Geochemical Perspectives Letters

A glimpse into the Roman finances of the Second Punic War through silver isotopes

F. Albarède[1,2]*, J. Blichert-Toft[1,2], M. Rivoal[1], P. Telouk[1]

Abstract

doi: 10.7185/geochemlet.1613

The defeat of Hannibal's armies at the culmination of the Second Punic War (218 BC–201 BC) was a defining moment in Western world history. One of the underappreciated consequences of the conflict was the Roman monetary reform of 211 BC, which ushered in a monetary system that would sustain Roman power for the next many centuries. This system would encapsulate many of the issues plaguing finances of governments until today, such as inflation, debasement, and the size of monetary mass. Here we approach the issue of financial fluxes using a newly developed powerful tracer, that of silver isotopic compositions, in conjunction with Pb isotopes, both of which we measured in Roman coinage minted before and after the 211 BC monetary reform. The results indicate that pre-reform silver was minted from Spanish metal supplied by Carthage as war penalty after the First Punic War, whereas post-reform silver was isotopically distinct and dominated by plunder, most likely from Syracuse and Capua. The 211 BC monetary reform and the end of debasement, therefore, were aimed at accommodating new sources of silver rather than being the response to financial duress. The drastic weight reduction of silver coins implemented by the Roman mint was not motivated by metal shortage but by the need to block inflation after a major surge of war booty.

Received 17 February 2016 | Accepted 30 March 2016 | Published 15 April 2016

Introduction

The three Punic Wars (264 BC–146 BC) between Rome and Carthage were a turning point in the history of the antique Mediterranean world and, more than any other conflict, the Second Punic War (218 BC–201 BC) appears to have been a defining time in Roman history. An understated consequence of Hannibal's war was the establishment of the denarius, the longest enduring monetary unit in the history of the western world. Carthage was a colony founded next to modern Tunis in the 8th century BC by Phoenician merchants. During the 3rd century BC its empire expanded westward into southern Spain and Sardinia, two major silver producers of the West Mediterranean. Meanwhile, Rome's grip had tightened over the central and southern Italian peninsula. The Punic Wars marked the beginning of Rome's imperial expansion and ended the time of Carthage. The First Punic War (264 BC–241 BC), conducted by a network of alliances in Sicily, ended up with Rome prevailing over Carthage. A consequence of this conflict was the Mercenary War (240 BC–237 BC) between Carthage and its unpaid mercenaries, which Rome helped to quell, again at great cost to Carthage. Hostilities between the two cities resumed in 219 BC when Hannibal seized the Spanish city of Saguntum, a Roman ally. At the outbreak of the Second Punic War, Hannibal crossed the Alps into the Po plain and inflicted devastating military defeats on the Roman legions in a quick sequence of major battles, the Trebia (December 218 BC), Lake Trasimene (June 217 BC), and Cannae (August 216 BC). As a measure of the extent of the disaster, it was claimed that more than 100,000 Roman soldiers and Italian allies lost their lives in these three battles, including three consuls. A modern account of the Punic Wars with references to original Greek and Latin literature can be found in Hoyos (2011).

In addition to the military setbacks, the most crucial collateral damage inflicted by Hannibal's invasion of Italy was the collapse of Rome's young monetary system (Frank, 1933; Crawford, 1974; Marchetti, 1978; Kay, 2014). At the outbreak of the Second Punic War with the sack of Saguntum (219 BC), the Carthaginians had paid off to Rome the war indemnities of the First Punic War (264 BC–241 BC) and the Mercenary War (240 BC–237 BC). Their hands, therefore, were largely free to use whatever remaining monetary resources they had. According to Strabo (*Geography* 3.2.10) quoting Polybius, ore deposits in the Neogene Betic (Bætic) Cordilleras in the region of Carthago Nova produced 35 tons of silver each year (Kay, 2014). In contrast to Rome, which armed its own citizens and those from allied cities, Carthage military forces relied heavily on large numbers of mercenary Numidian cavalry and foot soldiers from Gaul, which, in addition to plunder expectations, were paid in Spanish silver. Both in Rome and confederate cities, the *aerarium* (treasury) was in need of funds, silver in particular, large enough to provide for the *stipendium* (pay) and supplies of Roman legions and *socii* (Latin allies). The legionary received a compensation of two obols (c. 1.2 grams) of silver per day, a centurion twice as much, and a cavalryman a drachma (Polybius *Histories* 6.39.12). A legion with a nominal strength of about 4,500 men, therefore, would cost well over 2 tons of silver a year. Of course, a large fraction of this silver would eventually return to the *aerarium* through taxes and donations. Assuming that hoarding and loss concerned only a small fraction of the total mass of available silver and that most worn out coins were recycled, the rest of the silver would be lost to commerce, which would quickly deplete Roman monetary supply.

