Archaeometry **62**, 3 (2020) 577–592 doi: 10.1111/arcm.12547

ROME'S RISE TO POWER. GEOCHEMICAL ANALYSIS OF SILVER COINAGE FROM THE WESTERN MEDITERRANEAN (FOURTH TO SECOND CENTURIES BCE)*

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We present the results of geochemical analysis of silver coinage issued by Rome and dated between the fourth and second century BCE, which are complemented by data of coinage issued by Carthage, the Brettii, and the Greek colony of Emporion. Each of these minting authorities represents one of the major parties involved in the struggle for hegemony in the fourth to second centuries BCE Western Mediterranean region. This study retraces how the metal supply shifts in response to the transforming power relations and how this change is related to Rome's rise to the virtually uncontested ruler of the region.

KEYWORDS: ROME, SILVER COINAGE, WESTERN MEDITERRANEAN, PB ISOTOPES, TRACE ELEMENTS, SECOND PUNIC WAR

INTRODUCTION

In this study, we consider a timespan ranging from the first issues of Roman silver coinage in the late 4th century BCE up until the early 1st century BCE (i.e. until the beginning of the Social War

*Received 11 January 2019; accepted 7 February 2020

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and Civil Wars). Within this period, the emerging regional power Rome rose to become the virtually uncontested ruler of the Western Mediterranean, a position which it kept for centuries. This process is closely intertwined with its financial evolution. Rome issued its first silver coinage during a period in which it consolidated its hegemony in central Italy after defeating the Etruscans and the Samnite tribes. The denarius as the dominant silver coin and a corresponding set of fiduciary bronze coins were introduced in 211 BCE during the Second Punic War, after the previous monetary system was on the brink of collapse (Crawford 1985).

While the historical narrative is well known and Rome's overall economic situation has been investigated from a multitude of perspectives (e.g. Bowman and Wilson 2009), this study aims to empirically retrace the background of Rome's rise to power. Based on analytical data of a suite of silver coinage from this turbulent and defining timespan, we address the following questions: How do political conflicts and potential metal shortages influence the fineness of the coins? How do the bullion sources change in this period with Rome successively rising to the predominant power in Italy, and later, large parts of the Mediterranean region?

MATERIALS AND METHODS

Investigated samples

We studied 70 coins issued by Rome and dated between 310–300 and 101 BCE (Crawford 1974; Rutter 2001). For comparative purposes, we selected coinage issued by Carthage, the tribal group of the Brettii in southwest Italy and the Greek colony of Emporion in northeast Spain (Table 1, Figure 1). Each of these minting authorities represents one of the major parties involved in the struggle for hegemony in the 4th to 2nd centuries BCE Western Mediterranean region. The two coins issued by Carthage were minted in the western part of Sicily and date to the 4th century BCE (Jenkins 1974). Due to their dating before the conflicts with Rome, these coins have been sampled to get an insight into earlier Carthaginian coin production. The three samples of Brettian coins date between 218–214 BCE and 216–211 BCE, respectively (Rutter 2001). By investigating these coins, we aim to get an impression whether the Brettii had access to different metal sources than Rome since they joined forces with Carthage in the Second Punic War (cf. Figure 1). One coin from the Greek colony of Emporion dated between 241 to 218 BCE (Villaronga 2002) has been studied. Due to the fact that the city was a well-established trading hub (e.g. Cabrera 1998), the potential metal provenance of this coin allows a glimpse into the economic relations between the 'Iberian/Phoenician' and 'Greek' sphere.

Sampling and sample preparation

The coins were sampled by drilling to obtain fresh and chemically representative metal. Drilling chips from the first few millimetres were discarded to avoid surficial material potentially affected by e.g. corrosion processes or conservation treatment (also see Birch et al. (2020) and Birch et al. (in press)) [Correction added on 10 March 2020, after first online publication: "micrometres" has been changed to "millimetres"]. One part of the drillings was mounted and polished for metallography, electron microprobe analysis (EPMA) and laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS). A second part was chemically dissolved and measured for its Pb isotope signature. Sampling revealed that one coin (MS001) is subaerate (an ancient counterfeit coin with a copper (−alloy) core) and only plated with silver. The drilling chips of this sample have

Table 1 *Description of the investigated coins. Nomenclature and dating are from Crawford (1974), Jenkins (1974), Rutter (2001) and Villaronga (2002). Roman didrachms are dated according to Rutter (2001).*

