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THE EARLY ROMAN IMPERIAL *AES* COINAGE III: CHEMICAL AND ISOTOPIC CHARACTERISATION OF AUGUSTAN COPPER COINS FROM THE MINT OF LYONS/ LUGDUNUM

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1. Introduction

Some years ago we started a research project on Roman Imperial copper coins and the provenance of the copper used for the official coinage from the first to the third century A.D[1]. We investigated the coin units *as* and *quadrans* made from pure, un-alloyed copper. Considering the low value of the coins, it seemed probable that we could exclude the use of recycled copper as raw material. There would have been too few opportunities to recycle copper, because copper was not processed for other artifacts as a 'pure' copper, but was alloyed with bronze or brass. For reuse, it would have to have been separated again in a complex process. Coins from 'pure' copper were first minted in the mint of Rome in connection with the coinage reform of Augustus[2] , probably in the year 16 B.C[3].

As a part of our master project, we present here the results of the lead and copper isotope analyses and the chemical composition of official Roman copper coinage from the mint at Lyons/Ludgunum, the capital of the three Gauls. We investigated whether the Roman administration oversaw and standardised the use of raw material within official mints, or whether the important mint of Lyons in Gaul used raw material of its own choice, perhaps from local sources, during the reign of Augustus.

Forty-four coins were selected for chemical and isotopic analysis. Chemical characterisation provides important information about the material from which the coins were produced. The lead isotope analysis can be used to trace potential ore sources and their geological background, and can reveal the mines from which the copper was produced. As an additional source of information, copper isotope analysis was carried out on the material in order to build up a reference database of the copper isotopes of ores and archaeological material in the context of our main project.

The analysed coins came from Mainz/Mogontiacum, an important garrison on the Middle Rhine[4], the site of the fort at Worms/Borbetomagus[5], the sanctuary of the Treveran deity Lenus-Mars on the Martberg near Pommern in the Mosel valley[6], as well as from the Roman colony of Augst/Augusta Raurica near Basel[7].

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1 Klein/von Kaenel 2000; Klein/Lahaye/Brey/von Kaenel 2004; for a different approach see C. H. V. Sutherland, Procurement of *aes* for coinage of the early Empire. In: P. Kos/Z. Demo (eds.), Studia Numismatica Labacensia Alexandro Jelocnik oblata (Ljubljana 1988) 27–33.

2 Klein/von Kaenel 2000, 63–64.

3 RIC I² 373. 376. 379 (moneyers Gallus, Celer, Lupercus); Klein/von Kaenel 2000, 65–66. 68. 92.

4 FMRD IV 1, 1148–1203 and FMRD IV 1, N 1; J. Gorecki/G. Rupprecht, Fundmünzen aus dem Römischen Mainz. Archäologische Ortsbetrachtungen 9 (Mainz 2007).

5 FMRD IV 1, 1250–1252 and FMRD IV 1, N 2, 1608.

6 FMRD IV 4, 1.

7 Peter, Augusta Raurica I.

2. Historical and Numismatic Background

In the summer of 16 B.C. Augustus left Rome for Gaul and Spain[8]. He did not return to Rome until the summer of 13 B.C. He spent another year in Gaul from late 11 B.C. and, as far as we know from the sources, visited the region for a final time in 8 B.C. During his stays Augustus resided for much of the time in Lugdunum[9], the capital of Gallia Lugdunensis and the seat of the Council of the three provinces Gallia Aquitania, Gallia Lugdunensis and Gallia Belgica *(concilium Galliarum).*

The presence of Augustus and his stepsons Drusus and Tiberius in Gaul marks a decisive phase in the establishment of Roman power structures in the *Tres Galliae,* as well as coinciding with the earliest attempt to extend Roman rule across the Rhine[10]. This first phase of Augustus' German policy ended with the death of Drusus in Germany during the autumn of 9 B.C. The new offensives conducted by Tiberius and Germanicus were ended by Augustus' successor, Tiberius, soon after Augustus' death.

The implementation of these measures was supported by the presence of a large concentration of troops[11] within the Gallic provinces and on the Rhine. In this context it is not surprising that a mint[12] was established at Lugdunum in 15 B.C., during the emperor's residency there. In the ensuing years this mint produced the bulk of the gold and silver coins issued in the emperor's name[13]. *Aurei* and *denarii* were struck there in large numbers in the years 12, 11, 10 and 8 B.C. Small issues of gold *quinarii* were produced in 9, 8 and 7 B.C. From 7 to 3 B.C. Lugdunum appears not to have struck any precious metal coinage; the production of gold *quinarii* resumed in 2 B.C. and continued in A.D. 1, 2, 4, 6 and 7. At some point, probably between 2 B.C. and A.D. 4, the mint at Lugdunum also struck large quantities of *aurei* and *denarii* with the princes Caius and Lucius Caesares on the reverse[14]. *Aurei*

8 Sources: H. HALFMANN, Itinera principum. Geschichte und Typologie der Kaiserreisen im Römischen Reich. Heidelberger Althistorische Beiträge und Epigraphische Studien 2 (Stuttgart 1986) 158–162.

9 Most recently A.-C. LE MER/C. CHOMER, Carte archéologique de la Gaule 69/2, Lyon (Paris 2007); A. DESBAT (ed.), Lugdunum. Naissance d'une capitale. Exhibition catalogue Lyon 2005/06 (Gollion 2005); J. F. DRINKWATER, Lugdunum: ‚Natural Capital' of Gaul? Britannia 6, 1975, 133–140.

10 Survey in A. FERDIÈRE, Les Gaules (Provinces des Gaules et Germanies, Provinces Alpines). II^{e} siècle av. – V^{e} siècle ap. J.-C. (Paris 2005) 133–166; D. KIENAST, Augustus. Prinzeps und Monarch^{4} (Darmstadt 2009) 118–128. 357–366; J.F. DRINKWATER, Roman Gaul. The three Provinces, 58 BC – AD 260 (London/Sidney 1983) 20–25. 93–118; O. HIRSCHFELD, Die Organisation der drei Gallien durch Augustus. Klio 8, 1908, 464–476.

11 M. REDDÉ ET AL. (eds.), L'architecture de la Gaule romaine. Les fortifications militaires. Documents d'archéologie française 100 (Paris/Bordeaux 2006) 24–32; E. RITTERLING, Zur Geschichte des römischen Heeres in Gallien unter Augustus. Bonner Jahrbücher 114/115, 1906, 159–188.

12 On the mint at Lugdunum during the Augustan period: RIC I^{2} pp. 27–29; GIARD 1983, 38–47.74–114; AMANDRY/ESTIOT/GAUTIER 2003, 15–18.

13 Survey of the precious metal types from Lyons RIC I^{2} pp. 52–56.

14 RIC I^{2} 206–212. On the type: BERGER 1996, 25–31; R. WOLTERS, Gaius und Lucius Caesares als designierte Konsuln und principes iuventutis. Die lex Valeria Cornelia und RIC I^{2} 205 ff. Chiron 32, 2002, 297–323.

and *denarii* were then produced once more in A.D. 13/14[15], and some of the types featured Augustus' designated successor, Tiberius.

However, not just gold and silver, but also brass and copper[16] were produced at Lugdunum. As part of a programme implemented shortly before 20 B.C., Augustus reformed the bronze coinage[17], involving the introduction of new denominations in brass (*sestertius* and *dupondius*), and later in copper (*as* and *quadrans*). *Asses, sestertii* and *dupondii* were subsequently also produced at Lugdunum, as well as a new brass denomination, the *semis*[18] – although this last denomination was not struck until the second altar series. All of the brass and copper denominations from Lugdunum had the same reverse: the altar dedicated to Roma and Augustus in the central sanctuary of the Council of the Gauls[19]. The sanctuary was situated opposite the colony of Lugdunum, above the confluence of the Sâone and the Rhône *(Condate)*.

On the basis of differences in the obverse legends and portraits, numismatists have identified two series from the mint at Lugdunum (I and II)[20]. The following study is concerned solely with the copper *asses* of series I and II (*Fig. 1*). Two types which previously were regarded as *quadrantes* from Lyons/Lugdunum[21] (RIC I² 227 and 228) are excluded. The denomination and mintage of both types is now open to discussion since it has been established that their flans are made, not of copper, but of brass[22]. It is unlikely that they were struck in Ludgunum; their geographical distribution suggests a mint somewhere in Northern Gaul.

15 RIC I² 219–226.

16 RIC I² pp. 57–58.

17 Discussed in KLEIN/VON KAENEL 2000, 63–64 (with further references).

18 RIC I² 234.239.243.246.

19 M.-P. DARBLAIDE-AUDOIN, Nouvel Espérandieu II. Recueil général des sculptures sur pierre de la Gaule: Lyon (Paris 2006) 111–113; D. FISHWICK, The Imperial Cult in the Latin West. Studies in the Ruler Cult in the Western Provinces of the Roman Empire I, 1. Études préliminaires aux religions orientales dans l'Empire Romain (Leiden/New York 1987) 97–137; R. TURCAN, L'Autel de Rome et d'Auguste 'Ad Confluentum' in: ANRW II, 12,1 (Berlin 1982) 607–644; H. DRAGENDORFF, Der Altar der Roma und des Augustus in Lugdunum. JdI 52, 1937, 111–119. – On the overall context see also E.S. RAMAGE, Augustus' Propaganda in Gaul. Klio 79, 1997, 117–160; on the function of the council J. DEININGER, Die Provinziallandtage der römischen Kaiserzeit von Augustus bis zum Ende des dritten Jahrhunderts n. Chr. Vestigia 6 (München 1965) 99–107.

20 BMC Emp. I, pp. 92–97 (Series I: B.C. 10–6(?), Series II: C. A.D. 10–14); K. Kraft, Das Enddatum des Legionslagers Haltern. Bonner Jahrbücher 155/56, 1955/56, 95–111 (Serie I: 10–3 v. Chr.).

21 RPC I, 508. 509; see also the partly speculative ideas on both types in SAUER 2005, 35–42; J.-M. DOYEN, Économie, monnaie et société à Reims sous l'Empire romain. Recherches sur la circulation monétaire en Gaule septentrionale intérieure. Bulletin de la Société archéologique champenoise 100, No. 2 et 4, 2007, 85–93 argues for a mint at Reims (Durocortorum).

22 Our analyses of six examples have produced values of 78–81 wt% Cu and 18–22 wt% Zn.

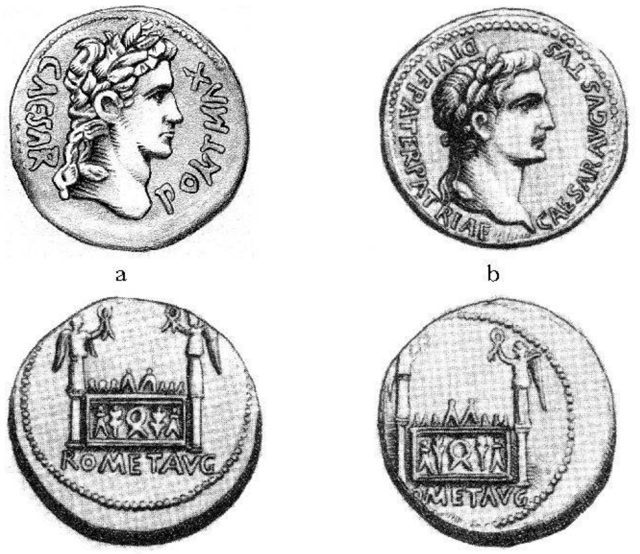

Fig. 1 *Asses* of Lyons altar series I (a, RIC I^2 230) and II (b, RIC I^2 233).

Evidence for the minting of coins at Lugdunum is provided not just by the coins themselves, but also by texts, inscriptions[23], and archaeological evidence. On the other hand, the coin flans found during excavations at Lyons-Vaise[24] do not seem to date to the early imperial period.

[23] Strab., Geogr. IV 3, 2; H. Dessau (ed.), Inscriptiones Latinae Selectae I (Berlin 1892) no. 1639; 2130 and III, 2 (Berlin 1916) no. 9077; Y. Le Bohec, *Coh. XVII Lugdunensis ad monetam.* Latomus 56, 1997, 811–818.

[24] A. Audra, Synthèse des trouvailles monétaires. I, Les découvertes des flans monétaires. In: Le Mer/Chomer (note 9) 231; A. Audra/P. Mathey, Les flans monétaires. In: E. Delaval et al., Vaise, un quartier de Lyon antique. Documents d'Archéologie en Rhône-Alpes 11 (Lyon 1995) 252; A. Audra, Les monnaies et les flans monétaires lisses de la place Valmy (Lyon-Vaise, 9e arrondissement). BSFN 49, 1994, 948–950; A. Audra, Découverte de flans monétaires dans la fouille du quai Arloing. BSFN 46, 1991, 200.

3. Asses of the first Lyons altar series, LAS I (7–3 B.C.)

Asses of the first Lyons altar series are found in large quantities[25] in both military and civilian contexts in the Gallic provinces and on the Rhine. The finds from the region of Kalkriese[26] clearly demonstrate the extent to which these altar *asses* dominated the small change carried by soldiers in A.D. 9.

The obverse type of these coins consists of a laureate portrait of Augustus facing right and the legend CAESAR PONT(ifex) MAX(imus), while the reverse displays the altar of the sanctuary of the Council of the three Gauls in Lugdunum and the legend ROM(ae) ET AVG(usto) (RIC I² 230).

The date of the minting of the first Lyons altar series cannot be determined precisely on the basis of the design and legend, although an indication is provided by the election of Augustus to the office of *Pontifex Maximus* early in 12 B.C. and the dedication of the *ara Romae et Augusti* on August 1st , 12 or 10 B.C.[27]. In 2 B.C. Augustus assumed the title *pater patriae,* which is not included in the imperial titulature of the first series.

On this basis it was assumed that the first series of *asses* was struck from 10–6 (?) or 10–3 B.C.[28]. J.-B. Giard suggested that this should be narrowed to 10–7 (?) B.C.[29], while P. Ilisch and J. van Heesch proposed that production can hardly have started before 7 B.C.[30], since the *asses* are not present at the Roman fortress at Oberaden on the Lippe. The dendrochronological and historical data from this site suggest that it is likely to have been constructed in 11 B.C. and abandoned in 8/7 B.C. Striking will have ended no later than 3 B.C., since the mint at Lugdunum resumed the production of precious metal in 2 B.C. This means that the first altar

25 Survey and reference to the distribution of series I *asses:* BERGER 1996, 34–38; J. VAN HEESCH, Some considerations on the circulation of Augustan and Tiberian bronze coins in Gaul. In: WIEGELS (ed.) 2000, 153–170; BESOMBES/BARRANDON/MARTINI 2004, 11–21; R. WOLTERS, Kalkriese und die Datierung okkupationszeitlicher Militäranlagen. In: LEHMANN/WIEGELS (eds.) 2007, 150–157; DOYEN 2007 (note 21), 51–62.

26 For the most recent figures (697 examples) F. BERGER, Unverändert: Die Datierung der Varusschlacht. In: LEHMANN/WIEGELS (eds.) 2007, 113–117; F. BERGER, Die Münzen von Kalkriese. Neufunde und Ausblick. In: WIEGELS (ed.) 2000, 11–45; BERGER 1996, 34–38. 102–169; for Kalkriese see G. MOOSBAUER/S. WILBERTS-ROST; Kalkriese und die Varusschlacht. Multidisziplinäre Forschungen zu einem militärischen Konflikt and A. ROST, Das Schlachtfeld von Kalkriese. Eine archäologische Quelle für die Konfliktforschung. In: Varusschlacht im Osnabrücker Land GmbH – Museum und Park Kalkriese (eds.), 2000 Jahre Varusschlacht-Konflikt (Stuttgart 2009) 56–67 and 68–76.

27 August 1th 12 or 10 B.C.? On the different interpretations of the relevant sources, most recently D. FISHWICK, The Dedication of the *Ara Trium Galliarum.* Latomus 55, 1996, 87–100; J.W. RICH, The foundation of the altar of Roma and Augustus at Lugdunum. In: H.D. JOCELYN/H. HURT (eds.), Tria Lustra. Essays and notes presented to J. Pinsent. Liverpool Classical Papers 3 (Liverpool 1993) 193–201.

28 Cf. note 20.

29 GIARD 1983, 44.

30 P. ILISCH, Die Münzen aus den Ausgrabungen im Lager Oberaden: In: B. TRIER (ed.), Die römische Okkupation nördlich der Alpen zur Zeit des Augustus. Akten Kolloquium Bergkamen 1989. Bodenaltertümer Westfalens 26 (Münster 1991) 146–147; VAN HEESCH 1993, 535–538; J.-S. KÜHLBORN, Bergkamen/Oberaden. In: REDDÉ ET AL. (eds.) 2006 (note 11) 220–224.

series was produced at a time when no precious metal coinage was being struck at Lugdunum.