The Roman monetary system was based on bronze, for which the demand in wartime was competing with the needs for weaponry (Harl, 1996). Bronze

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1. École Normale Supérieure de Lyon and CNRS, 69007 Lyon, France
* Corresponding author (email: falbarede@gmail.com; albarede@ens-lyon.fr)
2. Earth Science Department, Rice University, Houston, TX 77025, USA

therefore was made convertible to silver, which, however, was also in short supply (Crawford, 1974). The strain on the Roman treasury hence was extreme. Private hoards peaked (Crawford, 1969). The loan contracted in 216 BC with Hieron II, tyrant of Syracuse, (Livy *History of Rome* 23.21.7) was not repaid (Livy 23.38.12). After an ephemeral and ill-fated attempt at debasing silver in 213 BC, a completely new system was inaugurated in 211 BC or shortly before (Crawford, 1964; Marchetti, 1971; Crawford, 1974; Woytek, 2012; Fig. 1). Silver fineness (>92 %) was restored from the pre-211 BC *quadrigatus* (6.7 g) to the post-211 BC *denarius* (4.3 to 3.6 g), a monetary unit that would persist for centuries. The exception was the smaller and noticeably debased *victoriatus* (Walker, 1980), which was used largely to pay the *socii* and for circulation in Italy outside Rome (Marchetti, 1978), notably in the Cisalpine and Transalpine Gauls (Crawford, 1974). Associated with the new denarius coinage in 211 BC was a reduction of the weight of the bronze asses from three to two ounces (1 ounce = 1/12 of a 324 g Roman pound; Crawford, 1974). The question being addressed here with Ag and Pb isotopes is whether the 211 BC monetary reform was motivated by a simple need for devaluation upon silver shortage, or whether it consisted in readjustment responding to a necessity of managing new silver resources.

Quadrigatus Cr 29/3

Denarius Cr 60/1

Figure 1 The pre-reform (pre-211 BC) *quadrigatus* (**top**) vs. the post-reform *denarius* (**bottom**). 'Cr' refers to Crawford's nomenclature (Crawford, 1974).

The standard silver purification process is known as cupellation and requires the use of lead. Lead isotopes therefore are expected to provide indirect evidence of the provenance of both metals. Lead isotopes have a long history as a provenance marker in archaeology (Stos-Gale and Gale, 2009). The perspective it offers can, however, be made more instructive with the use of geochemically informed parameters, such as Pb model ages, μ (U/Pb), and κ (Th/U), which are characteristic of the geological history of the crustal segments from which the lead and silver ores derive (Desaulty *et al.*, 2011; Albarède *et al.*, 2012; Desaulty and Albarède, 2013). A downside is that Pb used for cupellation may not share the same geographic origin as its hosting silver (Pernicka, 1995; Budd *et al.*, 1996; Pollard, 2008). A clear advantage of silver isotopes is that they carry an intrinsic and clean signal of metal provenance. Even if they do not convey the same wealth of geological and geographic information as lead isotopes, they are largely free of assumptions about how Pb and Ag are related. Beyond the time-consuming, labour-intensive chemical separation of Ag and Pb and their isotopic analysis by mass spectrometry, they both constitute novel tracers that track the provenance of different stocks of core metal used for minting. Our exploratory work (Desaulty *et al.*, 2011; Desaulty and Albarède, 2013) demonstrated the strong potential of silver isotopes to determine whether coins from different mints may or may not share common metal sources. In the present work, silver isotope compositions were measured for 26 coins dating mostly from the Second Punic War and its aftermath in order to assess whether the 211 BC Roman monetary reform coincided with changes in silver sources. We complemented the silver isotopes with those of lead in the same coins in an attempt to identify the source(s) of lead used for silver purification.