Sample	*Minting authority*	*Dating [years BCE]*	*Denomination*	*Reference*
MS001	Rome (Naples?)	310–300	Didrachm	RRC 13/1 = HN 266
TB037	Rome (Naples?)	310–300	Didrachm	RRC 13/1 = HN 266
MS002	Rome?	c. 260	Didrachm	RRC 15/1a = HN 275
MS003	Rome	c. 250	Didrachm	RRC 22/1 = HN 295
GE056	Rome	c. 250	Didrachm	RRC 22/1 = HN 295
GE057	Rome	c. 250	Didrachm	RRC 22/1 = HN 295
MS008	Rome	c. 240	Didrachm	RRC 25/1 = HN 297
TB038	Rome	c. 235	Didrachm	RRC 26/1 = HN 306
MS004	Rome	c. 235	Didrachm	RRC 26/1 = HN 306
MS005	Rome	225–212	Didrachm	RRC 30/1 = HN 334
MS006	Rome	225–212	Didrachm	RRC 28/3 = HN 334
MS007	Rome	225–212	Didrachm	RRC 28/3 = HN 334
TB039	Rome	225–212	Didrachm	RRC 28/3 = HN 334
DE004	Rome	211	Sestertius	RRC 44/7
MS011	Rome (Sicily?)	209–208	Denarius	RRC 71/1c
MS009	Rome	209–208	Denarius	RRC 50/2
DE003	Rome	206–195	Denarius	RRC 113/1
MS010	Rome	206–195	Denarius	RRC 115/1
MS014	Rome	189–180	Denarius	RRC 141/1
MS015	Rome	179–170	Denarius	RRC 162/2a
MS013	Rome	189–180	Denarius	RRC 139/1
MS012	Rome	157–156	Denarius	RRC 197/1a
MS016	Rome	157–156	Denarius	RRC 197/1a
MS029	Rome	153	Denarius	RRC 203/1
MS017	Rome	152	Denarius	RRC 204/1
MS018	Rome	151	Denarius	RRC 205/1
MS019	Rome	150	Denarius	RRC 206/1
MS020	Rome	149	Denarius	RRC 208/1
MS021	Rome	149	Denarius	RRC 210/1
MS022	Rome	148	Denarius	RRC 216/1
MS023	Rome	147	Denarius	RRC 218/1
MS025	Rome	146	Denarius	RRC 219/1e
MS031	Rome	143	Denarius	RRC 222/1
MS030	Rome	142	Denarius	RRC 223/1
MS032	Rome	141	Denarius	RRC 225/1
MS033	Rome	140	Denarius	RRC 227/1b
MS034	Rome	139	Denarius	RRC 230/1
MS036	Rome	138	Denarius	RRC 233/1
MS038	Rome	137	Denarius	RRC 235/1c
MS047	Rome	137	Denarius	RRC 234/1
MS048	Rome	137	Denarius	RRC 234/1
MS035	Rome	136	Denarius	RRC 238/1
MS037	Rome	135	Denarius	RRC 240/1a
MS028	Rome	134	Denarius	RRC 245/1
MS039	Rome	131	Denarius	RRC 254/1
MS040	Rome	130	Denarius	RRC 257/1
MS041	Rome	129	Denarius	RRC 258/1
MS043	Rome	128	Denarius	RRC 262/1

(*Continues*)

Table 1 *(Continued)*

Sample	*Minting authority*	*Dating [years BCE]*	*Denomination*	*Reference*
MS042	Rome	127	Denarius	RRC 265/1
MS044	Rome	126	Denarius	RRC 266/1
MS045	Rome	125	Denarius	RRC 270/1
MS051	Rome	124	Denarius	RRC 273/1
MS026	Rome	123	Denarius	RRC 275/1
MS027	Rome	122	Denarius	RRC 277/1
MS024	Rome	121	Denarius	RRC 278/1
MS049	Rome	119	Denarius	RRC 281/1
MS046	Narbo	118	Denarius	RRC 282/2
MS053	Rome	117–116	Denarius	RRC 284/1b
MS052	Rome	116–115	Denarius	RRC 286/1
MS050	Rome	115–114	Denarius	RRC 287/1
MS054	Rome	113–112	Denarius	RRC 295/1
MS056	Rome	112–111	Denarius	RRC 297/1b
MS057	Rome	111–110	Denarius	RRC 299/1a
MS055	Rome	109–108	Denarius	RRC 305/1
MS058	Rome	108–107	Denarius	RRC 308/1b
MS059	Rome	106	Denarius	RRC 311/1a
MS060	Rome	105	Denarius	RRC 314/1b
MS062	Rome	103	Denarius	RRC 320/1
MS061	Rome	102	Denarius	RRC 322/1b
MS063	Rome	101	Denarius	RRC 324/1
GE001	Carthage (on Sicily)	350–320	Tetradrachm	Jenkins series 2d 101–102
GE002	Carthage (on Sicily)	320–300	Tetradrachm	Jenkins series 3a 176, MMHNT
TB026	Brettii	218–214	Drachm	HN 1960
TB027	Brettii	218–214	Drachm	HN 1970
MS064	Brettii	216–211	Drachm	HN 1958
GE055	Emporion	241–218	Drachm	CNH p. 20–21

The abbreviations RRC refer to Crawford (1974), HN to Rutter (2001) and CNH to Villaronga (2002), respectively.

only been analysed for their composition, but not for their Pb isotope ratios because contamination of the bulk signatures by Cu-rich portions of the drilling chips was expected.

Analytical techniques

Electron microprobe analysis The major and minor element composition was determined using a Jeol JXA 8900 R Superprobe (Institute for Geosciences, Goethe-University, Frankfurt/Main). A total of 17 elements was measured at an accelerating voltage of 20 kV and a beam current of 30 nA with a beam size of 6 µm. The precision and accuracy of the analyses were checked by measuring the silver-alloy reference materials AGA1, AGA2 and AGA3 (cf. Birch et al. 2020). An average composition was calculated by analysing each coin sample seven to ten times and normalising the single analyses to 100 wt %. The raw totals are on average 100.81 wt % ± 0.68 wt % (Supplementary Material S1). Only Ag, Pb and Cu were consistently detected. Based on their main element composition, modern forgeries typically characterised by elevated contents of e.g. Cr, Ni, Zn and Cd can thus be excluded. Other elements included in the measurement setup and not detectable by EPMA have been analysed by LA-ICP-MS.