Further support for this suggestion is provided by the fortress at Dangstetten on the Upper Rhine[31]. The site cannot be dated as precisely as Oberaden, but on the basis of historical events, as well as the characteristic composition of the extensive pottery ensemble, the site seems to have been abandoned at about the same time, and Lyons first series altar *asses* are also absent there.

The date of 7–3 B.C. for the first series of altar asses has found wide acceptance, although it has recently been called into question again[32]. Clearly the closing date of 3 B.C. is not as certain as the start date of 7 B.C., secured as the latter is by the archaeological evidence (Oberaden). The terminal date is based on (1.) the assumption that the new title *pater patriae* must immediately have been adopted into the emperor's titulature on the coins from Lugdunum, and (2.) the argument that the capacity of the mint at Lugdunum would have been exhausted by the production of the precious metal coinage which resumed in 2 B.C., and so it will have not been in a situation to continue producing copper. Both arguments may be plausible, but neither is firmly supported by the available evidence or is conclusive.

Recently E. Sauer proposed that the production of the first altar series continued until the beginning of the second series at the end of the first decade A.D.[33]. His evidence for this was provided by a study of the proportions of the second series from Nemausus and the first series from Lugdunum in particular archaeological contexts. However this is problematic, as it implies the continued production of a coin type for some 15 years without any typological development.

J.-B. Giard was able to distinguish between two separate groups of *asses* from the first altar series on the basis of weight and fabric: a 'heavier' (11.26 g.) and a 'light' (9.50 g.) group[34]. He argued that in addition to the mint at Lugdunum ('heavier' group), an auxiliary mint (*atelier auxiliaire,* 'light' group) must also have been responsible for the production of the first series. This proposition has not been widely accepted[35], in spite of the fact that in defining the groups J.-B. Giard employed criteria that can and must be used in this situation, since

31 G. Fingerlin, Küssaberg-Dangstetten (WT) – Lager für eine größere Truppeneinheit. In: D. Plank (ed.), Die Römer in Baden-Württemberg. Römerstätten und Museen von Aalen bis Zwiefalten (Stuttgart 2005) 156–160; G. Fingerlin, Dangstetten, ein augusteisches Legionslager am Hochrhein. Vorbericht über die Grabungen 1967–1969. 51./52. Bericht der Römisch-Germanischen Kommission 1970/1971, 1972, 213–215; for the chronological discussion see U. Ehmig, Zum Vergleich der gestempelten Sigillata aus den römischen Militärlagern von Dangstetten und Oberaden. Archäologisches Korrespondenzblatt 40, 2010, 551–556.

32 Sauer 2005, 24–35; Besombes/Barrandon/Martini 2004, 11–21; R. Wolters, Kalkriese und die Datierung okkupationszeitlicher Militäranlagen. In: Lehmann/Wiegels (eds.) 2007, 150–157.

33 Sauer 2005, 30–31.

34 Giard 1967, 126–129; Giard 1983, 47.112–114. The average weights given here are taken from Besombes/Barrandon/Martini 2004, 18.

35 For counterarguments see van Heesch 1993, 538; H. Zehnacker/J.-C. Richard/J.-N. Barrandon, La trouvaille de la Villeneuve-au-Châtelot (Aube). Trésors monétaires 6 (Paris 1984) 63.

there are no substantial typological variations on the obverse and reverse types of the first series. E. Sauer revived the thesis that there was an auxiliary mint[36], but without refuting the objections which had been made, and without providing any new arguments. On the other hand, P.-A. Besombes discussed the numismatic evidence and the various views expressed in order to arrive at a compromise an a slightly modified chronology[37]. He suggests that the altar *asses* of the 'light' group were not the product of an auxiliary mint, but were an initial issue from Lugdunum to be dated to 10 B.C.; the majority of the 'heavier' *asses* were then produced in 7–3 B.C.

In view of the archaeological evidence presented above, which is of paramount importance for the dating of the first altar *asses* series, we find this revised chronology unlikely. Furthermore, since the metrology of these pieces has not yet been the subject of a systematic numismatic study, it is difficult to decide just how decisive and relevant the variations in weight are. Instead, we feel that the limited knowledge we have at present means that we must work on the assumption that the time and place of production of the two groups should not be separated. Within the context of this study no new solutions can be expected to the open questions on the matter of the emission of the first series of altar *asses*. However, it does seem important to ascertain where the copper ingots that were used to cast the flans analysed here came from. After all, they were the first copper coins to be struck at Lugdunum. Were ingots from the nearby copper mines in the Alpine region or Gaul used? Or did the copper come from Italy or the Iberian Peninsula? In order to answer these questions, the chemical composition and the lead-isotope fingerprint of *asses* from the first altar series were analysed.

As far as the arrangement of the coins was concerned, it seemed sensible to treat the *asses* that were clearly 'imitations' as a special group (C), separate from the rest. Since there were also clear differences in their fabric[38], the Lugdunum *asses* are here divided into two classes (A and B).

Group A consists of *asses* on which the bust of Augustus has a squarish basic shape and long, finely arranged hair on the forehead. One end of the tie that holds the laurel wreath on the emperor's head together has a characteristic fold to the right and runs across the neck. This group corresponds to the altar *asses* of the 'heavier' group which J.-B. Giard attributed to the mint at Lugdunum[39]. Group B on the whole consists of somewhat lighter *asses* struck from poorer dies, where the emperor's bust is basically roundish. The relevant locks of hair tend to be shorter and less clearly arranged, while the ends of the tie of the laurel wreath are parallel and run straight down, almost without any overlay on the neck. Group B is the equivalent of the products of J.-B. Giard's auxiliary mint[40].

Coins were classified as 'imitations'[41] if their fabric, style, weight, and die design differs significantly from the 'regular' issues of groups A and B.

36 Sauer 2005, 32.
37 Besombes/Barrandon/Martini 2004, 18–20.
38 Giard 1983, pl. 20. 21. 29–31; Giard 1976, pl. 62–65; H. Zehnacker/J.-C. Richard/J.-N. Barrandon 1984 (note 35) pl. 14–22.
39 Giard 1967, 126–129; Besombes/Barrandon/Martini 2004, 19–20.
40 See note 39.
41 Overview: J.-B. Giard, La pénurie de petite monnaie en Gaule au début du Haut-Empire. Journal des Savants Avril – Juin 1975, 81–102.

4. Asses of the second Lyons altar series, LAS II (8(?)/9–14 A.D.*)*

The second altar series from Lyons comprises a number of brass and copper issues that were struck at Lugdunum at the end of Augustus' reign. In contrast to the first series, for which there was only one *as* type, the *asses* of the second series consist of five (perhaps six) different types[42]. While all of these have a common reverse with the Lyons altar for Rome and Augustus and the legend ROM(ae) ET AVG(usto), they have different obverses. One type, RIC I² 233, has an Augustan portrait and legend; the others have legends and busts of the crown prince Tiberius (RIC I² 237, 238, 245). The legends of the coins for Tiberius have the numbers of his imperatorial acclamations (V, VI (?) and VII), thus dating the production of the *asses* to the period between 8 (?)/9 and 14 A.D.[43]. J.-B. Giard argues – in our view unconvincingly – that RIC I² 245 continued to be struck after Augustus' death[44].

The type with the portrait of Augustus (RIC I² 233) contains the title *pater patriae* in the legend, which Augustus assumed in 2 B.C. The coins could have been struck at any time after this date. However, based on the similarities in the fabric of these *asses* and those struck in the name of Tiberius, and taking into account the fact that, just like the *asses* of Tiberius, the copper *asses* in the name of Augustus were struck together with brass *sestertius* and *dupondius* units, as well as with a new *semis* denomination, it is assumed that the issues for Augustus and for Tiberius are contemporary[45]. The absence of the *as* type RIC I² 233 among the copper coins from Kalkriese[46] also indicates that they were struck in the final years of Augustus' reign.

The second series of *asses* cannot be divided into two groups in the way that the coins of the first series were. Their weight and fabric is more homogeneous. As a result the samples analysed were placed into a single group, D, and distinguished only from the corresponding imitations (group E).

5. Numismatic questions regarding the copper of LAS I and LAS II asses

In the context of this numismatic discussion the scientific analyses were performed with the following questions in mind:

1. Is the copper of the flans within groups A, B (series LAS I) and D (series LAS II) homogeneous with respect to elemental composition and provenance (lead isotope ratios)? Where did the copper for these coins come from?
2. Is the chemistry and provenance of the copper from the flans in group A different from that used in group B and/or in group D? Does the copper employed permit us to differentiate the flans of groups A, B and D spatially or temporally?

42 RIC I² 233 (Giard 1983, 97); RIC I² 237 (Giard 1983, 101); RIC I² 238 a.b (Giard 1983, 105.109); RIC I² 242 (IMP VI: the coins referred to are doubtful); RIC I² 245 (Giard 1983, 114).

43 D. Kienast, Römische Kaisertabelle. Grundzüge einer römischen Kaiserchronologie³ (Darmstadt 2004) 78.

44 Giard 1983, 47.

45 BMC Emp. I, p. 94; RIC I², p. 57.

46 See note 26.

3. Is there a relationship between the copper used in Lyons for minting *asses* and the copper that was used by the mint in Rome?
4. Is the chemistry and provenance of the copper used for the imitations in group C (LAS I) and group E (LAS II) different from that used for the official coins?
5. Can our data for the chemical composition of LAS I and LAS II *asses* be related to those published by J.-N. Barrandon in 2003 and 2004?

6. Analytical methods

Samples were taken from the Lugdunum coins by drilling with drill bits of 0.8 to 1.0 mm in diameter. Non-corroded material was obtained by drilling into the rim of the coin flans, with the corrosive outer section discarded. Approximately 10–12 milligrams of sample metal from each coin were obtained by this method.

6.1. Electron microprobe analysis

The electron microprobe analysis (EPMA) was carried out with a Jeol Superprobe JXA-8900 with wavelength-dispersive spectrometer system. Copper, tin, zinc, and lead, silver, gold, arsenic, antimony, bismuth, sulphur, iron, manganese, nickel, cobalt, and cadmium were analysed with a beam size of 6 μm in diameter. Ten analyses were performed on each sample to gain a statistically meaningful bulk analysis. Pure metal standards were used for the calculation of concentrations, and we applied the iterative correction scheme ZAF. Detection limits of the elements were in the low ppm range.

For monitoring the accuracy and precision of the analysis, certified standard material was measured simultaneously as unknown samples: NBS Standard Reference Material C1251 (phosphoresced copper – Cu VIII) and C1252 (phosphoresced copper – Cu IX).

6.2. Lead and copper isotope analysis

Ten mg of metal drillings were dissolved in a mixture of ultra-pure nitric and hydrochloric acid. Then an ion-exchange column separation process was applied in order to separate the lead and copper from the copper metal. The copper and lead solutions were finally diluted to a concentration of 500 ppb each. Nickel (500 ppb using a single element Claritas ppt solution from SPEX^{TM}) or thallium (50 ppb using NIST997) was added to the copper or lead solutions respectively for mass bias corrections. The standard reference materials NIST981 and NIST976 were used to monitor the precision and accuracy of the measurements over the whole period of analysis. Isotopic measurements were performed with an MC-ICP-MS (Neptune^{TM}, Finnigan MAT) at low resolution ($\Delta m/m = 400$) using 9 blocks of 9 integrations of approximately 8.4 s each for lead, and 5 blocks of 9 integrations for copper, followed by a 40s baseline measurement. Mercury (^{202}Hg) and Nickel (^{60}Ni) interferences on lead and copper isotopes respectively were monitored during acquisition.

The average accuracy obtained is estimated to be 0.15 ‰ (2σ) for $^{208}Pb/^{206}Pb$ and $^{207}Pb/^{206}Pb$ and 1.3 ‰ (2σ) for $^{206}Pb/^{204}Pb$. External precision for $\delta^{65}Cu$ values is estimated to be 0.4 ‰.

7. *Analytical data and discussion*

7.1. Chemical composition

The results of the chemical analysis are presented in detail in Table 1.

The coins of the early Lyons altar series I (LAS I) are very homogeneous in chemical composition. All the coins are made of a pure copper metal (98.2–99.9 weight % Cu) with traces of some associated elements: tin, silver, arsenic, antimony, sulphur, nickel, cobalt, and iron. In *Figure 2,* the composition of the LAS I series coins (except copper) is plotted in a modified spider diagram.

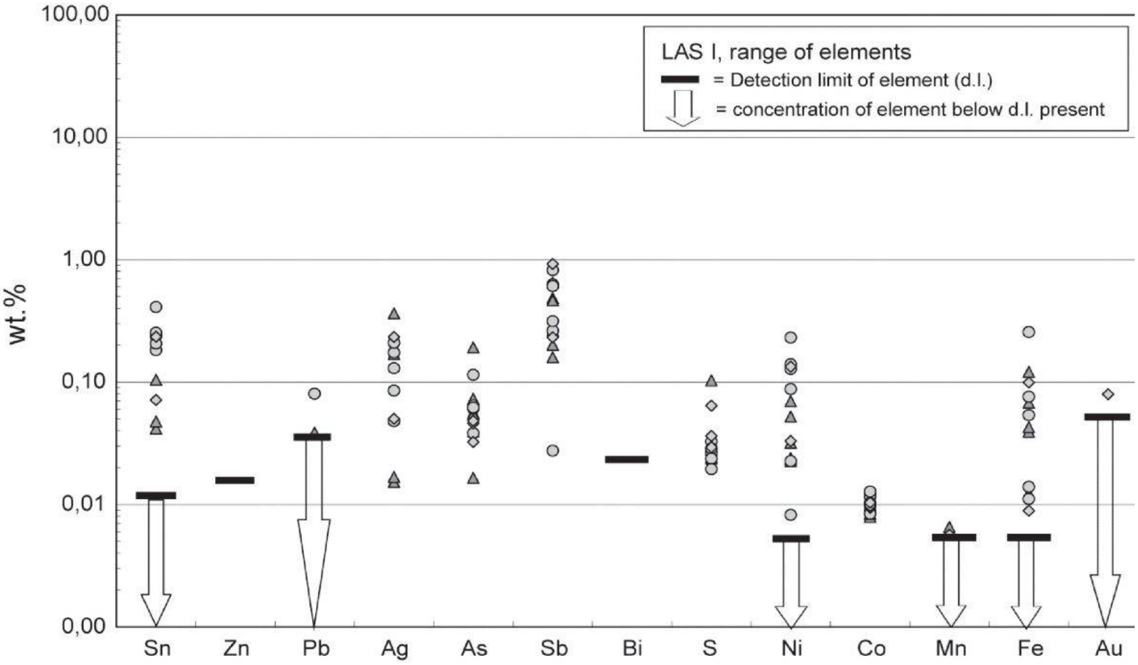

Fig. 2 Element composition (except copper) in weight percentage of LAS I regular issues. Analysis by EPMA (WDS = wavelength dispersive system). The coins are of a very pure copper with traces of additional elements. The black bars indicate the detection limits of the elements calculated for the Frankfurt EPMA system. Blank arrows below the black bars indicate the presence of coins for which the concentrations are lower than the detection limit of the method. [wt.% = concentration of element in weight percentage. Symbols: triangle = group A coins, circle = group B coins, rhombus = coins of group A or B].