Material and Methods

The silver coins analysed in this study were purchased from professional dealers. The die identifications provided by the sellers (Table 1) were carefully checked and verified against Crawford's (Crawford, 1974) original nomenclature and photographs.

We devised a new minimally-destructive analytical procedure. Each coin was individually cleaned and then leached in fresh solutions of Suprapur methanol-hydrogen peroxide-ammonia (MHPA), prepared in the proportions of 4:1:1, by keeping the coin submerged in the MHPA solution in an ultrasonic bath until bubbles started to form, then removing it after a few seconds of bubbling. This step served to remove a thin surface layer prone to Pb contamination and, hence, the solution was discarded. The same procedure was repeated with a new batch of 4:1:1 MHPA solution, but this time lasting for 45 seconds of bubbling, long enough to guarantee that sufficient Pb would be available for isotopic analysis. This batch of solution was kept for Ag and Pb separation chemistry. After the MHPA leaching, the coin was rinsed in distilled water and stored away. Upon later polishing of the coins, no trace of their having been leached for Ag and Pb extraction was visible. This technique therefore holds potential for analysis of rare exhibit-quality coins in the future. The recovered leachate was dried down and the residue dissolved in concentrated distilled nitric acid and evaporated to dryness overnight. The next steps were largely identical to the procedure described for Ag separation and isotopic analysis by Desaulty *et al.* (2011). Briefly, after dissolution of the sample in 15 ml distilled water, the solution was heated for 20 minutes at 95 °C followed by addition of 7 ml 0.15 M Suprapur ascorbic acid to precipitate pure silver. The solid silver precipitate was centrifuged out and the supernatant saved for Pb separation. The Ag metal was dissolved in concentrated distilled nitric acid and dried down overnight to obtain pure silver nitrate. The silver yield of this procedure is >99.8 %. A 5 % aliquot was dedicated to elementary concentration analysis on a Thermo Scientific iCAP 7200 ICP-OES.

Silver isotopic compositions were measured on a Nu Plasma 500 HR MC-ICP-MS. Silver was dissolved in 0.05 M distilled nitric acid immediately prior to isotopic analysis to make a 400 ng ml^{-1} solution. Mass fractionation was controlled with an external standard of chlorine-free Alfar-Aesar palladium in HNO_3 media. Standard-sample bracketing was done using an Alfa-Aesar 1,000 μg/ml^{-1} solution cross-calibrated against NIST SRM 978. Each measurement was repeated 7-9 times to achieve the necessary precision of 5-10 ppm on ^{109}Ag/^{107}Ag. The total procedural Ag blank was <10^{-4} of the sample size, which is negligible.

The supernatant containing the Pb was taken up in 6 M distilled hydrochloric acid and evaporated to dryness. The sample was then redissolved in 1 M distilled hydrobromic acid and Pb separated on an anion-exchange column filled with 0.5 mL AG1-X8 resin using 1 M distilled hydrobromic acid to elute the sample matrix and 6 M distilled hydrochloric acid to elute the Pb. Lead isotope compositions were measured on a Nu Plasma 500 HR MC-ICP-MS using Tl doping and sample-standard bracketing with the values of Eisele *et al.* (2003) for NIST SRM 981. The total procedural Pb blank was <20 pg, again negligible with respect to the amount of coin Pb analysed. External 2σ reproducibilities of ^{206}Pb/^{204}Pb, ^{206}Pb/^{204}Pb, and ^{208}Pb/^{204}Pb were ±100-200 ppm (or 0.01-0.02 %).