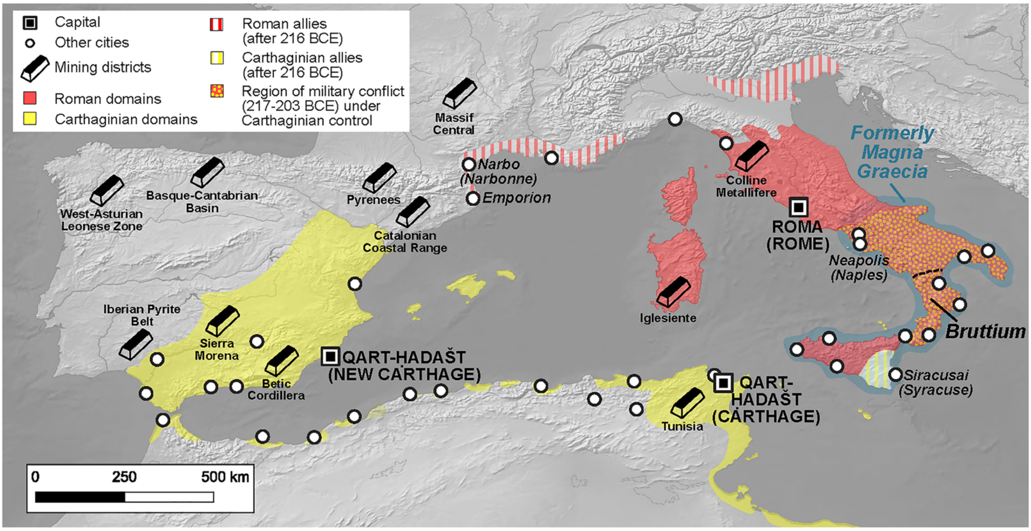

Figure 1 *Map of the Western Mediterranean (made with Natural Earth) showing Roman and Carthaginian domains at the outbreak of the Second Punic War in 218 BCE and their respective allies after 216 BCE (data taken from Wittke et al. (2011)), as well as mints, other settlements and mining districts mentioned in the text. The regions of Bruttium and the former area of Magna Graecia, i.e. Greek colonies in southern Italy and Sicily, are indicated on the map. [Colour figure can be viewed at wileyonlinelibrary.com]*

LA-ICP-MS The trace element abundances were quantified using a ThermoFisher Scientific Element 2 sector field ICP-MS coupled to a RESOlution M-50 (ASI) 193 nm ArF excimer laser (ComPexPro 102F, Coherent) system (Frankfurt Isotope and Element Research Center (FIERCE), Goethe University Frankfurt). The masses ^{53}Cr, ^{55}Mn, ^{59}Co, ^{60}Ni, ^{66}Zn, ^{75}As, ^{77}Se, ^{106}Pd, ^{111}Cd, ^{118}Sn, ^{121}Sb, ^{128}Te, ^{130}Te, ^{194}Pt, ^{195}Pt, ^{197}Au, ^{208}Pb and ^{209}Bi were acquired using a laser spot diameter of 67–100 µm, 10 Hz repetition rate, 50–80 mJ laser energy and 50%T attenuator value, resulting in an output laser energy (fluence) of c. 2 J/cm^2. Lead, whose contents have been determined by EPMA beforehand (see above), was used as internal standard. The masses ^{63}Cu and ^{65}Cu were added to the measurement setup to be used as internal standards if samples with Pb contents below the detection limit of the EPMA were analysed (only for TB026). The standards AGA1, AGA2, and AGA3 were measured every ten ablations, that is, before and after every coin measured. The standards AgRM1 and AgRM2 were routinely analysed as unknowns for accuracy and precision testing (cf. Birch et al. 2020). Data reduction was carried out with the GLITTER™ software (Griffin et al. 2008). Due to their small width and thickness, the drilling chips of the plated coin MS001 did not provide sufficient signal, and hence the data was not further evaluated.

Pb isotopes The sample solutions were chromatographically separated according to procedures reported by Durali-Mueller *et al.* (2007). Pb isotope solutions were diluted with 2% HNO_3 to a concentration of c. 500 ppb and spiked with 100 ppb Tl solution. The analyses were carried out using a ThermoFisher Scientific NEPTUNE multi collector ICP-MS (Frankfurt Isotope and Element Research Center (FIERCE), Goethe University Frankfurt) operated in low resolution mode ($\Delta m/m = 400$). ^{202}Hg was measured to monitor the interference of ^{204}Hg (on ^{204}Pb), and ^{203}Tl and ^{205}Tl were determined to correct for mass fractionation using the natural ^{205}Tl/^{203}Tl ratio of 2.3871 (Dunstan et al. 1980) and exponential law (cf. Belshaw et al. 1998; White et al.

2000). Precision and accuracy were checked by repeatedly analysing the NIST SRM981 standard (cf. Birch et al. 2020). Pb–Pb model ages (derived from ^{206}Pb/^{204}Pb and ^{207}Pb/^{204}Pb ratios), ^{238}U/^{204}Pb (μ), ^{232}Th/^{204}Pb (ω) and ^{232}Th/^{238}U (κ) were calculated according to Stacey and Kramers (1975). Euclidean distances were calculated on a point-by-point basis for sample and reference data (e.g. Stos-Gale and Gale 2009), whereas Mahalanobis distances (e.g. Delile *et al*. 2014) were determined for archaeological groupings of sample and reference data. These values have been used to establish and verify isotopically similar reference data (see Supplementary Material S2). For Pb isotope plots containing literature data, the ratios ^{208}Pb/^{206}Pb and ^{207}Pb/^{206}Pb were used to avoid analytical artefacts caused by comparably lower precision and accuracy and mass bias often associated with ^{204}Pb ratios of particularly older reference data.

Statistical analysis and visualisation of analytical data Statistical analysis and visualisation of data has been carried out using the open source programming language R (R core team 2017) and the package ggplot2 (Wickham 2016). Fill colour gradients have been created with the package viridis (Garnier 2018).