Just as with the LAS I, the Lyons altar series II (LAS II) consists of a pure copper metal with >97 weight % Cu. The metal contains traces of various elements (tin, lead, silver, arsenic, antimony, sulphur, nickel, cobalt, and iron). The range of elemental concentrations (except copper) and the element pattern of the LAS II coins analysed are plotted in *Figure 3.*

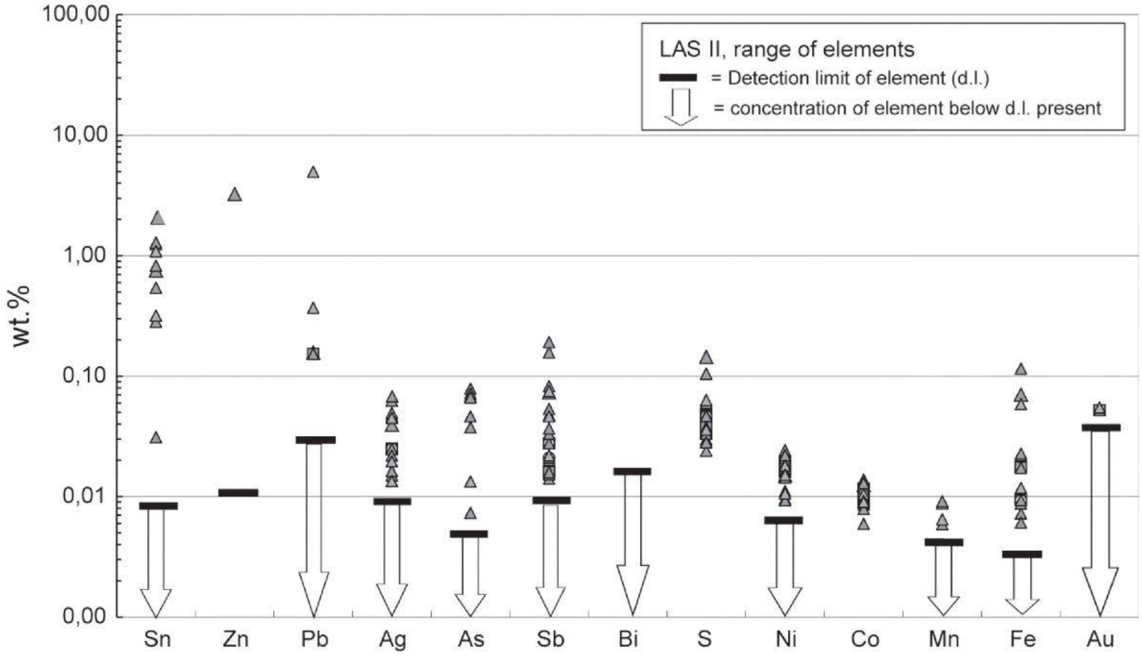

Fig. 3 Element composition (except copper) in weight percentage of LAS II issues. The coins are of a very pure copper with traces of additional elements. The black bars indicate detection limits of the elements calculated for the Frankfurt EPMA (WDS) system. Blank arrows below the black bars indicate the presence of samples for which the concentrations are lower than the detection limit of the method. [wt.% = concentration of element in weight percentage. Symbols: Triangles = group D coins].

7.2. Lead isotope results

All isotope data gained by MC-ICP-MS analysis are presented in Table 2. In the plots of $^{207}Pb/^{206}Pb$ versus $^{206}Pb/^{204}Pb$ *(Fig. 4)* and $^{207}Pb/^{206}Pb$ versus $^{208}Pb/^{206}Pb$ *(Fig. 5), asses* of Lyons altar series I and Lyon altar series II both reveal two tight concentrations of lead isotope ratios. For the following discussion, the two isotope concentrations are circled in the diagrams as two distinct fields. These are labelled LIF (lower isotope field) and UIF (upper isotope field) respectively.

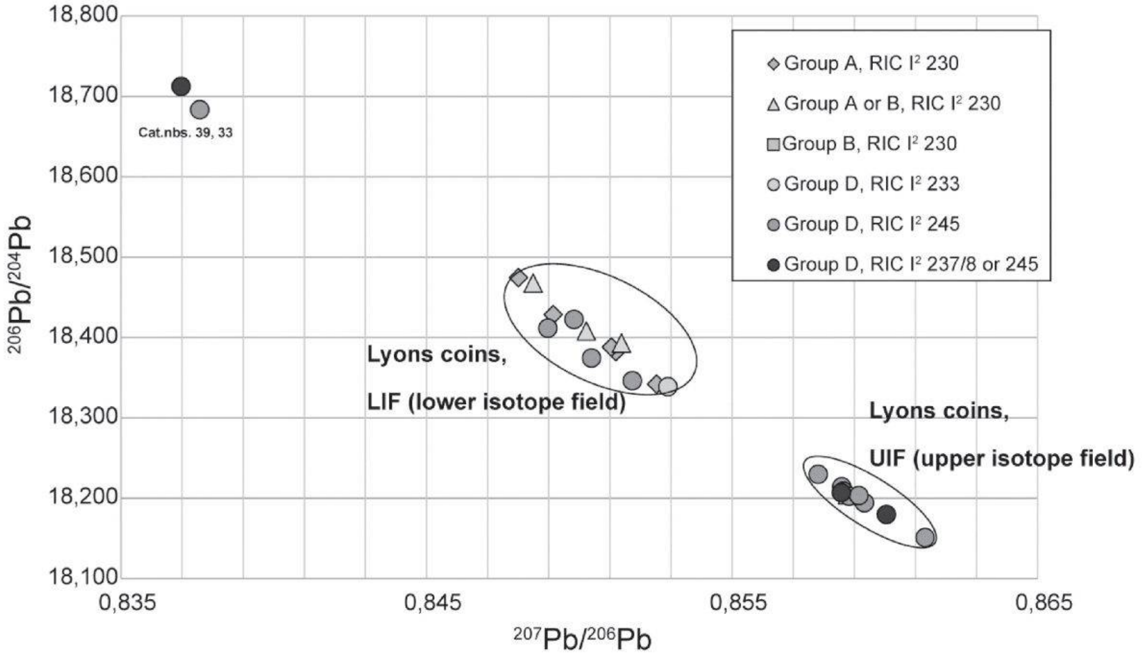

Fig. 4 Diagram ^{207}Pb/^{206}Pb versus ^{206}Pb/^{204}Pb, *Asses* of LAS I and LAS II: two concentrations of lead isotope ratios. [Statistical errors are smaller than symbols].

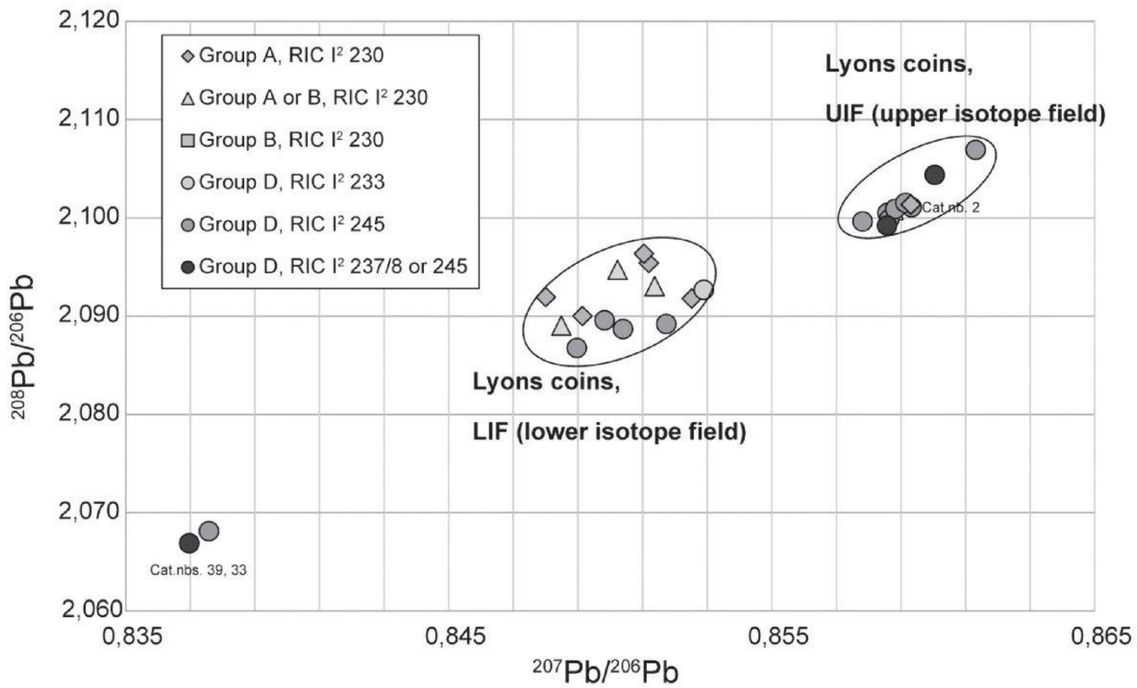

Fig. 5 Diagram ^{207}Pb/^{206}Pb versus ^{208}Pb/^{206}Pb, Lyon copper coins of LAS I and LAS II. The lead isotope ratios obtained by MC-ICP-MS result in two isotope fields. Isotope field UIF is dominated by LAS II coins – only one coin of LAS I (coin no. 2) plots within this field. Isotope field LIF comprises of both LAS I and LAS II coins. [Statistical errors are smaller than symbols].

1. Lead isotope field LIF (lower isotope field) has lower $^{207}Pb/^{206}Pb$ (0.847–0.853) and $^{208}Pb/^{206}Pb$ ratios (2.083–2.096) than UIF. Within LIF, coins of both LAS I and LAS II are found. To summarise, all LAS I coins of group A, B and A/B (except coin no. 2) and about half of the LAS II coins of group D plot within LIF.
2. In lead isotope field UIF (upper isotope field) the data are very tightly accumulated with higher $^{207}Pb/^{206}Pb$ (0.857–0.861) and higher $^{208}Pb/^{206}Pb$ ratios (2.099–2.106). In this field, the other half of the LAS II *asses* (group D) are found, and coin no. 2 from LAS I.
3. Two outliers belong to group D (coins no. 33 and 39). They have the lowest lead isotope ratios and fit neither into UIF nor into LIF.

7.3. Copper isotope results

At present, the aim of the copper isotope analysis is to collect copper isotope data in order to create a database similar to that which exists for lead isotopes in archaeometry. The high potential of copper isotope measurements for distinguishing different types of copper ores (such as oxidized, supergene or primary sulphide copper) has been demonstrated previously[47]. Substantial fractionation of copper isotopes occur between hypogene and supergene copper sulphides, and also oxidised copper ores (such as the hydrocarbonates malachite and azurite), so that a clear distinction between the ore types is possible. Expressed in the $\delta^{65}Cu$ notation, supergene sulphides have values less than −0.4‰ down to negative values of −2‰, primary sulphides have a value around zero (more precisely between −0.4 and +0.3‰), and oxidized copper ores lean towards positive values higher than +0.3‰[48].

However, the overall interpretation of the copper isotope results remains open and must be discussed when more data from relevant ore deposits and objects are available.

The copper isotope results gained for the Lugdunum coins are provided in Table 2. Copper isotope values of LAS I and about half of LAS II concentrate around $\delta^{65/63}Cu = 0$ *(Fig. 6)*. They represent per definition primary sulphides. The remaining LAS II coins scatter widely from $\delta^{65}Cu$ = -5.73 to +1.74 with $^{208}Pb/^{206}Pb$ ratios between 2.10 and 2.11. These lead isotope ratios were characterised earlier for ores from the Iberian Pyrite Belt (South Portuguese Zone). These coins tend to originate from supergene sulphide ores (coins no. 12, 27, 28, 31, 34) or oxidised copper ores (coins no. 15 and 24).

47 Klein/Brey/Durali-Müller/Lahaye 2010.

48 D. Asael/A. Matthews/M. Bar-Matthews/L. Halicz, Copper isotope fractionation in sedimentary copper mineralization (Timna Valley, Israel). Chemical Geology 243, 2007, 238–254; M. Haest/Ph. Muchez/J.C. Petit/J. Vanhaecke, Cu isotope ratio variations in the DIKULUSHI Cu-Ag deposit, DRC: Of primary origin or induced by supergene reworking? Economic Geology 104, 2009, 1055–1064.

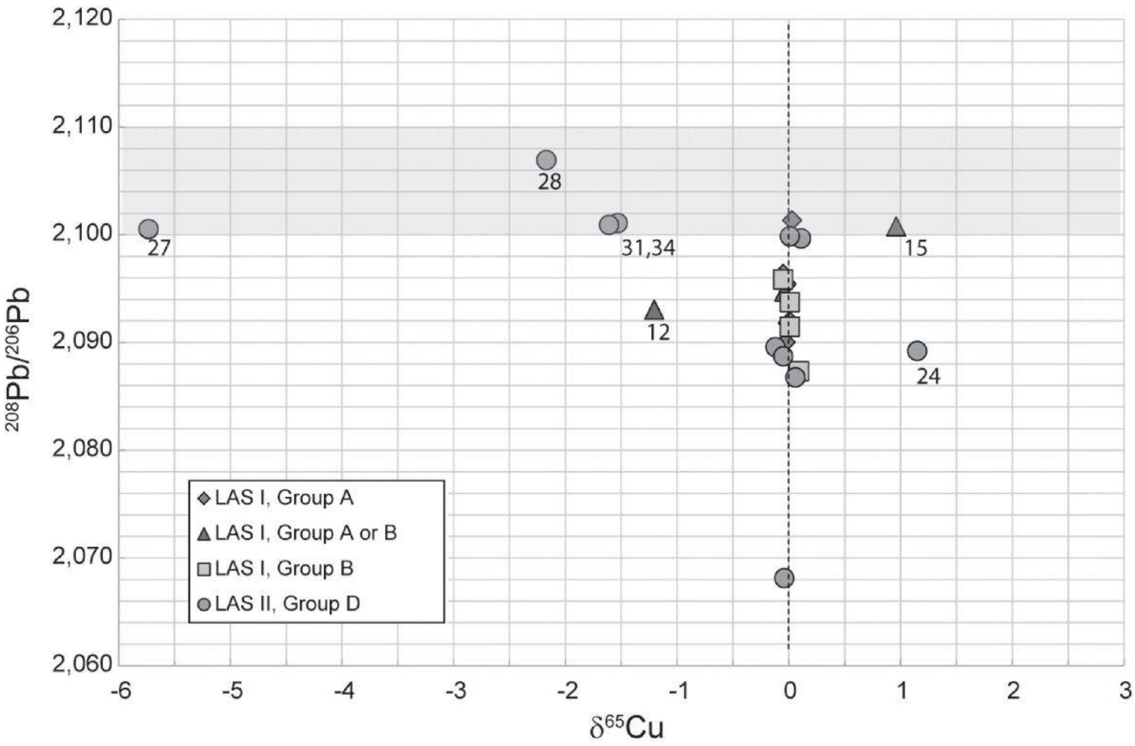

Fig. 6 Copper isotope diagram δ^{65}Cu versus $^{208}Pb/^{206}Pb$. A strong accumulation of data is found along a vertical line δ^{65}Cu=0‰. The horizontal strip (grey) represents the isotope signature of Iberian Pyrite Belt ores.

7.4. Discussion of the analytical data

The aim of lead isotope analysis was to relate the Lugdunum copper coins to possible raw material sources. To this end, the isotope data for the coins have to be compared with the published lead isotope data of ores from locations relevant to the Roman period. These can be found in the literature.

A statistically relevant body of reference data from individual ore deposits or mines can be used to define one or more isotope fields in a lead isotope diagram. If the artefact data fall within these fields then the ore source is most probably found. Difficulties that prevent precise interpretation may arise from a lack of reference data for a deposit, insufficient data being available from a deposit or region, the overlapping of isotope fields of different deposits, and artefacts produced from mixed raw material. In the last case, however, mixing lines can be drawn in the lead isotope diagram, which is framed by two or more end-members[49].

Given that the LAS series were produced in the Western part of the Roman Empire, the most relevant region for comparison with the coinage from Lugdunum is the Mediterranean area. The published data available from the

49 S. Klein, Dem Euro der Römer auf der Spur – Bleiisotopenanalysen zur Bestimmung der Metallherkunft römischer Münzen. In: G. Wagner (ed.), Einführung in die Archäometrie (Heidelberg 2007) 139–152 and Klein/Rico/Lahaye/von Kaenel/Domergue/Brey 2007.

Aegean[50], Cyprus[51], Spain[52], Italy[53], the Alpine region[54] and from France[55], can be plotted to create reference diagrams of the various lead isotope ratios.

By plotting the lead isotope ratios of the Lugdunum coinage into such reference diagrams, the most probable sources of the copper used for minting can be traced.

7.4.1. Correspondence of Lyons upper isotope field (UIF) with the South Portuguese Zone (Iberian Pyrite Belt)

The *asses* of the Lyon UIF match perfectly with the isotope field of ores from deposits within the Iberian Pyrite Belt *(Fig. 7)*. The Iberian Pyrite Belt is one of the largest sulphide provinces in the world, and its deposits have been exploited for metal since the Chalcolithic era. Numerous pre-Roman and Roman mining activities

50 Z. Stos-Gale/N.H. Gale/N. Annetts, Lead isotope data from the Isotrace Laboratory, Oxford: Archaeometry data base 3, Ores from the Aegaen, Part 1. Archaeometry 38, 1996, 381–390.

51 Z.A. Stos-Gale/G. Maliotis/N.H. Gale/N. Annetts, Lead isotope characteristics of the Cyprus copper ore deposits applied to provenance studies of copper oxhide ingots. Archaeometry 39, 1997, 83–123 and S. Stos-Gale/G. Maliotis/N.H. Gale, A preliminary survey of the Cypriot slag heaps and their contribution to the reconstruction of copper production on Cyprus. In: TH. Rehren/A. Hauptmann/J. Muhly (eds.), Metallurgica Antiqua. Der Anschnitt, Beiheft 8 (Bochum 1998) 235–262.