Results and Discussion

Silver in the present coins records a sudden change in ^{109}Ag/^{107}Ag of the coinage at the time of the monetary reform (Fig. 2; Table 1). Data are reported in units of $\varepsilon_{^{109}Ag}$, which is the deviation in parts per 10,000 of ^{109}Ag/^{107}Ag from the NIST SRM 978. The general lack of Ag isotopic data on ancient ores prevents direct provenance assessment, but comparison with silver and lead isotopic data on silver coins that circulated at different periods of time in production places such as Spain and the Aegean world before the colonisation of Spanish Americas (Desaulty *et al.*, 2011; Desaulty and Albarède, 2013) nevertheless permits relatively robust conclusions to be drawn. Pre-reform Roman coinage has positive $\varepsilon_{^{109}Ag}$ values very similar to silver from Southern Spain (see Supplementary Information). Roman silver between 241 and 211 BC was largely minted out of the war indemnities paid in Iberian silver by Carthage to Rome. Crawford (1974) actually argues that the Janus-faced Roman didrachm (*quadrigatus*) was introduced after the First Punic War (264 BC–241 BC), which launched Rome as a financial power: defeated Carthage had to pay the victor an indemnity of 2,200 talents (66 tons) of silver in ten annual installments, plus an additional immediate indemnity of 1,000 talents (30 tons) (Polybius 1.62-63). Moreover, Rome annexed Sardinia in the wake of the Mercenary war (240 BC–237 BC), thereby not only depriving Carthage of its traditional silver source, but also adding another 1,200 silver talents to the earlier war indemnities. Such financial burden, exorbitant as it seems, would, however, not have drained Carthage's resources if these are considered in the perspective of the 150 pounds (50 kg, 1 pound = 324 g) of silver produced by one Spanish mine in Hannibal's days (Pliny the Elder *Natural History* 33.31) and which over the entire region of Carthago Nova, according to Strabo (3.2.10) quoting Polybius, produced 35 tons a year (Kay, 2014).

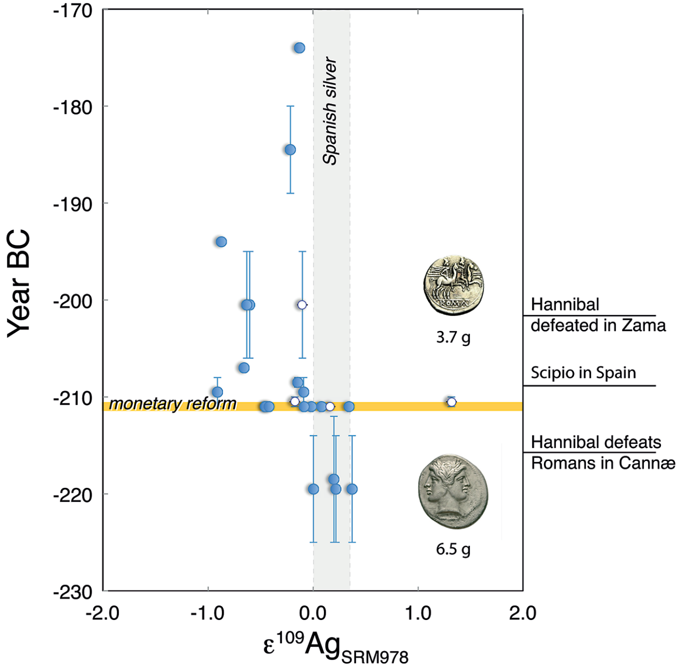

Figure 2 Silver isotope compositions of Roman silver coins pre- and post-dating the 211 BC monetary reform. Solid symbols: *denarii* (**top**) and *quadrigati* (**bottom**). Open symbols: *victoriati*. Mint ages and uncertainties are from Crawford (1974). Error bars on silver isotope proportions are the same as or smaller than the symbol size. Events listed on the right-hand side are chosen for historical relevance. See Supplementary Information for the range of Spanish values.

Table 1 Coin description, Ag/Cu and Ag/Pb ratios, and Ag and Pb isotopic compositions.