RESULTS

Major element data

The Ag content of all investigated coins ranges between 67.83 and 99.70 wt % (S1). Overall, the fineness is very high, with mean and median values of Ag of 97.88 and 98.84 wt %, respectively. Lower Ag contents are balanced by increased Cu abundances, which scatter between 0.05 and 31.57 wt % (mean 1.51, median 0.49 wt %). Lead is the third major element in the analysed coins with contents ranging from 438 ppm to 1.27 wt % (mean 0.42 wt %, median 0.41 wt %).

Highly varying Ag contents are restricted to Roman coins (Figure 2). The Ag abundances of the other samples are in excess of 96.52 wt %. A lower fineness of the Roman coins typically is associated with an older dating. Silver contents below 95 wt % have been solely observed in samples dating prior to 212 BCE. Several coins from this period, however, have Ag contents ≥98 wt%, indicating that not all coins issued before 212 BCE generally had a lower fineness.

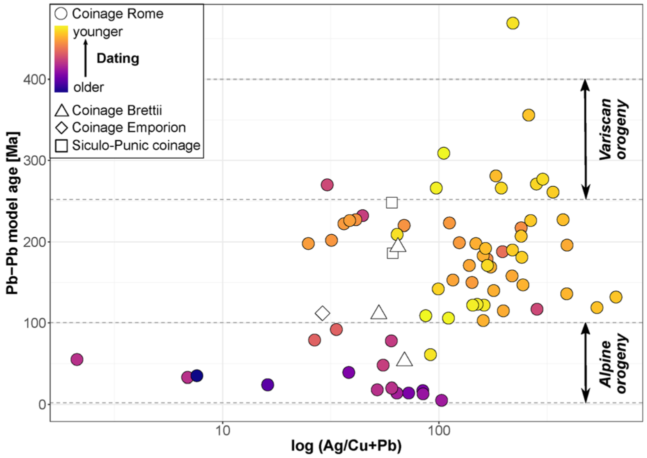

Figure 2 *Pb–Pb model ages (Stacey and Kramers (1975)) versus the log (Ag/Cu + Pb) ratios of the analysed Roman (filled symbols, colour scheme refers to archaeological dating), Brettian, Emporion and Siculo-Punic coins (open symbols). [Colour figure can be viewed at wileyonlinelibrary.com]*

Minor and trace element data

The most frequently occurring minor and trace elements (based on their median contents) are Au (2300 ppm) and Bi (843 ppm), followed by Sn (13 ppm). All other elements, if detectable at all, show median abundances ≤4 ppm (S1). The abundances of several elements, including Cr, Co, Se and Te, are routinely below the detection limit (i.e. below 0.1–0.4 ppm; S1). These results are in agreement with the overall depleted trace element signature of silver produced by cupellation of Ag-bearing crude lead, whereby most impurities are oxidised along with the lead (experimental: Pernicka and Bachmann 1983; L'Héritier *et al*. 2015; analytical: Flament *et al*. 2017). The abundances of the elements mainly collected by crude lead (Bi, Au, Pt, Pd) are only weakly positively correlated to uncorrelated with each other (R^2 = -0.1 to 0.4), and their contents are not related to the fineness of the coins.

Pb isotopes

The ratios $^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$ range between 18.120 and 18.844, 15.619 and 15.693, 38.258 and 38.999, respectively (S1). Corresponding Pb–Pb model ages (Stacey and Kramers 1975) vary between 5 and 469 Ma, that is, between the Alpine and Variscan orogeneses (Figure 2). ^{207}Pb model ages are markedly higher than ^{208}Pb model ages (Figure 3).

DISCUSSION

Reconstruction of potential metal sources

Geochemical constraints Two large groups within the sample set (Figure 3; S1) can be established based on the calculated model ages and U-Th-Pb ratios (cf. Albarède *et al*. 2012; Pernicka 2014). Group I comprises coins with Alpine model ages <100 Ma. Within the group, Roman coins dating from 310–300 to 225–212 BCE and one Brettian coin (MS064) possess geological ages between 5 and 55 Ma, and are tightly clustered in their Pb isotope ratios (Group Ia). Roman samples dated to 211 BCE and the 2nd century BCE (Group Ib) are marked by comparatively older model ages (61–92 Ma) and somewhat larger variation in their Pb isotope