52 J.F. Santos Zalduegui/S. García de Madinabeitia/J.I. Gil Ibarguchi/F. Palero, A lead istope database: The Los Pedroches-Alcuida Area (Spain); Implications for archaeometallurgical connections across southwestern and southeastern Iberia. Archaeometry 46, 2004, 625–634; Z. Stos-Gale/N.H. Gale/J. Houghton/R. Speakman, Lead isotope data from the Isotrace Laboratory, Oxford: Archaeometry data base 1, Ores from the Western Mediterranean. Archaeometry 37, 1995, 407–415; E. Marcoux/J.-M. Leistel/F. Sobol/J.-P. Milési/J.-L. Lescuyer/X. Leca, Signature isotopique du plomb des amas sulfurés de la province de Huelva, Espagne. Conséquences métallogéniques et géodynamiques. Comptes Rendus de l'Académie des Sciences Paris 1992, t. 314, Série II, 1469–1476; E. Marcoux, Lead isotope systematics of the giant massive sulphide deposits in the Iberian Pyrite belt. Mineralium Deposita 33, 1998, 45–58; J.-L. Lescuyer/J.-M. Leistel/E. Marcoux/J.-P. Milési/D. Thiéblemont, Late Devonian-Early Carboniferous peak sulphide mineralization in the Western Hercynides. Mineralium Deposita 33, 1998, 208–220; C. Pomiès/A. Cocherie/C. Guerrot/E. Marcoux/J. Lancelot, Assessment of the precision and accuracy of lead-isotope ratios measured by TIMS for geochemical applications: Example of massive sulphide deposits (Rio Tinto, Spain). Chemical Geology 144, 1998, 137–149.

53 For Sardinia: Z.A. Stos-Gale/N.H. Gale, New light on the provenance of the copper oxhide ingots found on Sardinia. In: R.H. Tykot/T.K. Andrews (eds.), Sardinia in the Mediterranean: A footprint in the sea (Sheffield 1992) 317–345 and F. Begemann/S. Schmitt-Strecker/E. Pernicka/F. Lo Schiavo, Chemical composition and lead isotopy of copper and bronze from Nuragic Sardinia. European Journal of Archaeology 4, 2001, 43–85. For Tuscany: Z.A. Stos-Gale/N.H. Gale/J. Houghton/R. Speakman, Lead isotope data from the Isotrace Laboratory, Oxford: Archaeometry data base 1, Ores from the Western Mediterranean. Archaeometry 37, 1995, 407–415.

54 Hirt 2010, 87; Domergue 2008, 87–88; O. Davies, Roman Mines in Europe (Oxford 1935) 77–78.

55 O. Brevart/B. Dupré/C.J. Allègre, Metallogenic provinces and the remobilization process studied by lead isotopes: Lead-Zinc Ore Deposits from the Southern Massif Central, France. Economic Geology 77, 1982, 564–575.

have been uncovered throughout this copper-rich region[56]. The polymetallic deposits of the Iberian Pyrite Belt are of a volcano-sedimentary character (VHMS) associated with the volcanic rocks of Devonian to Early Carboniferous volcanism[57]. Ores from the Iberian Pyrite Belt are genetically diverse (stock work sulphides, stratiform massive sulphide deposits and gossan[58]). However, the lead isotope signature of the Iberian Pyrite Belt mineralisation is remarkably homogeneous. With the exception of the deposits of Neves-Corvo on the Portuguese side of the belt, the ores of the Iberian Pyrite Belt form a very tight lead isotope field.

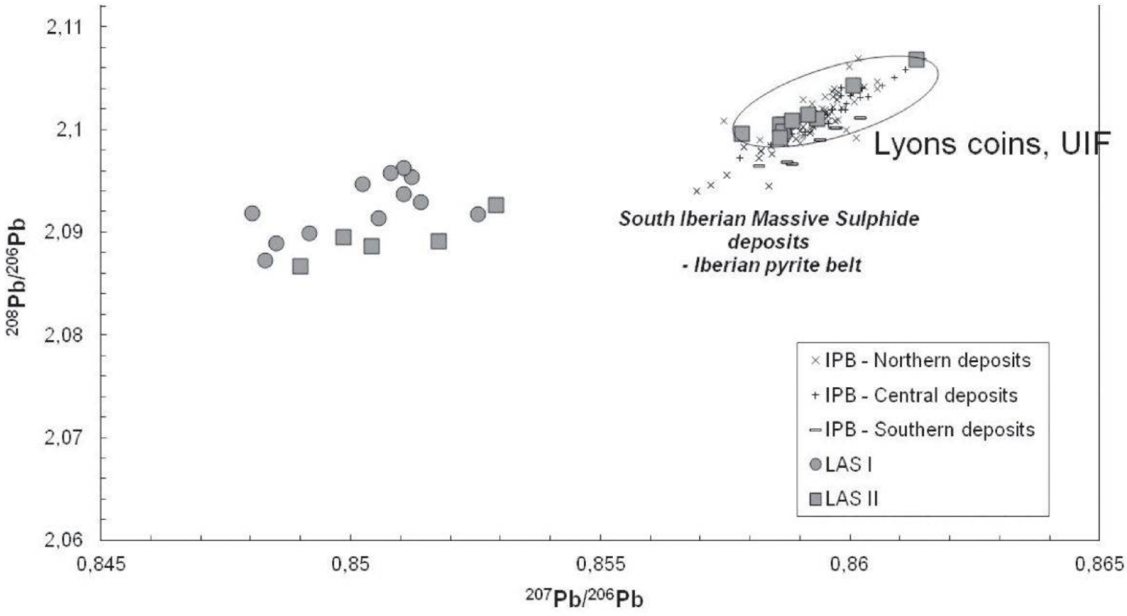

Fig. 7 Reference diagram of lead isotope data from copper ores of the Iberian Pyrite Belt, demonstrating the match with coin isotope field UIF (upper isotope field). All reference data are collected from literature. The Iberian Pyrite Belt ores accumulate very well.

56 C. Domergue, Catalogue des mines et des fonderies antiques de la Péninsule Ibérique. Publications de la Casa de Velázquez, Série Archéologie VIII (Madrid 1987) and C. Domergue, Production et commerce des métaux dans l'Occident romain: L'Hispanie et la Gaule. In: L. Pons Pujol (ed.), Hispania et Gallia: Dos provincias del occidente Romano. Instrumenta 38 (Barcelona 2010) 109–123; Domergue 2008, 87–88. Tableau V; Domergue/Serneels/Cauuet/Pailler/Orzechowski 2006, 137–138. 152; B. Cauuet/C. Domergue /M. Urteaga, Mines et métallurgies en Aquitaine et en Hispanie septentrionale sous les Julio-Claudiens. In: L'Aquitaine et l'Hispanie septentrionale à l'époque julio-claudienne. Organisation et exploitation des espaces provinciaux. IVe Coll. Aquitania, Saintes, 11–13 septembre 2003. Aquitania, Suppl. 13 (Bordeaux 2005) 423–460.

57 D. Thiéblemont/E. Pascual/G. Stein, Magmatism in the Iberian Pyrite Belt: petrological constraints on a metallogenic model. Mineralium Deposita 33, 1998, 98–110; R. Sáez/E. Pascual/M. Toscano/G.R. Almodóvar, The Iberian type of volcano-sedimentary massive sulphide deposits. Mineralium Deposita 34, 1999, 549–570, and J.-M. Leistel/E. Marcoux/D. Thiéblemont/C. Quesada/A. Sánchez/G.R. Almodóvar/E. Pascual/R. Sáez, The volcanic-hosted massive sulphide deposits of the Iberian Pyrite Belt – review and preface to the thematic issue. Mineralium Deposita 33, 1998, 2–30

58 F. Vázquez Guzman, Spain. In: F.W. Dunning/P. Garrard/H.W. Haslam/R.A. Ixer (eds.), Mineral Deposits of Europe 4/5, 1989: Southwest and Eastern Europe, with Iceland.

7.4.2. Correspondence of Lyons lower isotope field (LIF) with copper ores from central Southern Spain (Central Iberian zone), French ores, or similar from the Western Alps

7.4.2.1 Central Southern Spain

As shown by previous studies on isochronic copper coins from Rome and Roman copper ingots[59], a further potential source of copper is Central Southern Spain, including the Ossa-Morena zone and the Central Iberian zone[60]. The Ossa-Morena zone (named after the Portuguese Ossa and the Spanish Sierra Morena hills) and the Central Iberian zone are geological units of the Hesperian Massive, located on the western Iberian Peninsula. Precambrian and Palaeozoic material was affected through many phases of the Hercynian orogeny. Both the Ossa Morena and the Central Iberian zone are structurally divided into several domains, all running in a NW-SE direction. The ores of the two zones are geologically diverse and connected to the different stages of the geological evolution. Copper ores of the Ossa Morena zone were deposited in wide paragenesis of polymetallic composition as volcanogenic and sediment-hosted massive sulphides, skarns, magmatic deposits, veins, and replacement bodies. In the Central Iberian zone, copper is mostly connected with lead-bearing veins (lead-zinc ores). In the Ossa Morena zone, historical copper mines from which lead isotope data are known are located in the province of Huelva; more specifically these are Sultana (San Rafael), the mine of Cala, and Teuler[61]. The Sierra Morena in Central-Southern Spain (CIZ) is also one of these geological zones: the so-called *Aes Marianum* or *Aes Cordubense* (Pliny the Elder, *Naturalis Historia,* 34, 4) is presumed to have been produced in this region.

Due to the diverse deposition of copper ores within the Ossa Morena and the Central Iberian zone, and due to the relevant geological time periods, the lead isotope data of the Ossa Morena area scatter as a broad diagonal zone across the bivariate lead isotope diagrams. The most important mining area in Roman times was the Sierra Morena, which belongs geologically to the Central Iberian zone. This zone has well defined lead isotope accumulations resulting in two isotope fields[62]. For the Lugdunum coins, the match of the LIF with Central Southern Spanish ores is not convincing *(Fig. 8).*

59 For coins see Klein/Lahaye/Brey/von Kaenel 2004; for ingots: C. Rico/C. Domergue/M. Rauzier/S. Klein/Y. Lahaye/G.P. Brey/H.-M. von Kaenel, La provenance des lingots de cuivre romains de Maguelone (Hérault, France). Étude archéologique et archéométrique. Revue Archéologique de Narbonnaise 38/39, 2005/2006, 459–472.

60 Isotope data taken from 1) M.A. Hunt Ortiz, Prehistoric Mining and Metallurgy in South West Iberian Peninsula. BAR International Series 1188 (Oxford 2003); 2) F. Tornos/M. Chiaradia, Plumbotectonic Evolution of the Ossa Morena Zone, Iberian Peninsula: Tracing the Influence of Mantle-Crust Interaction in Ore-Forming Processes. Economic Geology 99, 2004, 965–985; 3) Klein/Domergue/Lahaye/Brey/von Kaenel 2009.

61 Note of C. Domergue, 30.3.2006.

62 Klein/Domergue/Lahaye/Brey/von Kaenel 2009.

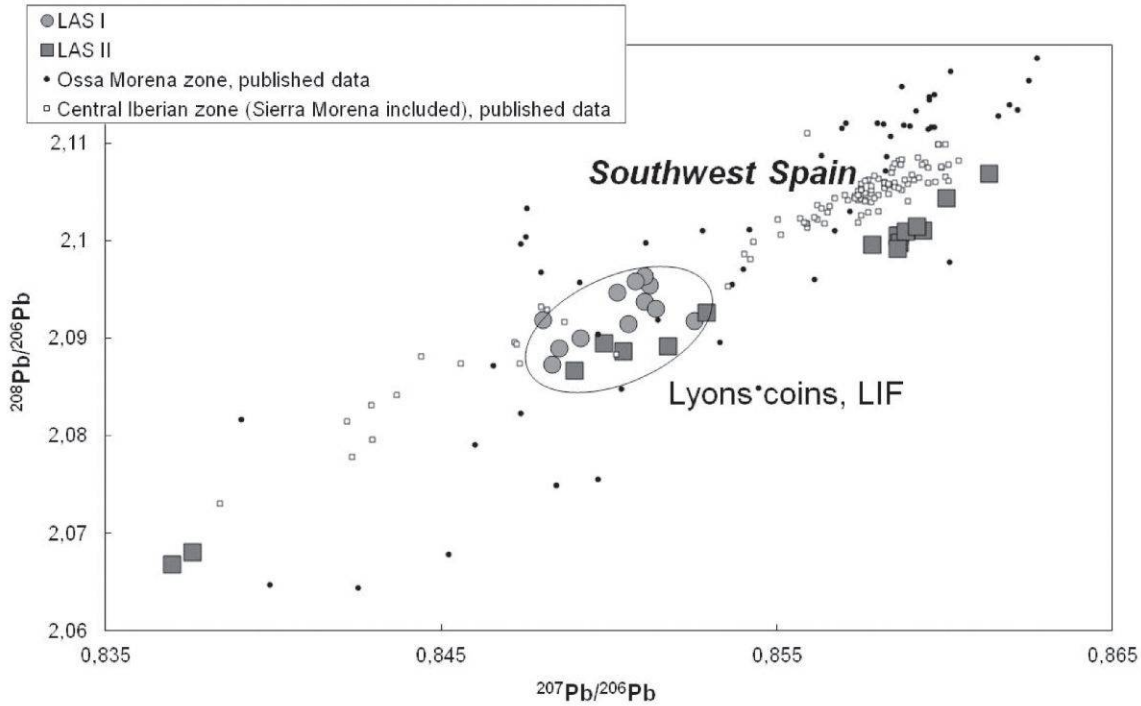

Fig. 8 Diagram $^{207}Pb/^{206}Pb$ versus $^{208}Pb/^{206}Pb$. Reference lead isotope data from copper ores of the Ossa Morena and the Central Iberian zone. No match can be seen between the coin isotope field LIF (lower isotope field) and the south-western ores. Reference data are collected from literature.

7.4.2.2. French copper ore deposits as a possible short-term local source?

From the outset, we thought that local raw material could have been used to mint *asses* at Lugdunum, at least to supplement material from larger deposits elsewhere. For this reason, we took a close look at French copper ore deposits as possible sources. Important ore formations in France are recorded in the Massif Central and neighbouring regions. The Massif Central ores range from Meso-Variscan (Late Devonian) to Neo-Variscan VMS deposits (Volcanogenic Massive Sulphide) of geological age ~ 330-315 Ma with Fe-Zn-Cu-Pb(-Ba), or peribatholitic quartz veins or breccia pipes (W-Fe-Cu-Zn-As-Bi). Of minor importance are Neo-Variscan porphyry ores (Cu-Mo) and hydrothermal replacements (Pb-Zn-Cu-Co-In). Published lead isotope data are available for ore deposits in the Southern Massif Central, in the western periphery of the Massif Central, Cevennes and Causses, Montagne Noire and its edges, and Vivarais[63]. The ores analysed in literature date geologically to the Jurassic, Triassic, Cambrian, or Variscan periods. The ores are greatly dominated by sphalerite and galena (Zn-Pb), and only very rarely contain copper minerals. Lead isotope reference data available from literature generate one major isotope accumulation and a broader scatter around

[63] C. Marignac/M. Cuney, Ore deposits of the French Massif Central: insight into the metallogenesis of the Variscan collision belt. Mineralium Deposita 34, 1999, 472–504.

it. The major isotope accumulation (ores from the Massif Central, predominantly Cevennes area) is a good match with the Lyons isotope field LIF (LAS I and part of LAS II coins) in the isotope diagrams ($^{204}Pb/^{206}Pb$, $^{208}Pb/^{206}Pb$, $^{207}Pb/^{206}Pb$). In general, copper appears to be under-represented in the Massif Central and is not represented in the available Cévennes reference data. Unfortunately, there is also very poor archaeological information concerning copper mines in the Massif Central. For some mines, like those from Cabrières and the Orb Valley in the Cévennes, archaeological evidence seems to confirm exploitation during the late first century B.C. and the early Roman Empire[64]. One mine near Carcassone is currently under study by a group in Toulouse[65].

The question arises: was copper mining in Gaul sufficiently widespread and developed to supply the official mint of Lugdunum with an appropriate amount of copper metal during the reign of Augustus? At this point, we rely on our analysis results, the reference data, and the poor archaeological evidence, but together these point strongly to France as a serious candidate for the metal supply of the Lugdunum mint *(Fig. 9)*, at least in the short-term.

