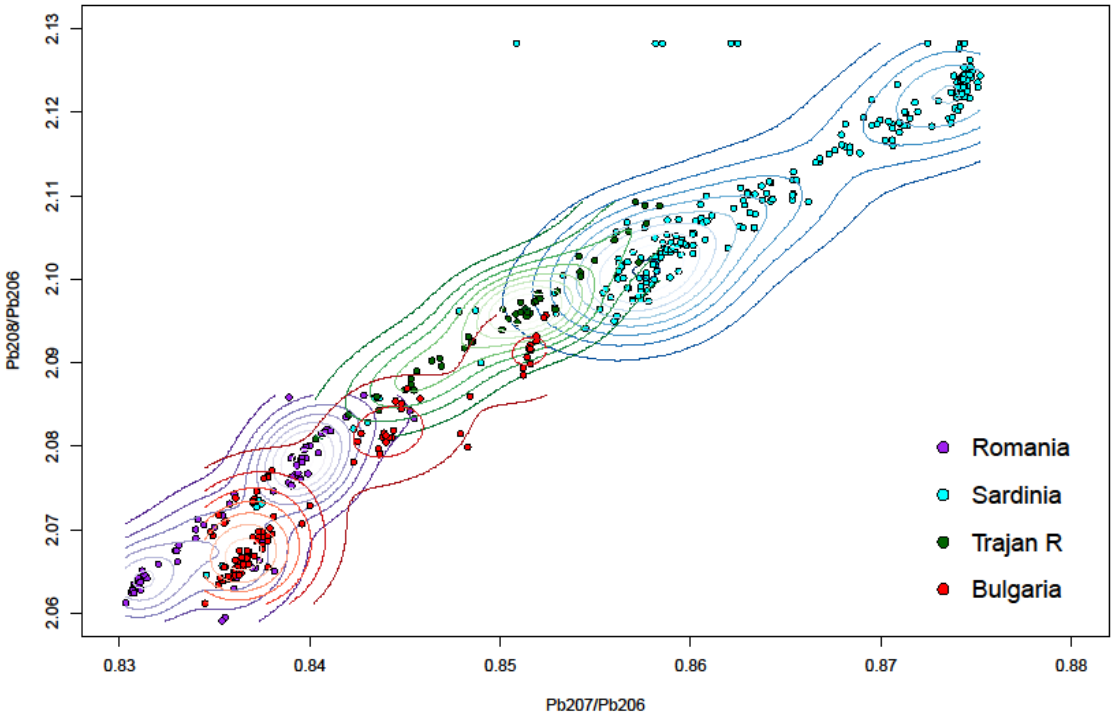

Figure. 15. 207Pb/206Pb v 208Pb/206Pb plot of Trajan's reformed denarii and sources in Romania, Sardinia and Bulgaria.

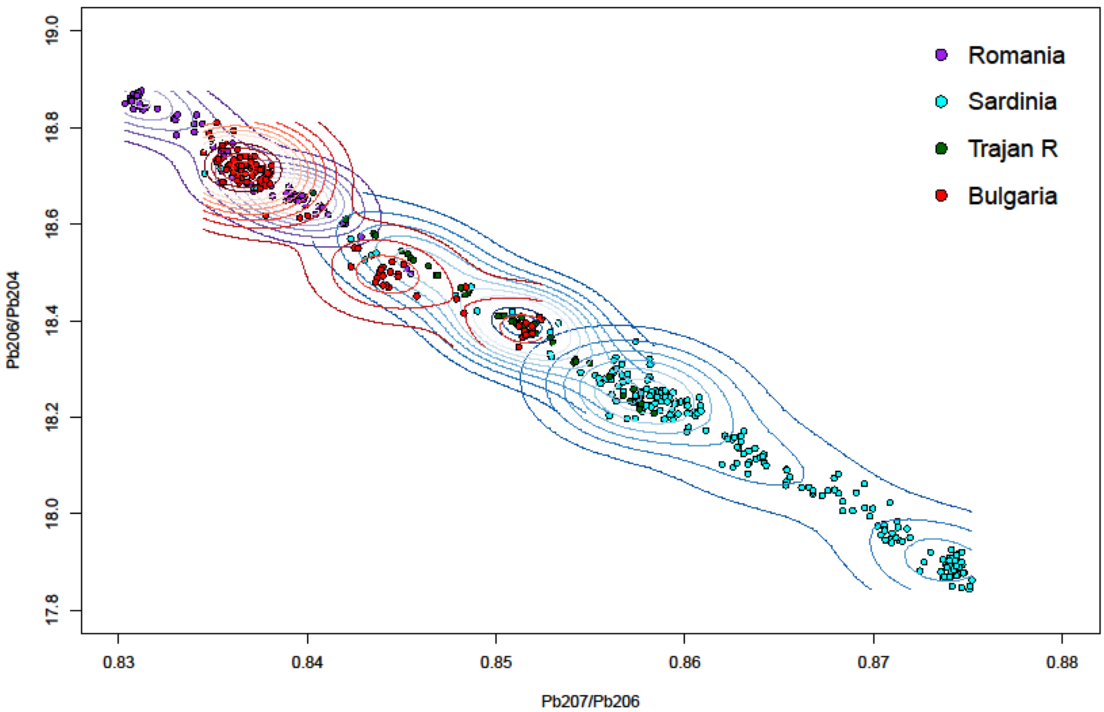

Figure. 16. 207Pb/206Pb v 206Pb/204Pb plot of Trajan's reformed denarii and sources in Romania, Sardinia and Bulgaria.

This is still a 'work in progress' and the author must thank Jane Evans, Peter Bray, Fred Hirt and other colleagues for helping to make what is hopefully a sensible use of the lead isotope data. On balance the evidence of both trace elements and lead isotopes suggests that Trajan's reform combined the primary re-cycling of older coin with an influx of new metal (as either booty or freshly produced bullion, or both). The sources identified sees Sardinia and not Spain as the main region of origin for the recycled silver that was mixed with metal from deposits in regions that are now within Romania and Bulgaria. This metal could be primary re-cycled booty or fresh metal, but it is definitely mixed and not from a single source. Such a model is consistent with the historical and numismatic data, but will no doubt be refined and adjusted as more data become available.

Re-cycling was clearly an important part of Roman silver coinage production with the sources from which this came constantly changing over time. Both trace element and lead isotope data present a complex picture of mixing, recycling, refining and episodic use of stored resources that are occasionally supported by references in historical documents and stylistic features of the coins themselves. But there is much more work to be done to construct new and better models and refine existing ones.

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