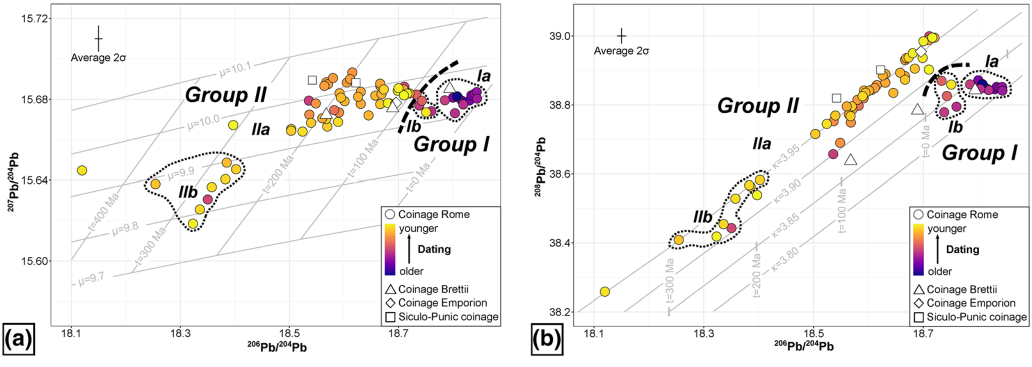

Figure 3 *(a) and (b) Pb isotope diagrams of Roman (filled symbols, colour scheme refers to the archaeological dating), Brettian, Emporion and Siculo-Punic coins (open symbols). Groups I and II and respective subgroups are separated by dashed lines. Model ages, μ and κ have been calculated according to Stacey and Kramers (1975); for the calculation of κ models, μ has been set to 9.74, i.e. the ratio of present day lead proposed by Stacey and Kramers (1975). [Colour figure can be viewed at wileyonlinelibrary.com]* systematics. Group II comprises Roman coins dating from 209–208 to 101 BCE, the two Carthaginian coins, and the coin from Emporion. Their model ages range between 103 and 469 Ma. The samples with broadly Alpine model ages from this group are distinguished from Group I by their higher Th/U ratios. Group II follows a linear trend in the $^{208}Pb/^{204}Pb$-$^{206}Pb/^{204}Pb$ diagram with most samples concentrating around Th/U = 3.95. Within Group II, a subgroup (Group IIb) with markedly lower U/Pb ratios (≤ 9.90) contains Roman coins, which have model ages from 261–281 and 369 Ma, and with one exception (DE003, 206–195 BCE) date not before 131 BCE. Up until model ages of c. 250 Ma, coins from Group IIa form a narrow cluster, in which the variation of the U/Pb ratios steadily increases with the model age. The remaining two Brettian coins (TB026, TB027) possess calculated Pb–Pb model ages of 194 and 111 Ma overlapping with those of Group II but have lower Th/U ratios similar to those of Group I.

The circum-Mediterranean region, where the metal sources for the coins should be primarily sought, is widely dominated by the Alpine belt, which extends from southeastern Spain and northern Africa over the Balkans and Aegean. Variscan mountain ranges occur in Spain/Portugal (Iberian Massif), Sardinia, and France (Massif Central). Variations in U-Th-Pb characteristics derived from Pb isotope data extend over spatially distinct model age provinces across Europe (Blichert-Toft *et al*. 2016) and reflect the regional geodynamic and metallogenic evolution (e.g. Tosdal *et al*. 1999).

Lead-Zn-Ag ore deposits with high μ-ω-κ Pb isotope systematics (i.e. μ ~ 10, ω ~ 40, κ ~ 4 and higher ^{207}Pb than ^{208}Pb model ages), which are analogous to the characteristics of Group IIa coins, have been identified in large parts of southern Europe. This isotope province includes deposits in southwestern Sardinia (Iglesiente; e.g. Boni and Koeppel 1985), Tuscany (e.g. Lattanzi *et al*. 1992), Massif Central (e.g. Brevart *et al*. 1982), Pyrenees (e.g. García-Sansegundo *et al*. 2014), Betic Cordillera (Arribas and Tosdal 1994), Catalonian Coastal Range (Canals and Cardellach 1997), West-Asturian Leonese Zone (Tornos *et al*. 1996), and Basque-Cantabrian Basin (Velasco *et al*. 1996). The origin of this isotope signature has been related to contribution of Pb from a long-lived crustal source or remobilisation of Pb from earlier formed deposits. The narrowly clustered Pb isotope ratios of the broadly Alpine samples of Group IIa (model ages <125 Ma) indicate a homogenous, single source. Within the circum-Mediterranean region, these samples isotopically agree with Miocene Pb-Zn-Ag deposits of the Betic Cordillera and the

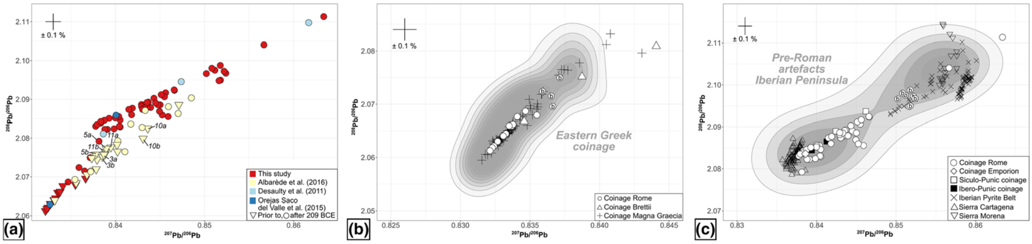

Figure 4 *Pb isotope diagrams. (a) Roman samples from this study in comparison with data on Roman Republican coinage from Desaulty et al. (2011), Orejas Saco del Valle et al. (2015) and Albarède et al. (2016). Triangles and circles correspond to a dating before and after 209 BCE, respectively. The dataset of Albarède et al. (2016) contains duplicates which are indicated as "a" and "b". (b) Samples assigned to Group I (a & b; indicated) in comparison with data of Eastern Greek coinage (Desaulty et al. 2011; Gale et al. 1980)) represented as Kernel density estimate (grey) and silver coinage from Magna Graecia (Birch et al. in press; Birch et al. 2020). (c) Samples assigned to Group II (a & b; indicated) in comparison with literature data of metallurgical (by) products from the Sierra Cartagena, Sierra Morena and the Iberian Pyrite Belt, and of pre-Roman artefacts from the Iberian Peninsula represented as Kernel density estimate (grey). See text for more information on the references. [Colour figure can be viewed at wileyonlinelibrary.com]*

Colline Metallifere in southern Tuscany. The lower Th/U ratios of Group I in contrast indicate a less evolved crustal source. They fit to the broader Aegean region (cf. Delile *et al*. 2014), including deposits of the Attic-Cycladic Belt (e.g. Laurion; Gale *et al*. 1980), the Serbo-Macedonian and Rhodope Massifs (e.g. Chalkidiki Peninsula; Kalogeropoulos *et al*. 1989), and mineralisations in Bouhlel 2016.