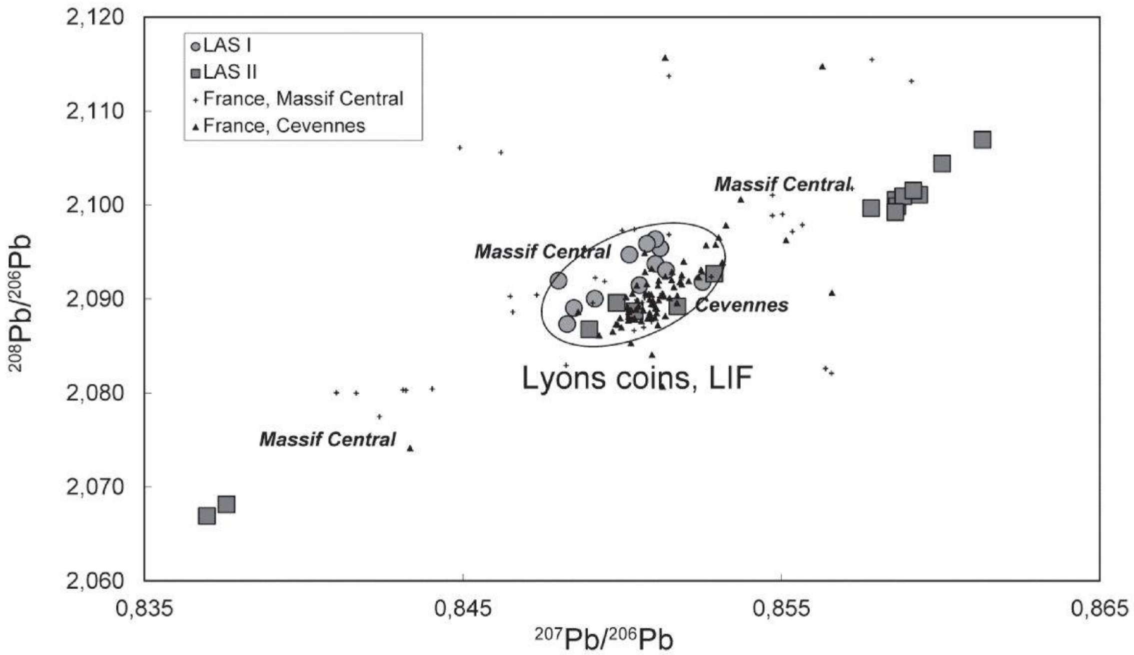

Fig. 9 Diagram $^{207}Pb/^{206}Pb$ versus $^{208}Pb/^{206}Pb$. Reference lead isotope data from French copper ores and the match with coin isotope field LIF (lower isotope field). Reference data are collected from literature.

[64] For a complete panorama see DOMERGUE 2008, 87–88. Tableau V. Les mines de cuivre, no. 23 and DOMERGUE/SERNEELS/CAUUET/PAILLER/ORZECHOWSKI 2006, 137–138.152.

[65] First results were presented at the 3rd conference of Archaeometallurgy in Europe (AIE) in Bochum in 2011: A. BEYRIE/J.-M. FABRE/É. KAMMENTHALER/J. MANTENANT/G. MUNTEANU/C. RICO, The „Barrencs" (South France). A copper and silver mine of the late Republic (II[nd] – I[st] C. BC.). About the archaeological researches 2009–2010. Metalla, Sonderheft 4, 2011, 121–122.

7.4.2.3. "Sallustian" copper or the Alpine region as a possible short-term local source?

In his *Naturalis Historiae* 34,3, Pliny the Elder wrote: '...*The next in quality was the Sallustius copper, occurring in the Alpine region of Haute Savoie* (i.e. in Centronum Alpino tractu), *though this also only lasted a short time; and after it came the Livia copper in Gaul: each was named from the owners of the mines, the former from the friend of Augustus and the latter from his wife. Livia copper also quickly gave out: at all events it is found in very small quantity....*'[66]. In this context, one must ask whether the "Sallustian" region of the Alps should be considered as a short-term copper supplier for the production of Augustan copper coinage (in this case for the Lyon Altar series I). Upon closer inspection, the Alpine region of interest must concentrate in the Western part of the Alps. Pliny reports copper sources in the territory of the *Ceutrones* in the Isère valley[67], but their location cannot be identified, neither archaeologically nor isotopically.

An important ore type in the Alps is the fahlore type. Fahlores are copper-iron-antimony or arsenic sulphides, in which copper, antimony, arsenic, and sulphur are present and can be replaced by various elements (Fe, Ag, Bi, Co, Hg, Ni, Pb, Zn, Ge, Sn, Bi, Se, and Te). In addition, fahlores are silver-rich in the Alps. A fahlore signature might be seen in the early Lugdunum coins of Augustus (LAS I), which are characterised by high silver, antimony, arsenic, and nickel content, as well as in the short-term production of very early Augustan *asses* from the mint of Rome, which have been demonstrated to also be relatively rich in silver, antimony, arsenic, and nickel[68].

Since the chemical fingerprint alone cannot conclusively prove the use of alpine ores in this early phase of minting, we turned to the lead isotopes. The availability of lead isotope reference data from the alpine ores is regionally biased, being very much focused on the Eastern Alps and on lead-zinc or gold ores[69]. Based on Pliny's reports, we carefully gathered published lead isotope data from the following locations: Switzerland, Valais, the Mont-Blanc region, the Massive of the Aiguilles Rouges and the Great St Bernard[70], Italy, and France (Monte Rosa

66 H. Rackham (ed.), Pliny Natural History IX, Libri XXXIII – XXXV. The Loeb Classical Library (London 1961) 129.

67 M. Segard, Les Alpes occidentales romaines. Développement urbain et exploitation des ressources des régions de montagne (Gaule Narbonnaise, Italie, provinces alpines). Bibliothèque d'Archéologie Méditerranéenne et Africaine 1 (Aix-en-Provence 2009) 153. 239–240; Domergue 2008, 88 with note 59.

68 Klein/von Kaenel 2000.

69 V. Köppel/E. Schroll, Pb-Isotope evidence for the origin of lead in strata-bound Pb-Zn deposits in Triassic carbonates of the Eastern and Southern Alps. Mineralium Deposita 23, 1988, 96–103; V. Köppel/F. Neubauer/E. Schroll, Pre-alpidic ore deposits in the Central, Eastern and Southern Alps. In: J.F. von Raumer/F. Neubauer (eds.), Pre-Mesozoic Geology in the Alps (Berlin/New York 1993) 145–162; T. Pettke/R. Frey, Isotope systematics in vein gold from Brusson, Val d'Ayas (NW Italy), 1. Pb-Pb evidence for a Piemonte metaophiolite Au source. Chemical Geology 127, 1996, 111–124.

70 B. Guénette-Beck, Minerais, métaux, isotopes: recherches archéométriques sur les mines de plomb et d'argent en Valais, Suisse. Ph.D. 2006, Institut de Minéralogie et Géochimie, Fribourg. Note though that the Switzerland reference data from Guénette-Beck are not based on copper ores but rather on lead ores (galenite). This can be misleading for provenance interpretation of copper objects.

and Limousin[71]). When compared with the Lugdunum copper coins, the result was negative: no convincing overlap between the alpine ores of interest and the coins could be found.

8. Numismatic questions and discussion

The results of the chemical and lead isotope analysis provide answers to questions 1–5 (above) as follows:

(1) Is the copper of the flans within groups A, B (series LAS I) and D (series LAS II) homogeneous with respect to elemental composition and provenance? Where did the copper used for these coins come from?

LAS I, groups A and B:
Both group A and B flans are made of a very pure copper. The copper content ranges between 98.2 to 99.9 weight % Cu. Significant trace elements for these coins are tin, silver, arsenic, antimony and nickel, but the concentration range of these elements is similar for A and B. The three coins from LAS I that cannot unquestionably be classified into group A or B (Group A or B, no. 12, 13, 14) are similar in chemical composition to the group A and B coins.

As for the lead isotope composition, A and B also correspond to each other. Therefore A and B cannot be differentiated by isotopes either. The two groups are treated as compositionally equal, and the raw metal for the production of the coins of groups A and B was most probably mined from French ores.

Figure 10 presents the result of a hierarchical cluster analysis with the Ward method using squared Euclidic distances. The differences between the resulting clusters are very small. Focused on the trace elements tin, arsenic, antimony and nickel, cluster 1 groups coins that contain nickel in lowest concentrations (0.02–0.09 weight percentage). Cluster 2 groups coins with highest antimony concentrations (0.6–0.9 weight percentage). Since the two clusters both contain coins from group A, B and A or B, the hierarchical cluster analysis underlines the similarity of the copper used for group A and B coins.

[71] G.R. TILTON/W. SCHREYER/H.-P. SCHERTEL, Pb-Sr-Nd isotopic behaviour of deeply subduced crustal rocks from the Dora Maira Massif, Western Alps, Italy-II: what is the age of the ultrahigh-pressure metamorphism? Contributions of Mineralogy and Petrology 108, 1991, 22–33; J.C. TOURAY/E. MARCOUX/P. HUBERT/D. PROUST, Hydrothermal processes and Ore-forming Fluids in the Le Bourneix Gold Deposit, Central France. Economic Geology 84, 1989, 1328–1339; E. CURTI, Lead and Oxygen Isotope Evidence for the Origin of the Monte Rosa Gold Lode Deposits (Western Alps, Italy): A Comparison with Achaean Lode Deposits. Economic Geology 82, 1987, 2115–2140.

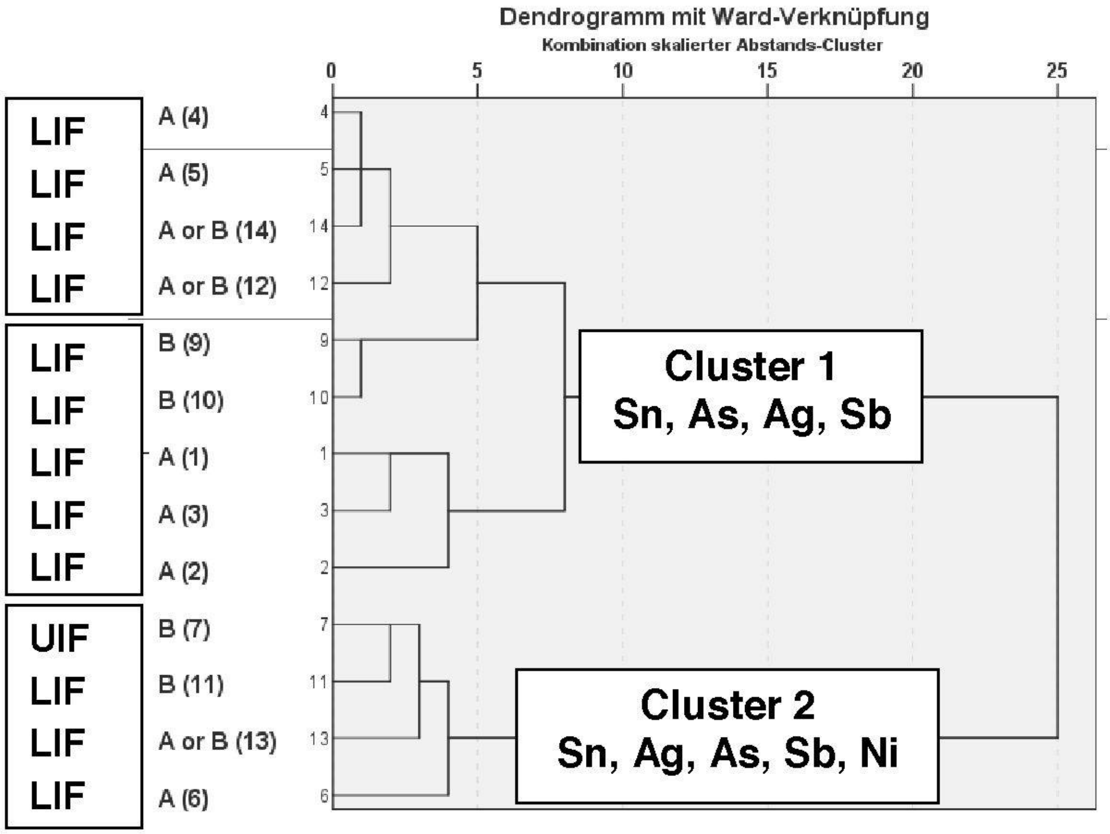

Fig. 10 Hierarchical cluster analysis with the Ward method using squared Euclidic distance as a dendrogram. Data for LAS I coins of groups A, B, and A or B (coin no. 8 is not represented due to absent lead isotope data).

LAS II, group D:

The copper content of most coins in LAS II group D is as high as that found in LAS I, A and B. The majority of the coins are of very pure copper (>97 weight % Cu), except no. 28, which has zinc in percentage range (3.25 weight %), and coins no. 20, 29, 30, 31, 36 and 41, which have increased tin contents (0.8–2 weight %). As for the isotopic composition, group D coins plot within both coin isotope fields UIF and LIF.

Figure 11 shows the result of a hierarchical cluster analysis of group D coins with the Ward method. The statistical analysis combines both chemistry and lead isotope ratios. Three clusters result. Cluster 3 coins are made of pure copper. Cluster 4 coins are those from LIF which contain tin in lower concentrations (<0.5 weight %). Cluster 5 coins belong to UIF and contain mainly tin in concentrations between 0.8–2 weight %.

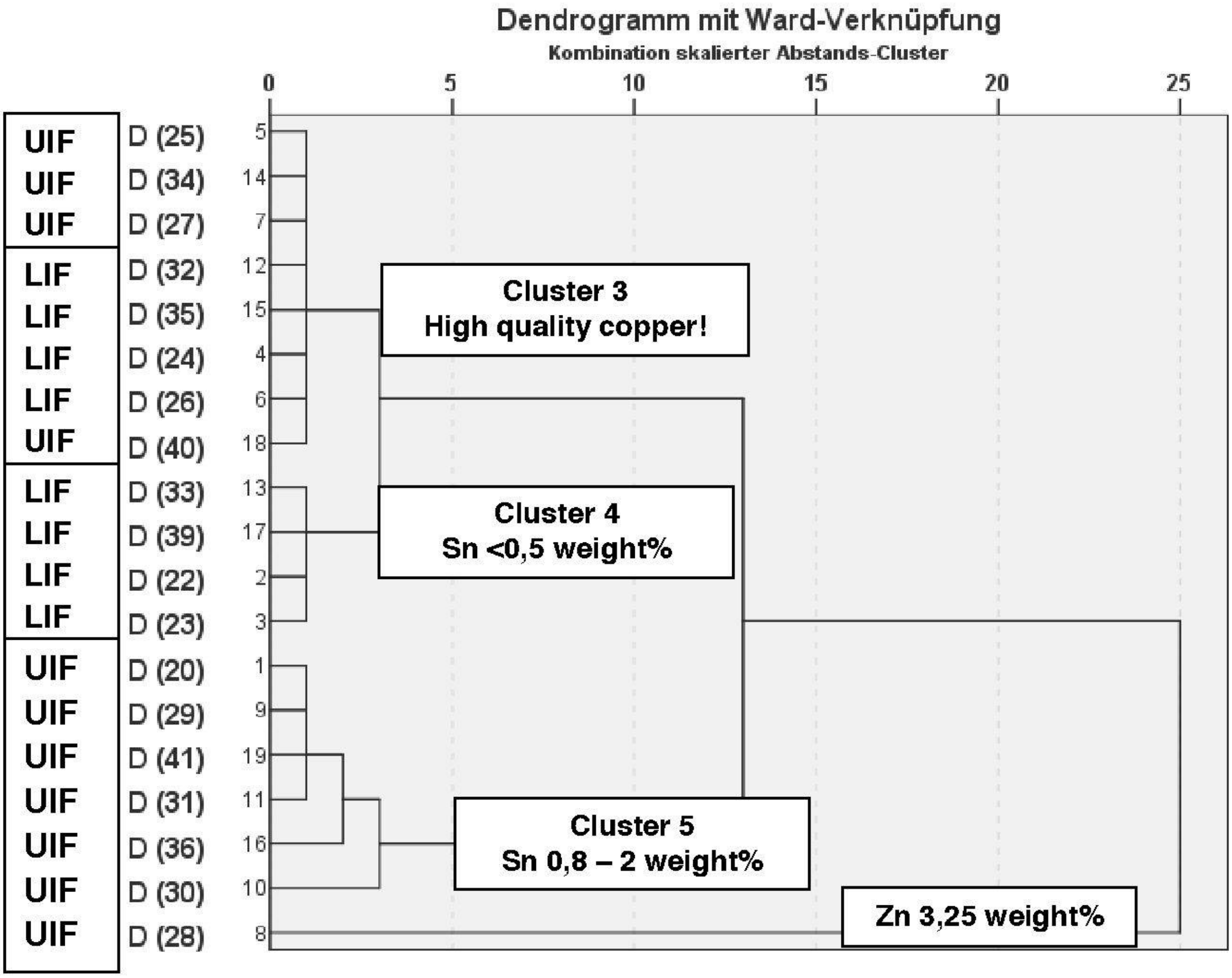

Fig. 11 Hierarchical cluster analysis with the Ward method using squared Euclidic distance as a dendrogram. Data for coins of group D.