Lab code #	Coin ID[1]	Craw-ford[1]	Age BC[1]	Ag/Cu[2]	Ag/Pb[2]	$\varepsilon_{109\mathrm{Ag}}$[3]	n[3]	$2s$[3]	^{206}Pb/^{204}Pb[4]	^{207}Pb/^{204}Pb[4]	^{208}Pb/^{204}Pb[4]	T_m (Ma)[5]	μ[5]	κ[5]
1	*Denarius*	44/5	211	444	15411	-0.44	9	0.06	18.731	15.684	38.864	80	9.77	3.94
2	*Denarius*	139/1	189-180	530	13991	-0.21	8	0.07	18.572	15.656	38.681	160	9.73	3.94
3	*Victoriatus*	44/1	211	137	184050	0.16	8	0.05	18.742	15.719	38.904	115	9.83	3.96
3 *duplicate*			211						18.706	15.686	38.818	100	9.77	3.93
4	*Quinarius*	44/6	211	710	70442	0.34	8	0.04	18.762	15.677	38.808	50	9.75	3.89
5	*Denarius*	53/2	211	3913	32557	-0.01	8	0.04	18.696	15.685	38.838	107	9.77	3.95
5 *duplicate*			211						18.713	15.677	38.844	84	9.75	3.94
6	*Victoriatus*	98A/1a	211-210	348	65772	-0.17	9	0.07	18.684	15.654	38.713	77	9.71	3.89
7	*Denarius*	Marcia	194	1592	102762	-0.87	9	0.08	18.438	15.645	38.542	241	9.72	3.95
8	*Denarius*	80/1a	209-208	921	46607	-0.14	9	0.05	18.631	15.682	38.820	150	9.77	3.97
9	*Denarius*	Maiana	174	2006	18756	-0.13	9	0.07	18.574	15.664	38.766	168	9.74	3.98
10	*Denarius*	53/2	211	87091	1740785	-0.08	9	0.04	18.487	15.596	38.500	148	9.62	3.89
10 *duplicate*			211						18.572	15.658	38.628	162	9.73	3.92
11	*Denarius*	44/5	211	1001	20368	-0.45	8	0.06	18.689	15.689	38.829	117	9.78	3.95
11 *duplicate*			211						18.672	15.663	38.772	97	9.73	3.92
12	*Denarius*	113/1	206-195	1276	29599	-0.60	8	0.06	18.771	15.682	38.843	50	9.76	3.91
13	*Denarius*	197/1a-b	157-156	47052	595597	-1.05	8	0.06	18.525	15.671	38.682	211	9.76	3.97
14	*Quinarius*	97/2	211-208	656	66235	-0.91	9	0.08	18.688	15.646	38.712	64	9.70	3.89
15	*Quadrigatus*	29/3	225-214	2213	88022	0.37	8	0.06	18.680	15.669	38.777	99	9.74	3.92
16	*Denarius*	60/1	211-208	10919	154324	-0.09	8	0.04	18.616	15.657	38.656	130	9.73	3.90
17	*Quadrigatus*	28/3	225-212	239	40597	0.20	8	0.03	18.458	15.636	38.551	217	9.70	3.94
18	*Denarius*	58/2	207	2165	29157	-0.66	8	0.04	18.611	15.638	38.698	110	9.69	3.92
19	*Denarius*	112/2a	206-195	58	77874	-0.63	8	0.03	18.422	15.604	38.434	205	9.64	3.90
20	*Tridrachma Carthage*			31	1135732	-0.31	8	0.05	18.679	15.667	38.791	96	9.74	3.93
21	*Quadrigatus*	29/3	225-214	1182	57692	0.01	7	0.04	18.631	15.653	38.721	114	9.72	3.92
22	*Denarius*	44/5	211	22627	274101	-0.42	8	0.05	18.689	15.660	38.770	81	9.73	3.91
23	*Denarius*	30/1	225-214	2966	6283	0.22	7	0.04	18.810	15.672	38.823	9	9.74	3.87
24	*Quinarius*	44/6	211	298	43986	0.08	7	0.04	18.639	15.661	38.705	118	9.73	3.91
25	*Victoriatus*	112/1	206-195	196	49471	-0.10	7	0.05	18.718	15.671	38.771	73	9.74	3.90
26	*Victoriatus*	102/1	211-210	233	12727	1.32	7	0.08	18.712	15.658	38.745	62	9.72	3.89

[1] Nomenclature and minting age from Crawford (1974).