The isotopic variation observed in pre-Variscan Group IIa coins indicates mixed contribution of Pb from several sources with differing formation age and source characteristics, both slightly more and less radiogenic than the broadly Alpine coins. The lower μ values of Variscan Group IIb samples reflect a comparatively somewhat U-depleted source and generally suggest contribution of material with a less prevalent (upper) crustal signature. Within the Iberian Massif, deposits of the Ossa Morena Zone are characterised by a rather primitive Pb isotope signature attributed to emplacement of a mafic sill in the Variscan period. Mineralisations in the Central Iberian and South Portuguese Zones in contrast possess predominantly crustal Pb signatures (e.g. Marcoux 1997; Tornos and Chiaradia 2004) but with μ values typically below those of the high μ-ω-κ province.

Archaeological evidence Studies on Roman coinage from the 3rd and 2nd centuries BCE (Albarède et al. 2016, Desaulty et al. 2011, Orejas Saco del Valle et al. 2015; Figure 4a) found a comparable clustering of Pb isotope signatures, i.e. one cluster with young model ages and another cluster with model ages trending towards the Variscan period (as well as some coins which are intermediate between these clusters). Even though both reference data clusters comprise coins from the 3rd and the 2nd century BCE, the Variscan-trending cluster predominantly consists of coins from the 2nd century BCE. Similar Pb isotope compositions as for Group I (Figure 4b) have been determined for coins issued by the Greek cities of Magna Graecia (Birch et al. in press; Birch et al. 2020). Their isotope signatures in turn are consistent with those of coinage from the Greek mainland (Desaulty *et al*. 2011; Gale *et al*. 1980; Stos-Gale 2017), which mostly have been interpreted to have been (initially) derived from ores of the broader Aegean region, predominantly from mineralisations in Laurion, Chalkidiki, and the Rhodopes. It is assumed that the cities of Magna Graecia used coins from the motherland as bullion source (Birch et al. 2020), which they received in exchange for trade goods (Rowan 2013). Subsequently, these coins could have also been used by Rome as material basis for minting.

The possible significance of Tunisia as metal source is unclear, as detailed field studies are lacking. Paleopollution recorded in drill cores near the city of Utica (Delile *et al*. 2019) does not specifically indicate Punic metal extraction in its hinterland. The strong correlation of Pb and Ag with P as typical settlement marker (i.e. human and animal waste; e.g. Oonk *et al*. 2009) in these sediments rather indicates urban sources, for example, metal workshops, as P was not mined in pre-modern time and is not associated with Pb and Ag in the Tunisian deposits. The Pb isotope signatures of the metal-enriched drill cores presented in Delile *et al*. (2019) indicate a Variscan Pb origin, which is contrary to the typically Alpine formation age of these mineralisations.

The deposits in southeastern Spain are the most likely metal source for the broadly Alpine coins of Group IIa because the mineralisations in Tuscany can be broadly excluded as they were exploited for lead and silver only from the medieval period on (e.g. Manasse and Mellini 2002). The Pb isotopes of these coins compare rather well with metallurgical (by) products from the Sierra Cartagena (Baron *et al*. 2017; Domergue *et al*. 2016; Trincherini *et al*. 2001; Trincherini *et al*. 2009; Figure 4c). 2010The Variscan coins from Group IIb with their somewhat lower U/Pb ratios fit to metallurgical by-products from the Iberian Pyrite Belt in the South Portuguese Zone of the Iberian Massif (Anguilano 2012; Hunt Ortiz 2003; Stos-Gale 2001; Figure 4c). Smelting debris from this district possesses a distinctive Pb isotope signature, which is marked by variable, typically more radiogenic isotope ratios than the local ore. This discrepancy has been related to addition of ’foreign’ lead to the furnace charge to sufficiently collect and extract the silver (e.g. Anguilano 2012). Lead ingots, which have been attributed to production from ores of the Sierra Morena (Domergue *et al*. 2012; Nesta *et al*. 2011), a mountain range covering the Central Iberian and Ossa Morena Zones of the Iberian Massif, agree less well with the Group IIb coins (Figure 4c).

Possible bullion sources for the remaining Group IIa coins include a plethora of mineralisations within southwestern Europe (see above). Historical development, however, strongly argues for the Iberian Peninsula. The oldest Roman coins from Group IIa were minted in 209/208 BCE. Their dating thus overlaps with Rome’s conquest of the Iberian Peninsula, which started with the sack of New Carthage, the Carthaginian stronghold in southeast Spain, in 209 BCE. The isotope signatures of pre-Roman artefacts found at the Iberian Peninsula (Figure 4c; data from Trincherini *et al*. 2009; Hermanns 2010; Rafel *et al*. 2010; Montero Ruiz *et al*. 2011; García-Bellido *et al*. 2015; Murillo-Barroso *et al*. 2016) echo widespread trade networks and are consistent with those of Group II coins. The Siculo-Punic and Ibero-Punic coins (García-Bellido *et al.* 2015) have a Pb isotope signature, which fits to the spread of pre-Variscan Roman Group IIa samples and further add to the hypothesis that the bullion of Group II coins was mostly derived from the (former) Carthaginian sphere of the Iberian Peninsula.