As is also evident from table 1, coin no. 28 is an outlier. Because of its good minting quality this coin was classified as an official coin according to numismatic criteria. Imitation can be excluded. In general, zinc is rather uncommon for official copper coins and appears only in imitation coins. From a material point of view, it is difficult to tell whether the zinc was introduced to the copper coin through contamination or whether it was added on purpose.

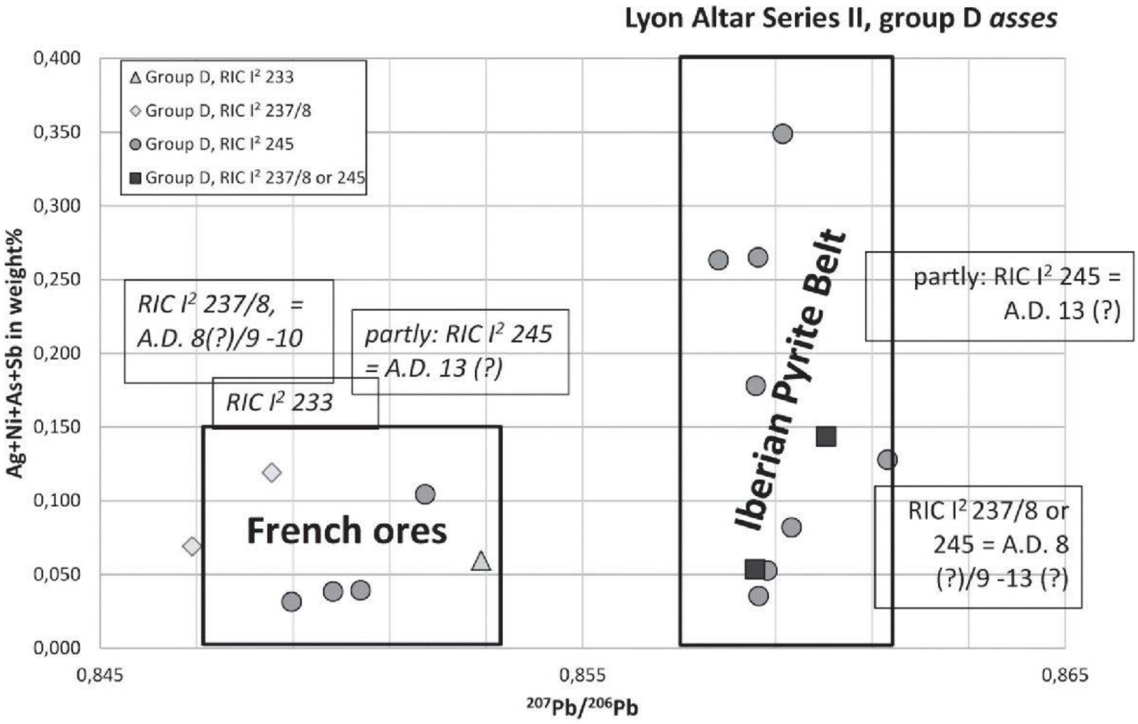

Fig. 12 Combined diagram ^{207}Pb/^{206}Pb versus elemental concentration of group D *asses.*

An attempt to distinguish the *asses* of group D from each other based on the RIC I^2 classification is seen in *Figure 12*. Those *asses* that are believed to contain local raw metal (France) are identified as coins of the type RIC I^2 237/8, RIC I^2 233 and RIC I^2 245. *Asses* whose raw metal came from Iberian Pyrite Belt ores are identified as coins of the type RIC I^2 245 and RIC I^2 237/8 or 245. This observation uncovers a switch between the use of local copper and Spanish raw metal during the production of the *asses* of RIC I^2 245. Whereas local sources continued to be used for the production of RIC I^2 237/8 and RIC I^2 233 (just as for LAS I coins), the RIC I^2 245 batch of production in A.D. 13(?) saw a change in the raw metal supply, with material now coming from Spain.

The three coins classified as RIC I^2 237/8 or 245 (no. 39, 40, 41) plot with the RIC I^2 245 asses, whereas the *asses* classified as RIC I^2 237/8 are assigned French provenance. We tentatively conclude from this that these three coins can be identified as RIC I^2 245 rather than RIC I^2 237/8.

(2) Is the chemistry and provenance of the copper from the flans in group A different from that used in group B and/or in group D? Does the copper employed permit us to differentiate the flans of groups A, B and D spatially or temporally?

As previously demonstrated, group A and B coins are very homogeneous in terms of chemical and isotopic composition. Differentiation between the two groups is thus impossible.

As for group D, the coins clearly differ from LAS I groups A and B. The distinction can be made by focusing on the elements silver, nickel, antimony and arsenic *(Fig. 13)*. Whereas *asses* from groups A and B contain a significant concentration of these elements (0.2–1.2 weight %), group D *asses* are very poor in these materials (<0.3 weight %). As for the isotopic composition, group D *asses* plot within both isotope fields LIF and UIF, whereas group A and B *asses* plot solely within LIF.

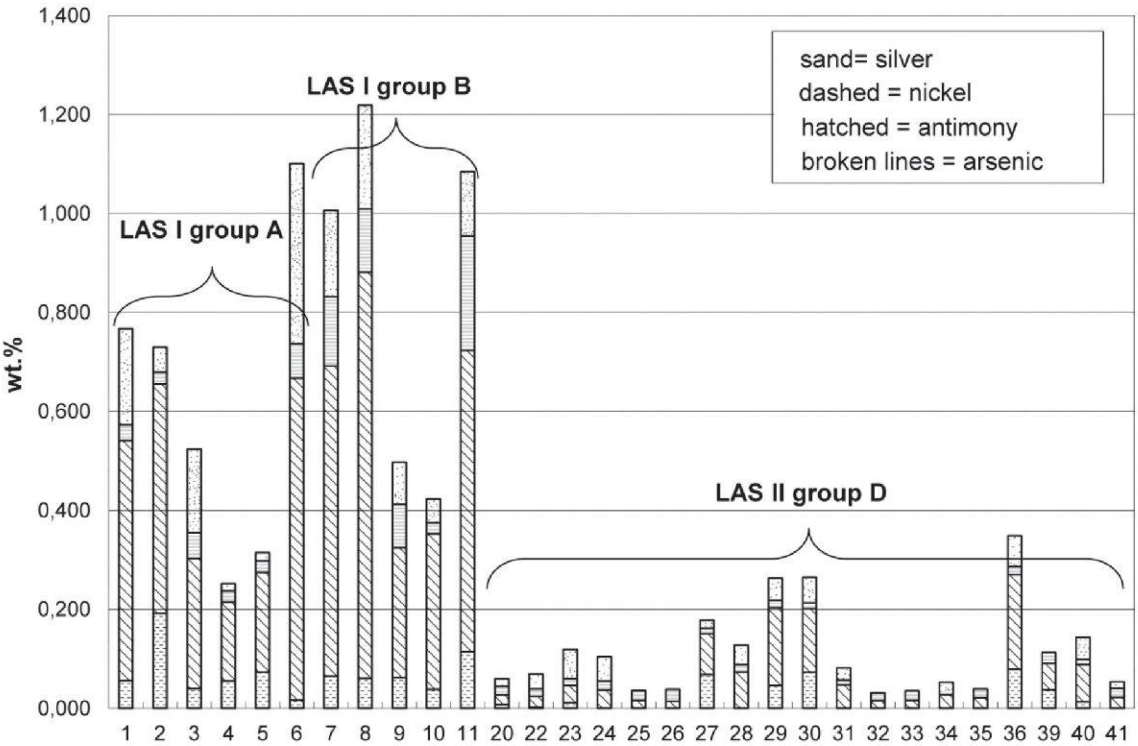

Fig. 13 Summary of concentrations of silver, nickel, antimony and arsenic for LAS I *asses* of groups A and B, and LAS II *asses* of group D. Although all *asses* of LAS I and II are generally of pure copper, LAS I groups clearly have higher concentrations of the four elements than LAS II *asses* of group D. [x-axis = catalogue numbers of coins.]

Whenever a differentiation has to be made between the coin groups A-B and D, it is helpful to discuss the nickel, silver, arsenic, and antimony contents, as well as the lead isotope signature.

(3) Is there a relationship between the copper used in Lugdunum for minting asses and the copper that was used by the mint of Rome?

Since they are closely connected in time, it is of great interest to compare the provenance of copper coins minted in Lugdunum *(asses)* with those minted by the official mint in Rome *(asses* and *quadrantes)*. We have previously demonstrated that after some few coins were produced from local copper sources in Italy, *asses* and *quadrantes* minted between 16 B.C. and 11 A.D. in Rome were produced with copper from the Iberian Pyrite Belt and the Central-South of Spain (Sierra Morena region). A chronology based on lead and copper isotopes was presented at that time, which was an attempt to uncover the switches between copper sources from both Spanish mining regions. The majority of Augustan *quadrantes* (9–4 B.C.) were produced solely from copper from the Iberian Pyrite Belt[72].

Compared to the *asses* minted in Lugdunum, those from Rome have widely scattered $^{207}Pb/^{206}Pb$ ratios with a tendency to elevated $^{208}Pb/^{206}Pb$ ratios. The latter is visualised by a trend line in *Figure 14.* The majority of the *quadrantes* from Rome plot within the isotope field UIF, which reconfirms the earlier interpretation of the Iberian Pyrite Belt as the copper source.

Both the differences and the similarities between copper coinages from Lyons and Rome are significant. Both mints used copper from the Iberian Pyrite Belt, but during their very early activities they relied on other sources. In the mint of Rome, copper from the Central Iberian Zone (Sierra Morena area) was used prior to the copper from the Iberian Pyrite Belt. From 5 B.C. the Iberian Pyrite Belt supplied Rome with copper for the *quadrantes. Asses* produced from copper from the Iberian Pyrite Belt did not appear until Tiberius' reign in 15/16 A.D. This indicates that Rome only produced coins using copper from the Iberian Peninsula, and this lasted until the middle of the third century A.D. In the mint of Lugdunum copper most probably came from a local source in France, which was used prior to the copper from the Iberian Pyrite Belt. It was only with the production of LAS II *asses* in 8(?)/9–10 and 13 A.D. that the mint of Lugdunum changed its metal supply to bullion coming from the Iberian Pyrite Belt in Spain.

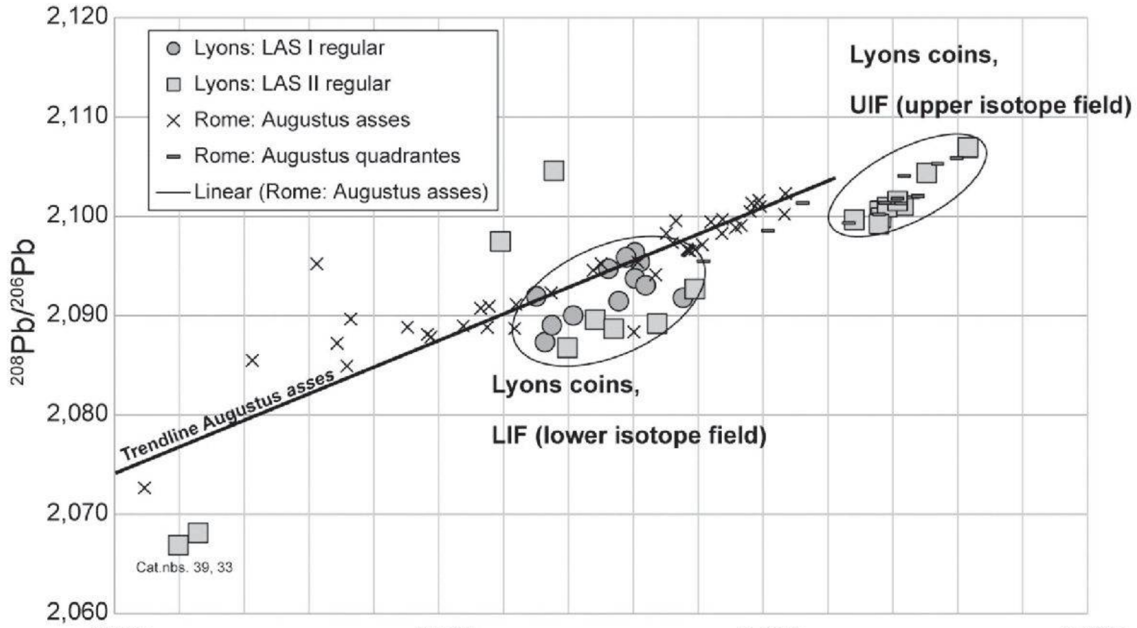

Fig. 14 Diagram $^{207}Pb/^{206}Pb$ versus $^{208}Pb/^{206}Pb$ comparing roughly contemporary Lugdunum coins with official coinage from Rome. [LAS I (groups A and B = circles), LAS II (group D = squares), Augustan *asses* (x) and Augustan *quadrantes* (-)]

72 KLEIN/LAHAYE/BREY/VON KAENEL 2004; KLEIN/DOMERGUE/LAHAYE/BREY/VON KAENEL 2009; KLEIN/LAHAYE/BREY/VON KAENEL 2010.

(4) Is the chemistry and provenance of the copper used for the imitations in group C (LAS I) and group E (LAS II) different from that used for the official coins?

Three of the five imitation coins of LAS I group C differ significantly from those in group A or B. Some imitation coins from Mainz (no. 16, 17, 18) are comprised of a variable Cu-Sn-Pb alloy composition (3–10 weight % Sn and 9–30 weight % Pb). Imitation coin no. 15 from Martberg shows traces of zinc (0,14 weight %). Other imitation coins from Augst (no.19, 21), from Mainz (no. 37, 38) and from Martberg (no. 42, 43, 44), are produced from very pure copper.

Figure 15 shows a combined hierarchical cluster analysis for the coins of groups A, B, and C (LAS I), as well as groups D and E (LAS II). The three imitations with high tin and lead concentrations were omitted (group C, no. 16, 17 and 18). The imitations from group C and E (no. 15, 19, 21, 37, 43, 44) appear to be included in the clusters of the official coins.

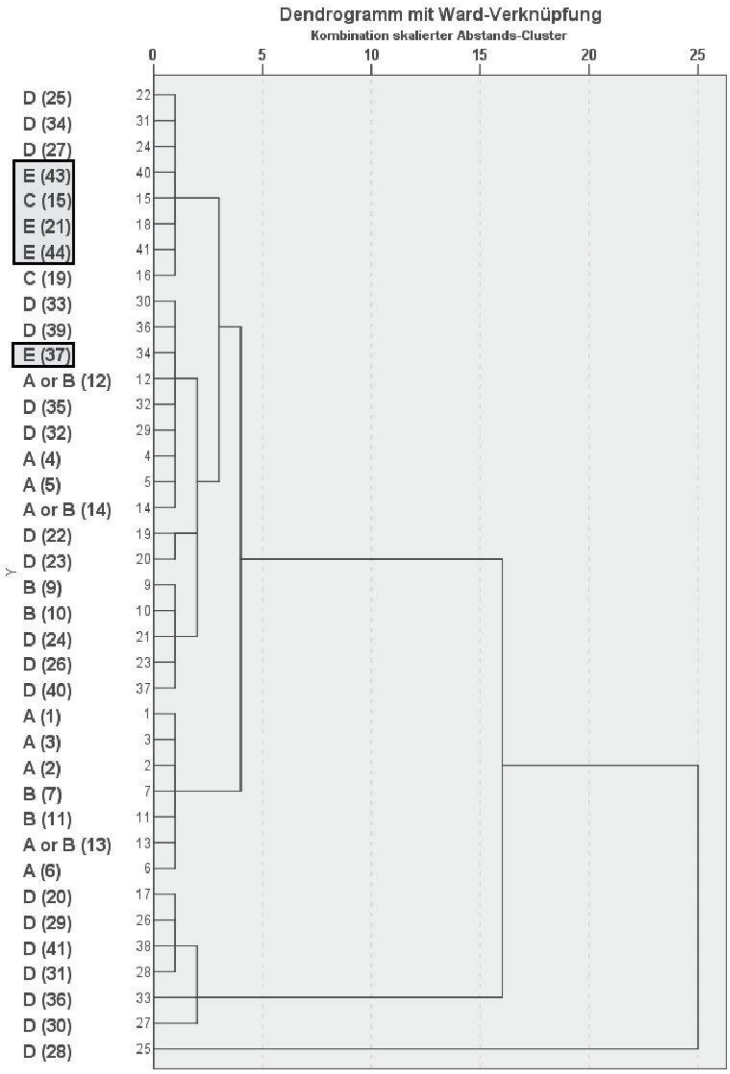

Fig. 15 Hierarchical cluster analysis with the Ward method using squared Euclidic distance as a dendrogram. Data for coins in the groups A, B, C, D and E. Imitations are highlighted.