[2] Weight ratios refer to the surface layer that was leached from the coin, not to the bulk coin (Ponting, 2012).

[3] Relative deviation of the ^{109}Ag/^{107}Ag ratio from the NIST SRM 978 value. Unweighted average and standard deviation s of n runs.

[4] Uncertainties on Pb isotope ratios are $<10^{-4}$.

[5] Tectonic model age T_m of the lead ore source and model ^{238}U/^{204}Pb (μ) and ^{232}Th/^{238}U (κ) calculated from the measured time-integrated Pb isotope ratios (Albarède *et al.*, 2012).

In contrast, post-reform Roman coinage systematically has recorded negative $\varepsilon_{109\mathrm{Ag}}$ values apparently no longer consistent with a provenance of silver in southern Spain. Scipio Africanus only captured Carthago Nova (today Cartagena) in 209 BC, two years *after* the reform. If silver did not come from the West, could it have come from the East? It is known that at some point between 210 and 215 BC, the Romans sent an ambassador to the king and pharaoh of Ptolemaic Egypt, Ptolemy IV Philopator, in an attempt to summon financial support (Polybius 9.11a). Meadows (1998) endorsed by Kay (2014) suggested that Ptolemy may have provided gold and bronze coinage used during the pre-reform period of 213-211 BC (Crawford, 1964). As far as silver was concerned, however, the classic view holds that Egypt had its own shortage problems in the aftermath of the battle of Raphia in 217 BC against the Seleucid king Antiochus III (Reekmans, 1951), but this line of thinking has recently been called into question (Lorber, 2000; Le Rider and De Callataÿ, 2006).

Regardless of metal provenance, the isotopic discontinuity displayed by post-reform Roman coinage is remarkably sharp and attests to new sources of precious metal suddenly having become available and prominent. An unexpected rise in output of the Roman military mint in Sicily occurred between 214 and 211 BC (Frank, 1933; Crawford, 1964, 1974), *i.e.* at a time when bronze asses were still weighing three ounces. Crawford (1974) associated this surge with the beginning of military operations against Syracuse in 212 BC by M. Claudius Marcellus. Livy (25.31.11) writes that 'the quantity of booty was so great, that had Carthage itself [..] been captured, it would scarcely have afforded so much'. The author does not mention, however, how much silver was found in the city and even less how much of it was brought to the Roman *aerarium*. Likewise, Capua fell after a long siege in 211 BC and the silver spoil amounted to 10 tons of silver (26.14). With Syracuse and Capua not being primary silver producers, alternative origins must, therefore, be sought. Negative $\varepsilon_{109\mathrm{Ag}}$ values have been reported for coinage of pre-Hellenistic Macedonian and Greek, Parthian and Roman Gaul and Spain provenance in the first and second centuries BC (Desaulty *et al.*, 2011). To get a better overview of the primary sources of post-reform silver, Ag isotope studies on silver ingots found in shipwrecks are warranted.