Two of the Brettian coins (TB026, TB027) possess Pb isotope characteristics intermediate between Group I and Group II. During the Second Punic War, in which period these coins were minted (218–214 BCE), the tribe was allied with Carthage (cf. Figure 1). The intermediate isotope signature thus might reflect its access to Iberian-dominated silver due to their connection with the Phoenicians and re-minting of coins issued by the Greek colonies in Bruttium. Precious metal hoards, which comprise Brettian coins and were deposited during the Second Punic War, typically do not contain Roman but Carthaginian coins (Rowan 2014) and confirm the monetary relationship between the Brettian and Carthaginian societies.

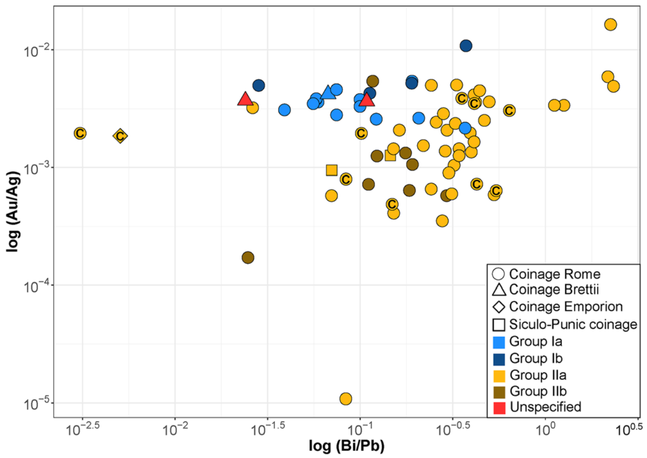

Figure 5 *log (Bi/Pb) – log (Au/Ag) diagram of the investigated coins. Symbols are coloured according to their Pb isotope groupings. Coins interpreted to have been produced by raw material from the Sierra Cartagena are marked with “C”. [Colour figure can be viewed at wileyonlinelibrary.com]*

Implications of trace elements for technology and provenance

Addition of copper (alloys) to the silver bullion introduces typically associated elements, particularly As, Sb, and Ni (cf. Pernicka 2014 and references therein). The highest abundances of Co, Ni, As, Se, Sb and Te were identified in the three Cu-richest coins (MS005, MS007, TB037; Cu contents 11.23–31.57 wt %). These samples therefore are assumed to have been intentionally debased. A lower threshold limit for debasement is difficult to establish from our dataset (also see Birch et al. 2020 on identifying debased silver).

Bismuth and Au are typical minor components of Pb-Ag ores (largely) unaffected by cupellation and hence are most suitable to characterise potential raw material sources. The Bi/Pb and Au/Ag ratios are comparatively less variable in Group I (Figure 5) but do not show any further relation to the subgroups. This is presumably caused by mixing of different metal sources, re-melting of the bullion and possibly debasement (cf. L'Héritier *et al.* 2015) as expected for the investigated coins, but also by the heterogeneous distribution of Bi within ore mineralisations. Following the hypothesis that Group I coins were the result of several cycles of re-minting, the relatively narrow clustered ratios probably reflect the thereby well-homogenised Au contents of this reservoir. The bullion of Group II samples in contrast was derived from more diverse sources (as indicated by their Pb isotopes) and was as a reservoir presumably less well homogenised by recycling.

Chronological variation of fineness and Pb isotope signatures: Historical implications

Both the fineness and Pb isotope signatures of the investigated Roman coins show chronological variations (S1). The dataset contains four relatively Cu-rich coins (Cu > 5 wt %) that date no later than the last quarter of the 3rd century BCE. The plated coin (MS001) also falls in this period. The comparably low fineness of the two coins minted at the end of the 4th and early 3rd century BCE (TB037, MS002) might be aligned with conventional silver contents of contemporaneous coins from southern Italy and Rome (Birch et al. in press; Birch et al. 2020; Burnett and Hook 1989; Hollstein 2000). The dating range of the two remaining coins (MS005 and MS007) falls in the period of the Second Punic War, during which it is assumed that Rome suffered from metal shortages and heavily debased its coinage (Crawford 1985). The booty gained from conquests of rebellious cities in Italy and Sicily from 212 BCE on helped Rome to restore its strained finances. Overall, the fineness of Roman coins minted before 212 BCE seems to indicate a fluctuating metal supply that stabilised towards the end of the Second Punic War.

The Pb isotope signatures of coins from Group I mirror those of currency issued by cities in Magna Graecia (see above). Before the Second Punic War, coins minted by the Greek colonies circulated parallel to Roman issues. After the war, non-Roman coinage disappears from hoards in southern and central Italy and Sicily, which indicates a monopolisation of the minting of silver coinage by Rome (Kemmers 2016; Rowan 2014). The bullion for Group I Roman coinage dated before the Second Punic War consequently was most likely obtained peacefully, that is by monetary transactions such as trade. By analogy to the Greek colonies of Magna Graecia, which are thought to have mainly relied on coins from the Greek 'motherland' as material basis for their coinage (Birch et al. 2020), pre-Second Punic War Rome probably also used silver coins as bullion supply for its coin production. The potential contribution of Iberian silver from Carthage's indemnities paid to Rome after the First Punic War (264-241 BCE; cf. Albarède et al. 2016) for the production of the early Roman silver issues investigated in this study is unclear.The local currencies confiscated by Rome after the war might have been re-minted to Roman coinage. The coins analysed in this study, however, typically show a Pb isotope signature that is markedly different to the pre-war Roman issues and interpreted to have been mainly derived from Iberian metal. The samples from Group Ib possess somewhat more scattered Pb isotope signatures intermediate to Groups Ia and IIa. This might reflect a mixture with a ‘foreign’ component isotopically similar to Group IIa and fits to the dating of Group Ib samples during/after the Second Punic War, when other metal sources than eastern Greek coinage became available to Rome. Three coins of Group Ib from the 2nd century BCE (MS014, MS015, MS057) fall into a period in which Rome received large volumes of booty, tributes, and war indemnities from Aegean regions in Greece and Asia Minor during or in the aftermath of the Macedon Wars (e.g. Kay 2014). The remaining coin of Group Ib (DE004) dates to 211 BCE, one year after Rome captured and looted Syracuse and Capua, both former allies to Carthage, and Taras/Tarentum.