The lead isotope values of the group C coins are not homogeneous either *(Fig. 16)*. The coins from Mainz (no. 16 and 17) have low lead isotope ratios (0.84–0.85 $^{207}Pb/^{206}Pb$ and 2.085 $^{208}Pb/^{206}Pb$) and plot within coin isotope field LIF. The coins from the Martberg (no. 15) and Augst (no. 19) show higher lead isotope ratios (0.859 $^{207}Pb/^{206}Pb$ and 2.100 $^{208}Pb/^{206}Pb$) and plot within coin isotope field UIF.

The match of coin no. 16 and 17 (LAS I imitations) with LIF was expected since this is also characteristic for group A and B coins. Coin no. 18 was not subjected to lead isotope analysis. Coin no. 19 plots within the UIF (Iberian Pyrite Belt), and not – as expected from the LAS I context – within the LIF.

The isotopic signature of coins from group D and E (LAS II) cannot be differentiated from each other: coins of both groups plot within the coin isotope field UIF (Iberian Pyrite Belt) or LIF (French ores). About half of the coins of group D and nearly all of group E match with the coin isotope field UIF. The predominant metal source for group D and E coins, therefore, was the Iberian Pyrite Belt.

As was the case with the officially minted coins, group E coins (imitations) are also of a high quality (>99.3 weight % Cu) and are therefore also of high chemical homogeneity. The only exception is coin no. 42. This coin is struck from a copper-lead alloy with 5 weight % Pb (no data for lead isotope ratios).

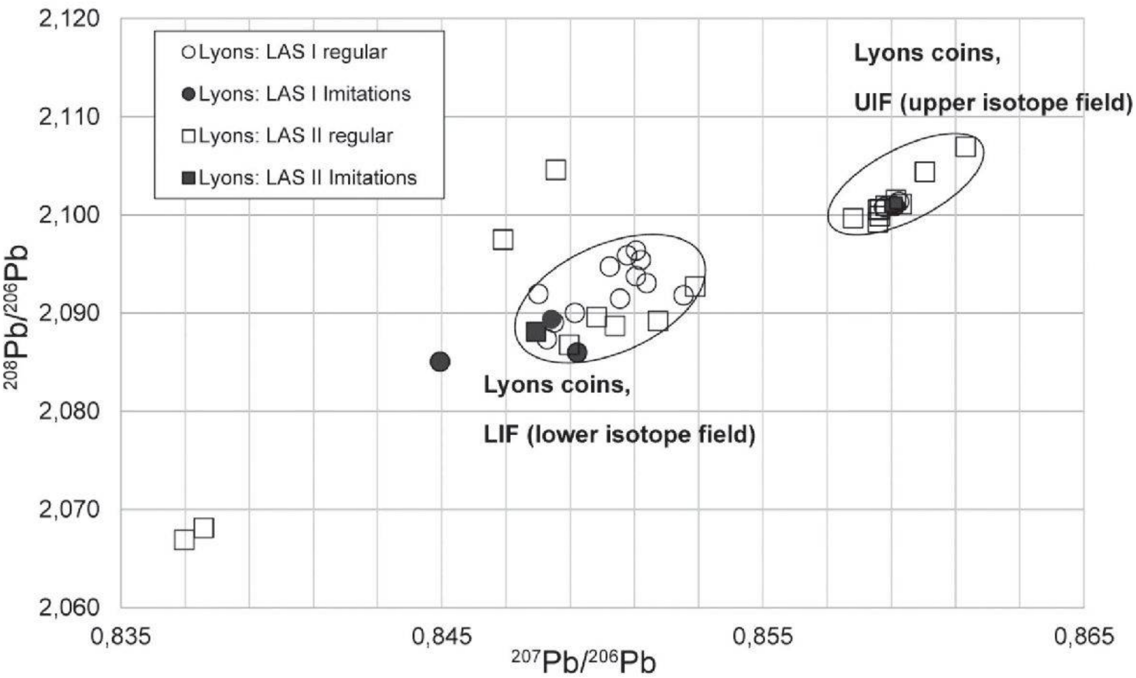

Fig. 16 Diagram $^{207}Pb/^{206}Pb$ versus $^{208}Pb/^{206}Pb$ comparing the Lugdunum official coinage with imitation coins. [LAS I regular (circles), LAS II (squares), LAS I imitations (filled circles), LAS II imitations (filled squares)]

It has to be emphasized here that most imitations stand out because they have not been produced in official mints, but by someone locally. Different material was used; regular coins or recycled material might have been re-melted to produce new flans for the minting of imitations. A more detailed analysis of the phenomenon of "imitations" during the first half of the 1st century A.D., using data coming from more than 120 imitations, will be presented in a forthcoming article.

A limited number of imitations are presented in this study and any generalized interpretation has to be treated with care. To draw a conclusion on a small scale, the three imitation coins of (leaded) tin bronze (no. 16, 17, 18) have to be discussed separately from the others. As for the imitation coins of group C (LAS I) and E (LAS II) produced from pure copper, the chemistry and provenance of the copper is quite similar to that used for the official coins. These coins are significantly different in composition, but the provenance of their copper is practically the same as the official coins.

(5) Can our data for the chemical composition of LAS I and LAS II *asses* be related to those published by J.-N. Barrandon in 2003 and 2004?

Some years ago, J.-N. Barrandon, together with P.-A. Besombes, analysed the chemical composition of a group of Lyons altar coins by neutron activation analysis using the cyclotron of the Centre Ernest Babelon, Orléans[73]. Only the main and the most important trace elements (Cu, Pb, Zn, Sn, Sb, As, Ni, Ag, Au and Fe) were determined. Lead and copper isotope ratios were not measured. We have therefore compared the analytical data of J.-N. Barrandon and our own chemical data using cluster analysis. *Figure 17* shows that the results coincide perfectly. With two exceptions all clusters contain coins either of LAS I or LAS II. The classifications of the clusters in *Figure 10* (LAS I, cluster 1 and 2) and *Figure 11* (LAS II, cluster 3, 4 and 5) are retained. All five clusters contain coins analysed in our study and coins measured by J.-N. Barrandon. This comparison shows a clear agreement amongst coins found in different geographical areas and analysed by different methods.

In conclusion:
LAS I: In interpreting his data J.-N. Barrandon[74] indicated – as we do – that the copper which was used to mint LAS I group A ('heavier group') and group B ('light group' = 'atelier auxiliaire') is indistinguishable. But contrary to J.-N. Barrandon, we believe that on this basis one cannot postulate the existence of two mints.

LAS II: In examining the chemical composition of LAS II *asses* the metal analytical data of J.-N. Barrandon coincide with our data. Barrandon's examples fall exactly within the three clusters we have identified above in *Figure 11*.

[73] J.-N. Barrandon in: Amandry/Estiot/Gautier 2003, 151–152; J.-N. Barrandon in: Besombes/Barrandon/Martini 2004, 179–180.
[74] J.-N. Barrandon in: Amandry/Estiot/Gautier 2003, 153.

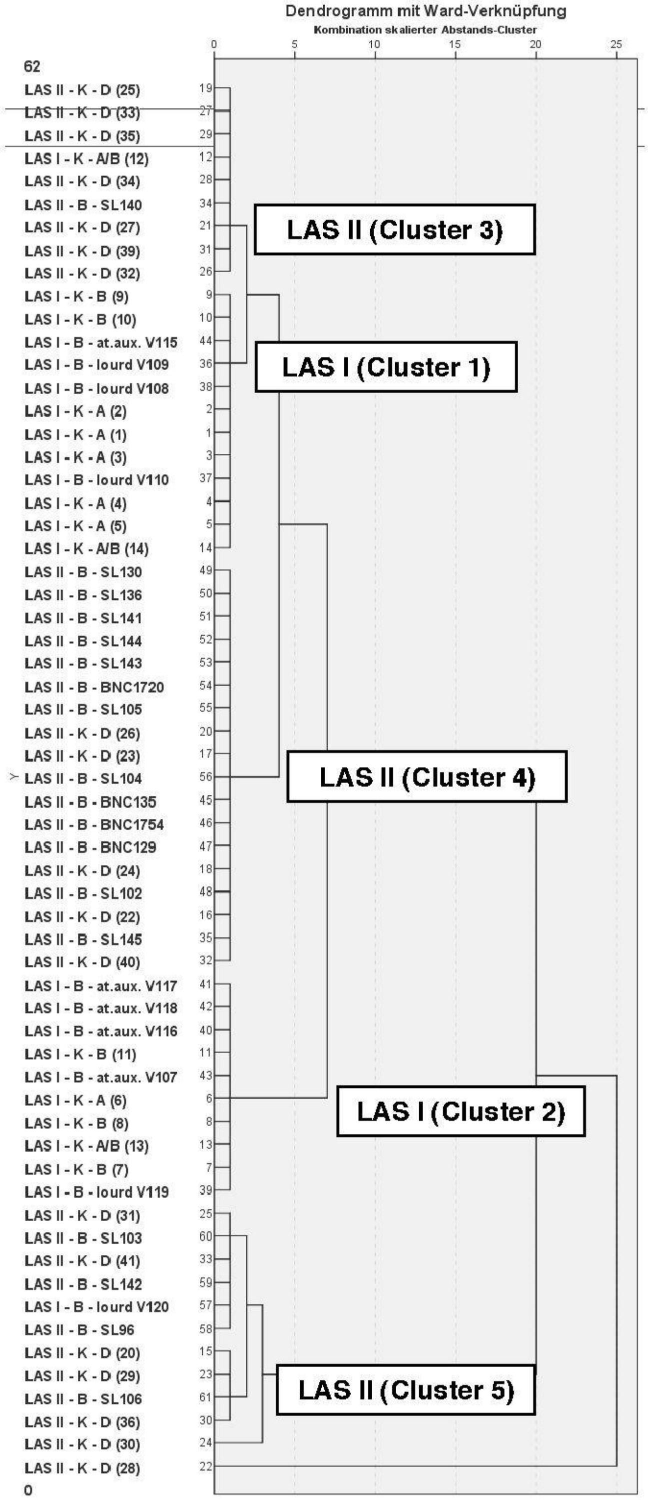

Fig. 17 Hierarchical cluster analysis with the Ward method using squared Euclidic distance as dendrogram. Comparison of our own data (LAS I/II – K (= Klein) – XXX) with data of J.-N. Barrandon (LAS I/II – B (= Barrandon) – XXX). XXX stands for the respective coin number.

9. Historical conclusions: Gaulish copper = Livian copper?

In the year 15 B.C., the emperor Augustus established a mint at Lyons/Lugdunum and subsequently struck coins in gold, silver, brass and copper. Our study focuses on the copper coins, in particular the *asses* that have a reverse showing the altar in the sanctuary of the Council of the *Tres Galliae* at Lugdunum, which was dedicated to the goddess Roma and to Augustus. On the basis of the portraits and the legends on the obverse of the coins, two series can be distinguished. The first, consisting of a single coin type (Augustus), was probably minted in the years 7–3 B.C. (LAS I). The second, consisting of several coin types with the portraits of Augustus and his appointed successor Tiberius, was minted in the years 8(?)/9–14 A.D. (LAS II). The *asses* are found in huge quantities in military and civilian contexts in northern Gaul and on the Rhine.

Forty-four coins found in Mainz/Mogontiacum, Worms/Borbetomagus, on the Martberg near Pommern in the Moselle valley, and in Augst/Augusta Raurica were sampled by using a thin drill to obtain a small amount (around 10 mg) of the inner part from the edge the coin. The samples were analyzed in the EMPA and MC-ICP-MS facility of the Institut für Geowissenschaften at the Goethe-Universität Frankfurt a. M., Facheinheit Mineralogie.

Most of the selected coins are regular issues from the official mint in Lugdunum (LAS I: Groups A and B (14 coins); LAS II: Group D (19 coins)). In addition, 11 coins were analysed (LAS I: Group C; LAS II: Group E) because their design, style and weight deviated markedly from the regular coins and they were therefore classified as local imitations of the official coins. These imitations are believed to be irregular coins. Imitations were in circulation during the early decades of the 1st century A.D.

While the copper used in the mint of Lugdunum for the LAS I and LAS II *asses* was found to be very pure (97.2% – 99.9%) in terms of its chemical composition, and its provenance can be narrowed down, the metal of the imitations deviates, often very significantly, from this standard. The copper used for the imitations came from various sources, was probably partly recycled from regular copper coins, and shows comparatively high levels of tin and lead. This is not surprising, because the imitations were produced illegally over a long period of time in local bronze workshops.

The classification of LAS I coins into groups A and B (regular mint – auxiliary mint) proposed by J.-B. Giard[75] is not supported by our analysis of the copper. The metal of the flans from groups A and B cannot be distinguished either in terms of chemical composition or raw metal provenance.

The origin of the ingots melted down in the mint at Lugdunum to produce the flans used for LAS I and LAS II *asses* can be differentiated according to their lead and copper isotope ratios. The copper mainly used for LAS I seems to come from Gaul. The metal for LAS II, however, also comes from Southern Spain (Iberian Pyrite Belt).

This result seems surprising at first, because to date it was not thought that a significant amount of copper ore was mined in Gaul in the Augustan period. Rather, one would have expected that the mint at Lugdunum obtained copper from the Iberian Peninsula, the main supplier of copper in the Western part of the Roman Empire. However, we have already shown in an earlier study on the copper employed at Rome

[75] See note 34.

for the minting of copper coins (*asses* and *quadrantes*) that one has to differentiate. The copper of the coinage minted at Rome in 16 B.C. and later came at first from Italian local sources (Tuscany), but predominantly from Southern Spain[76]. Individual coins were made of copper from a certain provenance; other flans came from a batch of copper that had been melted with copper ingots from different sources. That the copper of LAS II originates from southern Spain corresponds to the trend that was demonstrated in the study noted above. Striking is the purity of the copper, which reached a very high standard soon after the introduction of copper coinage in 16 B.C., a standard that even distinguished the regular *asses* of LAS I and LAS II.

As part of a discussion of copper mining regions, Pliny mentions in his *Naturalis Historia* (34, 3) quoted above, the *"Sallustian"* copper in the territory of the *Centrones* in the Western Alps. According to Pliny, this ore deposit was not mined for long and was followed later by the exploitation of the *"Livian"* copper in Gaul. These deposits were also quickly exhausted. The two adjectives used by Pliny to characterise the copper deposits point to the owners of the respective copper mines: *Sallustius Crispus*, a friend of Augustus, and *Livia*, the wife of the emperor[77]. Where exactly in Gaul the copper mines of the empress are to be located is not known. Since we have observed that in the last decade B.C. the mint at Lugdunum used local copper from Gaul (Massif Central, Cévennes), then the question must be raised, as to whether this copper may be Livia's copper as reported by Pliny. Obviously, this copper ore district was not sufficient for the whole copper coinage of Lugdunum produced during the Augustan period, because at the latest in 13 (?) A.D. copper ingots from southern Spain were employed for the minting of the LAS II series.

The decentralised structure of metal extraction reflected by the above examples is confirmed repeatedly during the reign of Augustus. For example, in two of the earliest Roman settlements on the Rhine, Dangstetten (15–9/8 B.C.)[78] and Waldgirmes (4 B.C. (at the latest) – 16 A.D.)[79], S. Durali-Müller found lead artefacts deriving from local lead deposits in the Eifel and the Siegerland, and also from the Massif Central[80]. Spectacular new results were obtained with regard to lead mining in the right-bank area of the Rhine during the reign of Augustus[81].

76 Klein/Lahaye/Brey/von Kaenel 2004, 472–473. 477–479.

77 On the ownership see Hirt 2010, 87–88.

78 G. Fingerlin, Küssaberg-Dangstetten. In: D. Planck (ed.) 2005 (note 31), 156–160.

79 G. Rasbach, Die Germanienpolitik des Augustus. In: F.M. Ausbüttel/U. Krebs/G. Maier (eds.), Die Römer im Rhein-Main-Gebiet (Darmstadt 2012) 16–28; A. Becker, Waldgirmes. *Praesidium, oppidum, colonia?* In: K. Ruffing/A. Becker/G. Rasbach (eds.), Kontaktzone Lahn. Studien zum Kulturkontakt zwischen Römern und germanischen Stämmen. Philippika 38 (Wiesbaden 2010) 5–19.