The lead isotope proportions of the coins until the defeat of Hannibal in Zama (201 BC) are too scattered to shed light on specific metal provenance (Table 1 and Fig. S-1). They correlate with neither $\varepsilon_{109\mathrm{Ag}}$ nor the date of mint. If the Pb isotope data are considered in terms of the model 'tectonic' age, μ (U/Pb), and κ (Th/U) representation (Albarède *et al.*, 2012; Table 1 and Fig. 3), tectonic ages scatter through Alpine and Hercynian values. It is only after the war ended that a stable supply to the mint of lead with a strong Hercynian tectonic age flavor (>150 Ma) similar to the lead used for the water distribution system of Rome (Delile *et al.*, 2014) was established. The model U/Pb ratios are inconsistent with Pb ores originating in the periphery of the Mediterranean, except for the southwestern Iberian Peninsula, which at that time was not under Roman control. Rather, the model U/Pb ratios are more consistent with ores from Germany or Northern Brittany in the West, and Macedon and the Pontus region

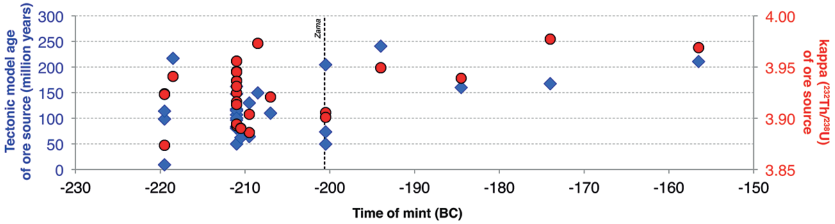

Figure 3 Lead tectonic model age (in blue, **left-hand scale**) and Th/U (κ) (in red, **right-hand scale**) of lead ore sources (see Albarède *et al.* (2012) for explanations and calculations of these parameters). Up until the last battle of Zama, the source of Pb used to purify silver remained chaotic with a mixture of Alpine and Hercynian ages and scattered κ values suggesting that scrap metal was collected for cupellation. Non-alpine lead (T_m > 150 Ma) seems to have dominated the supply afterwards.

on the southern coast of the Black Sea in the East. This disorderly isotopic pattern therefore reflects the lack of a steady and homogeneous lead supply. Roman mints were clearly recycling scrap lead from different origins to purify older coinage and metal plundered from their defeated enemies. Emergency minting as suggested here by Pb isotopes echoes the commonplace overstriking of seized coins (Crawford, 1974).

The present Ag and Pb isotopic results confirm that the monetary reform of 212-211 BC was conducted somewhat hastily and coincided in time with the delivery of massive amounts of silver from new sources, enough to replace the pre-reform silver supply from the by now expired Carthaginian war penalties. Crawford (1974) acknowledges that from 212 BC onwards metal again began to become available. New monetary windfalls also would account for the new financial system bringing attempts of silver debasement to an end. The reform, therefore, was not a consequence of monetary duress after major military setbacks (*e.g.*, Crawford, 1974; Livy's *inopia aerarii* (22.39.16; 23.5.5-6, 5.15; 24.18.11-13)), but instead was designed to accommodate new metal resources. Why then was the decision made to reduce the weight of the reference coin, from the Janus-faced *quadrigatus* to the lighter *denarius*? The reform clearly demonstrated the desire of aligning the different monetary units (Crawford, 1974). Beyond this concern, we speculate that it may have been an inspired move on the part of the Roman Senate, which in this manner introduced a form of permanent tax allowing more troops to be hired at the same cost in silver while anticipating the inevitable inflation that would consume the value of the hard-won silver booty. The effect of increased numbers of troops on demand and prices likely to be going up was at least temporarily compensated for by a reduction of the effective *stipendium* due to smaller coins being paid out. Reducing the size of the *denarius* at such a calamitous time while maintaining high silver fineness would both reassure the population made wary of debasement about the new silver value of coins and preempt the inflationary effect of massive injection of new money into the financial system. This study therefore suggests that the Roman government had already grasped some of the monetary pitfalls of a major state during wartime.

Acknowledgements

We thank the Agence Nationale de la Recherche (Grant *Minemet*) for supporting M.R.'s salary and the Institut National des Sciences de l'Univers (CNRS) and the Ecole Normale Supérieure de Lyon for their continuous support of the analytical facility at ENS Lyon. Claude Domergue was, as always, a great source of information. We further thank the professional dealers for providing quality material. We also acknowledge the thoughtful comments of three anonymous reviewers, Gil Davis, Michael Crawford, and the Editor, Bruce Watson.