For the coins assigned to Group II, a predominantly Iberian origin is assumed. The dating of the coins (209/208 to 101 BCE) fits to the era of Roman subjugation of the Iberian Peninsula, which started in 209 BCE with the conquest of New Carthage. The sack of this settlement alone reportedly yielded 18,300 pounds of silver and a large number of silver vessels (Livy, History of Rome, 26.47.7). The Pb isotope signatures of pre-Roman artefacts from the Iberian Peninsula reveal a complex picture including the utilisation of raw material from different sources and extensive trade networks (Bartelheim *et al.* 2012; Murillo-Barroso *et al.* 2016; Rafel *et al.* 2010). Silver gained as plunder during the Roman conquest of the Iberian Peninsula hence likely represents a mixture of metal from various districts, as it is apparently recorded in the Pb isotope data of the investigated Roman coins.

After the war ended with Carthage’s crushing defeat, Rome inflicted reparation payments on the opponent (annual indemnities from 201–151 BCE) and was provided with rich silver ore resources in its own territories to be mined for centuries. Archaeological evidence suggests that local exploitation already began at the beginning of the 2nd century BCE (e.g. Domergue 1990). When Polybios visited the mining district around New Carthage in the middle of the 2nd century BCE, activities were in full swing and reportedly attained daily revenues of 25,000 drachms (Strabo, Geography, 3.2.10). The plethora of lead ingot cargoes related to the Sierra Cartagena, dated between the late 2nd and 1st centuries BCE and discovered throughout the Mediterranean (Trincherini *et al.* 2009), mirrors the intensity of Roman metal production. The rugged terrain and resistance of Lusitanian (155–138 BCE) and Celtiberian (153–133 BCE) tribes impeded Roman mining activities in the southwestern part of the Iberian Peninsula, that is, the Sierra Morena and Iberian Pyrite Belt. Before the end of these conflicts, Rome probably did not have sufficient control over the two regions to exploit their mineralisations on a notable scale (Domergue 1990). This is mirrored by Roman coins from Group IIb that are interpreted to have been minted from metal largely derived from the Iberian Pyrite Belt and date with one exception not before 131 BCE.

CONCLUSIONS

Our results indicate that the Second Punic War was an important turning point, which supplied Rome with the financial basis to maintain and further expand its territory. Roman coins from the period before the end of the Second Punic War are marked by varying silver fineness and possess Pb isotope signatures comparable to those of coins issued from cities of Magna Graecia, which were supplied with metal initially won from resources of the broader Aegean (Birch et al. 2020). The metal of the Roman coinage presumably was obtained in a peaceful way, that is, by monetary transactions. Roman coins minted after the Second Punic War show an overall high fineness. Their Pb isotope signatures typically correspond to those of metallurgical (by) products from the Iberian Peninsula. The bullion of these coins presumably was acquired as booty and reparation payments and only subordinately won by mining. Overall, our analyses indicate that metal won from the Iberian Peninsula, presumably 'second hand' metal (e.g. from booty, tribute, reparations), at least for the last decade of the third and the largest part of the second century BCE, was far more important for Rome's coinage production than metal directly obtained through mining activities.

ACKNOWLEDGEMENTS

This work was funded by the Volkswagen Foundation (under the Lichtenberg scheme), whose financial support is thankfully acknowledged. FIERCE is financially supported by the Wilhelm and Else Heraeus Foundation and by the Deutsche Forschungsgemeinschaft (DFG, INST 161/921-1 FUGG and INST 161/923-1 FUGG), which is gratefully acknowledged. This is FIERCE contribution No. 11. We are greatly indebted to the curators of the university coin collections of Gießen (Prof. A. Klöckner and Dr. M. Recke), Düsseldorf (Dr. J. Wienand), Heidelberg (Prof. C. Witschel and Dr. S. Börner), and Tübingen (Prof. Th. Schäfer and Dr. S. Krmnicek), and of the LWL-Museum für Kunst und Kultur Westfalen-Lippe (S. Kötz), who generously gave us the permission to sample their coin collections. M. Bladt and N. Prawitz (Goethe University Frankfurt) and P. Späthe (University Würzburg) are thanked for the preparation of the metallographic blocks. The manuscript benefitted greatly from suggestions by Th. Rose (Ben-Gurion University of the Negev) and was significantly improved by the comments of the two reviewers.

AUTHOR CONTRIBUTIONS

Discussion and interpretation of the data and the draft of the text were undertaken by Westner. The manuscript was significantly improved by the respective archaeological, numismatic, or geochemical expertise of Birch, Kemmers, and Klein. The method development of LA-ICP-MS multi-standard element quantification was carried out by Birch. Sampling and analysis of the coins was performed by both Westner and Birch. The overall project was designed by Kemmers, who obtained the funding. Klein, Seitz, and Höfer set up the analytical protocols for MC-ICP-MS, LA-ICP-MS and EPMA, respectively. All authors contributed to and approved the final manuscript.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

Data S1 Supporting information

Data S2 Supporting information