Editor: Bruce Watson

Additional Information

Supplementary Information accompanies this letter at www.geochemicalperspectivesletters.org/article1613

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Cite this letter as: Albarède, F., Blichert-Toft, J., Rivoal, M., Telouk, P. (2016) A glimpse into the Roman finances of the Second Punic War through silver isotopes. *Geochem. Persp. Let.* 2, 127-137.

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A glimpse into the Roman finances of the Second Punic War through silver isotopes

F. Albarède[1,2]*, J. Blichert-Toft[1,2], M. Rivoal[1], P. Telouk[1]

Supplementary Information

The Supplementary Information includes:

- The ^{109}Ag/^{107}Ag of silver from Southern Spain
- Figure S-1
- Supplementary Information References

The ^{109}Ag/^{107}Ag of silver from Southern Spain

An event particularly relevant to the provenance of coinage silver was the union of Castile and Aragon through the wedding of the Catholic Kings (1479). The Spanish armies overran the Emirate of Grenada in southern Spain in 1482, allowing the Spanish rulers to capture the silver mines in southern Spain that had been under Carthage and Roman rule nearly two millennia earlier. Positive $\varepsilon_{109\mathrm{Ag}}$ values ranging from 0.0 to +0.2 and lead model ages consistent with the young tectonic age of the Betic Cordilleras are observed in coins minted at the time the Catholic Kings invaded the Grenada Emirate (Desaulty *et al.*, 2011). In contrast, medieval silver coinage predating the invasion has negative $\varepsilon_{109\mathrm{Ag}}$. It therefore can be concluded that silver from southern Spain is characterised by $\varepsilon_{109\mathrm{Ag}} > 0$ (Albarède *et al.*, 2012).

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1. École Normale Supérieure de Lyon and CNRS, 69007 Lyon, France
* Corresponding author (email: falbarede@gmail.com; albarede@ens-lyon.fr)
2. Earth Science Department, Rice University, Houston, TX 77025, USA

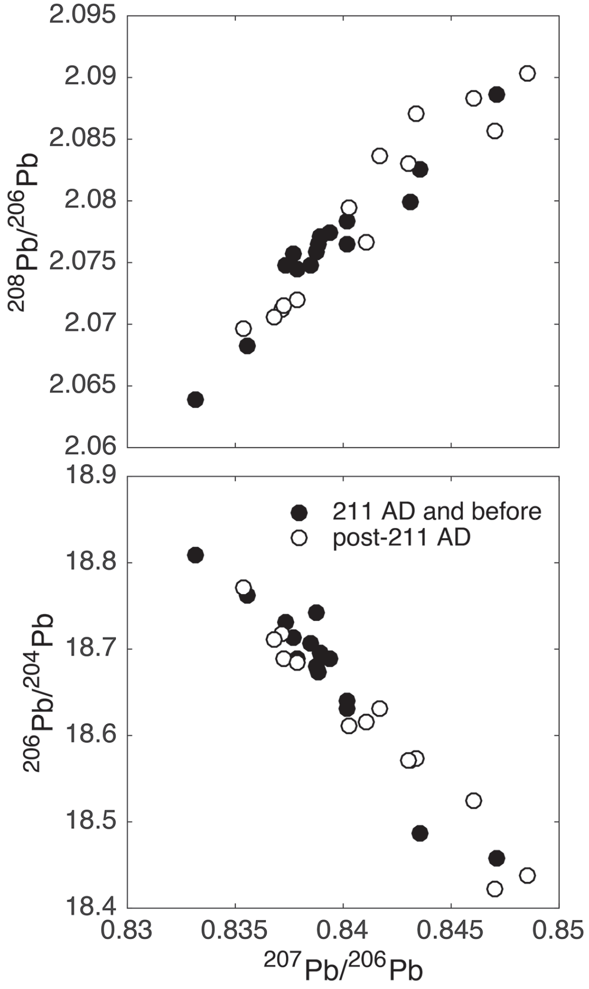

Figure S-1 Conventional lead isotope plots of the samples analysed in the present study.

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