80 S. Durali-Müller/G.P. Brey/D. Wigg-Wolf/Y. Lahaye, Roman lead mining in Germany: its origin and development through time deduced from lead isotope provenance studies. Journal of Archaeological Science 34, 2007, 1555–1567.

81 N. Hanel/P. Rothenhöfer, Römische Bleigewinnung im Raum Brilon und der Bleitransport nach Rom. In: W. Melzer/T. Capelle (eds.), Bleibergbau und Bleiverarbeitung während der römischen Kaiserzeit im rechtsrheinischen Barbaricum. Soester Beiträge zur Archäologie 8 (Soest 2007) 41–46; N. Hanel/P. Rothenhöfer, Germanisches Blei für Rom. Zur Rolle des römischen Bergbaus im rechtsrheinischen Germanien im frühen Prinzipat. Germania 83, 2005, 53–65. – For a divergent interpretation of the ownership of the lead ingots with the stamp *Augusti Caesaris Germanicum (plumbum)* see Hirt 2010, 104–106.

Obviously, during the reign of the first emperor local resources were used, systematically developed and exploited[82]. Only with time could structures be established through which metals from important mines could be widely distributed[83]. Nevertheless, the local mining industry maintained its importance throughout the Roman Empire. In this context, the origin of copper used in the official mint at Lyons/Lugdunum under Augustus seems to be typical of this period.

Abstract

Subject of the study are 44 copper coins, all *asses* of the first (RIC I² 230) and second (RIC I² 233. 237/38. 245) Lyons altar-series (LAS I and LAS II). They belong to the oldest copper coins and were produced during the reign of the Emperor Augustus between 7–3 (?) B.C. and 8 (?)/9–14 A.D. in the mint of Lyons/ Lugdunum. In order to clarify the question where the copper for the production of the flans was obtained, samples from 44 coins were analyzed for their chemical composition using electron microprobe analysis (EPMA), and for their lead and copper isotope ratios by mass spectrometry with inductively coupled plasma (MC-ICP-MS).

The mint of Lugdunum used very pure copper (97.2–99.9%). The copper for the first altar series appears to be obtained mainly from Gaul, especially from the Massif Central, Cévennes. For the second altar series the copper has been additionally imported from southern Spain in 13 (?) A.D. The effort to exploit local mineral deposits and to open up new deposits is typical for the use of resources under the first Roman emperor.

82 Hirt 2010, 334–335. 357–359.

83 Hirt 2010, 107–167; C. Domergue, Production et commerce des métaux dans l'Occident romain: L'Hispanie et la Gaule. In: Pons Pujol (ed.) 2010 (note 56) 109–123; D. Domergue, L'État romain et le commerce des métaux à la fin de la République et sous le Haut-Empire. In: J. Andreau/P. Briant/R. Descat (eds.), Économie Antique. Les échanges dans l'Antiquité: le rôle de l'État. Entretiens d'Archéologie et d'Histoire (Saint-Bertrand-de-Comminges 1994) 99–113.

Zusammenfassung

Gegenstand der Studie sind 44 Kupfermünzen, alles *asses* der ersten (RIC I^2 230) und zweiten (RIC I^2 233. 237/38. 245) Lyoner Altar-Serie (LAS I bzw. LAS II). Sie gehören zu den ältesten Kupfermünzen und wurden in der Regierungszeit des Kaisers Augustus in den Jahren 7–3 (?) v. Chr. bzw. 8 (?)/9–14 n. Chr. in der offiziellen Münzstätte Lugdunum/Lyon geprägt. Um die Frage zu klären, woher das für die Herstellung der Schrötlinge verwendete Kupfer stammte, wurden anhand der an den 44 Münzen gewonnenen Proben mit Hilfe der Elektronenstrahl-Mikrosonde (EPMA) die chemische Zusammensetzung analysiert und mittels eines Massenspektrometers mit induktiv gekoppeltem Plasma (MC-ICP-MS) die Blei- und Kupferisotopen-Verhältnisse bestimmt.

Die Münzstätte von Lugdunum verwendete sehr reines Kupfer (97,2–99,9%). Das Kupfer der ersten Lyoner Altar Serie scheint im Wesentlichen aus Gallien, dem Massiv Central bzw. den Cevennen zu stammen, während für die Ausprägung der zweiten Altar Serie ab 13 (?) n. Chr. auch Kupfer aus Südspanien importiert worden ist. Das Bestreben, lokale Erzvorkommen weiter abzubauen und neue zu erschließen ist für den Umgang mit den Ressourcen unter dem ersten römischen Kaiser typisch.

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Catalogue of the analyzed asses of Lyons altar series I and II

Altar series I: B.C. 7 – 3 B.C. (?)

Obv.: CAESAR PONT MAX. Laureate head of Augustus to right
Rev.: ROM ET AVG. Altar of Lugdunum
RIC I[2] 230; GIARD 1983, 73

Group A (regular issues; GIARD 1983, 73 with pl. 20–21)
1) Mainz 9, Dagobertstraße, no. FM 87-135/136. 8,7 g. 30°. FMRD VI 1, Nachtrag 1, 1258 no. 331 seq.
2) Mainz 12, Dagobertstraße, no. FM 87-135/136. 9,6 g. 90°. FMRD VI 1, Nachtrag 1, 1258 no. 331 seq.
3) Martberg 3, no. 29712. 10, 6 g. 330°. Obv.: cmk BECH COLL. p. 36–39 (wheel). Rev.: cmk BECH COLL. p. 140–143 (VARVS)
4) Martberg 4, no. 27193. 10,2 g. 330°. Obv.: cmk BECH COLL. p. 48–52 (AVC)
5) Martberg 5, no. 22938. 10,6 g. 60°
6) Martberg 24, no. 29646. 9.6 g. 30°

Group B (regular issues, GIARD 1983, 117 with pl. 29–31)
7) Martberg 2, no. 20439. 9,3 g. 210°
8) Mainz 2, Dagobertstraße, no. FM 87-135/136. 8,7 g. 330°. FMRD VI 1, Nachtrag 1, 1258 no. 331 seq.
9) Mainz 5, Dagobertstraße, FM 87-135/136. 8,7 g. 150°. FMRD VI 1, Nachtrag 1, 1258 no. 331 seq.
10) Mainz 6, Dagobertstraße, FM 87-135/136. 7,9 g. 240°. FMRD VI 1, Nachtrag 1, 1258 no. 331 seq.
11) Martberg 1, no. 28160. 9,9 g. 270°

Group A or B (regular issues)
12) Mainz 10, Dagobertstraße, no. FM 87-135/136. 6,3 g. 210°. Obv. cmk BECH COLL. p. 129–136 (TIBIM). FMRD VI 1, Nachtrag 1, 1258 no. 442
13) Mainz 1 (halved), Dagobertstraße, no. FM 87-135/136. 3,9 g. FMRD VI 1, Nachtrag 1, 1258 no. 385 seq.
14) Augst Ins. 30, no. 1960.1530. 10,5 g. 135°. PETER, Augusta Raurica I, p. 232, Ins. 30/99

Group C (imitations)
15) Martberg 13, no. 29306. 5,8 g. 180°
16) Mainz 3, Dagobertstraße, no. FM 87-135/136. 10,2 g. 30°. FMRD VI 1, Nachtrag 1, 1258 no. 331 seq.
17) Mainz 8, Dagobertstraße, no. FM 87-135/136. 8,4 g. 60°. FMRD VI 1, Nachtrag 1, 1258 no. 331 seq.
18) Mainz 4 (fragm.), Dagobertstraße, no. FM 87-135/136. 4,85 g. 60°. FMRD VI 1, Nachtrag 1, 1258 no. 431
19) Augst, Ins. 28, no. 1965.4486A. 5,0 g. 135°. PETER, Augusta Raurica I, p. 207, Ins. 28/27

Altar series II: A.D. 8(?)/9–14
Obv.: CAESAR AVGVSTVS DIVI F PATER PATRIAE. Laureate head of Augustus to right
Rev.: ROM ET AVG. Altar of Lugdunum
RIC I² 233; GIARD 1983, 95

Group D (regular issues)
20) Augst, Ins. 24, no. 1958.11739. 9,2 g. 360°. PETER, Augusta Raurica I, p. 160 Ins. 24/75

Group E (imitation)
21) Augst, Region 14 (Osttor), no. 1966.2763. 3,84 g. 165°. PETER, Augusta Raurica II, p. 74, reg. 6–14/6

Imperator V = A.D. 8 (?)/9–10
Obv. TI CAESAR AVGVST F IMPERAT V. Bare/laureate head of Tiberius to left/right
Rev. ROM ET AVG. Altar of Lugdunum
RIC I² 237/8; GIARD 1983, 101.105.109

Group D (regular issues)
22) Kaiseraugst, Region 16A, no. 1988.009.C03852.1. 9,96 g. 225° Holed. Unpublished.
23) Augst, Region 9D, no. 2001.064.E04792.2. 10,03 g. 15°. Unpublished.

Imperator VII = A.D. 13 (?)
Obv.: TI CAESAR AVGVSTI F IMPERAT VII. Laureate head of Tiberius to right
Rev.: ROM ET AVG. Altar of Lugdunum
RIC I² 245; GIARD 1983, 114

Group D (regular issues)
24) Mainz 18, Kästrich, no. FM 84-107. 8,4 g. 330°. FMRD VI 1, Nachtrag 1, 1254 no. 189
25) Mainz 21, Bauhofstraße, no. FM 96-008, no. 34. 8,7 g. 30°. FMRD VI 1, Nachtrag 1, 1258 no. 488
26) Mainz 29, Obere Zahlbacher Straße, no. FM 88-049. 9,9 g. 30°. Obv. cmk Bech coll. p. 105–109 (TIB). FMRD VI 1, Nachtrag 1, 1256 no. 270
27) Mainz 30, Obere Zahlbacher Straße, no. FM 88-49. 8,0 g. 360°. Obv. and rev. cmk Bech coll. p. 129–136 (TIBIM). FMRD VI 1, Nachtrag 1, 1256 no. 273
28) Mainz 31, Obere Zahlbacher Straße, no. FM 88-049. 10,3 g. 60°. FMRD VI 1, Nachtrag 1, 1256 no. 261/262
29) Worms, town centre, Am römischen Kaiser, no. FM 90-101. 9,9 g. 360°. Obv. and rev. cmk BECH COLL. p. 129–136 (TIBIM)
30) Martberg 18, no. 22056. 7,25gr. 120°
31) Martberg 19, no. 19753. 9,1 g. 245°
32) Martberg 20 (pierced), no. 29333. 9,75g. 330°

33) Martberg 21, no. 27603. 240°
34) Martberg 22, no. 29568. 10,9 g. 30°. Obv. cmk Bech coll. p. 105–109 (TIB)
35) Martberg 23, no. 29321. 10,6 gr. 120°
36) Augst, Schönbühl, gr. Tempel, no. 1957.3679. 9,3 g. 150°. PETER, Augusta Raurica I, p. 40 Reg. 2B/75

Group E (imitations)
37) Mainz 20, Kästrich, no. FM 84-107. 7,45 g. 150°. FMRD VI 1, Nachtrag 1, 1254 no. 198
38) Augst, Ins. 20, no. 1967.6393. 4,4 g. 180°. PETER, Augusta Raurica I, p. 122 Ins. 20/36

Imperator V or VII = A.D. 8 (?)/9–13 (?)
RIC I^2 237/8 or 245

Group D (regular issues)
39) Mainz 14, Dagobertstraße; no. FM 87-135/36. 6,9 g. 210°. FMRD VI 1, Nachtrag 1, 1258 (not to identify)
40) Mainz 26, Obere Zahlbacher Straße; no. FM 88-049. 8,1 g. 30°. Obv. cmk BECH COLL. p. 105–109 (TIB). FMRD VI 1, Nachtrag 1, 1256 no. 284
41) Augst, Schönbühl, kl. Tempel; no. 1957.3825. 7,4 g. 270°. PETER, Augusta Raurica I, p. 48 Reg. 2B/203

Group E (imitations)
42) Mainz 25 (fragm.), Obere Zahlbacher Straße; no. FM 88-049. 8,2 g. 300°. Obv. cmk BECH COLL. p. 130–136 (TIB IM). FMRD VI 1, Nachtrag 1, 1256 no. 285
43) Martberg 14, no. 29709. 4,4 g. 30°
44) Martberg 15, no. 22055. 6,4 gr. 60°

Table 1: Chemical composition of the Lyons altar series analysed by EPMA

All values in weight%. The analyses are normalised to 100% total. [n.d. = not detected].

Catalogue nb.	Analysis nb.	Cu	Sn	Zn	Pb	Ag	As	Sb	Bi	S	Ni	Co	Mn	Fe	Au
Lyons altar series I (RIC I^2 230)															
Group A															
1	MZM9	**99,11**	n.d.	n.d.	0,039	0,194	0,056	0,485	n.d.	0,024	0,032	0,008	n.d.	0,039	n.d.
2	MZM12	**99,09**	0,042	n.d.	n.d.	0,050	0,192	0,464	n.d.	0,026	0,024	0,010	n.d.	0,068	n.d.
3	MBM3	**99,38**	n.d.	n.d.	n.d.	0,169	0,039	0,263	n.d.	0,028	0,052	0,011	n.d.	0,012	n.d.
4	MBM4	**99,54**	0,104	n.d.	n.d.	0,015	0,055	0,159	n.d.	0,024	0,022	0,012	0,007	0,043	n.d.
5	MBM5	**99,45**	0,048	n.d.	n.d.	0,017	0,073	0,201	n.d.	0,031	0,023	0,008	n.d.	0,121	n.d.
6	MBM24	**98,43**	n.d.	n.d.	<0.038	0,364	0,016	0,650	n.d.	0,103	0,070	0,011	n.d.	<0,005	n.d.
Group B															
7	MBM2	**98,44**	0,238	n.d.	<0.038	0,174	0,065	0,627	n.d.	0,033	0,140	0,012	n.d.	0,256	n.d.
8	MZM2	**98,49**	0,183	n.d.	<0.380	0,210	0,061	0,820	n.d.	0,027	0,128	0,012	n.d.	0,054	n.d.
9	MZM5	**98,88**	0,410	n.d.	<0.380	0,085	0,062	0,262	n.d.	0,027	0,088	0,013	n.d.	0,076	n.d.
10	MZM6	**99,22**	0,252	n.d.	n.d.	0,048	0,038	0,314	n.d.	0,029	0,023	0,008	n.d.	0,014	n.d.
11	MBM1	**98,63**	0,207	n.d.	n.d.	0,130	0,115	0,609	n.d.	0,024	0,231	0,010	n.d.	0,011	n.d.
Group A or B															
12	MZM10	**99,89**	<0.012	n.d.	<0.038	n.d.	n.d.	0,028	n.d.	0,019	0,008	0,010	n.d.	n.d.	n.d.
13	MZM1	**98,26**	0,234	n.d.	n.d.	0,234	0,046	0,923	n.d.	0,036	0,133	0,009	n.d.	0,099	n.d.
14	AuM9	**99,40**	0,071	<0,015	<0.038	0,050	0,032	0,232	<0,023	0,064	0,033	0,010	0,006	0,009	0,080
Group C (imitations)															
15	MBM13	**99,60**	<0.012	0,141	n.d.	0,042	0,048	0,053	n.d.	0,029	0,014	0,010	n.d.	0,007	n.d.
16	MZM3	**65,64**	**3,430**	n.d.	**30,031**	0,077	0,166	0,537	n.d.	0,008	0,049	0,016	n.d.	n.d.	n.d.
17	MZM8	**83,61**	**5,603**	n.d.	**9,934**	0,190	n.d.	0,505	n.d.	0,091	0,027	0,011	<0.006	n.d.	n.d.
18	MZM4	**77,76**	**9,954**	0,024	**11,156**	0,090	0,148	0,476	n.d.	0,149	0,125	0,025	0,006	0,071	n.d.
19	AuM5	**99,57**	<0.012	n.d.	n.d.	0,030	0,194	0,074	<0,023	0,035	0,018	0,011	0,010	<0,005	<0,052

Lyons altar series II

RIC I² 233, GIARD 1983, 95															
Group D (regular issues)															
20	AuM10	**98,56**	**1,239**	n.d.	<0,038	0,015	0,007	0,020	<0,023	0,054	0,017	0,006	0,009	0,022	<0,052
Group E (imitation)															
21	AuM6	**99,52**	<0.012	n.d.	0,127	0,041	0,107	0,091	<0,023	0,029	0,010	0,008	0,009	<0,005	<0,052
RIC I² 237/8, GIARD 1983, 101.105.109: Imperator V = A.D. 8(?)/9–10															
Group D (regular issues)															
22	CuM701	**99,48**	0,288	n.d.	<0,038	0,030	0,002	0,022	<0,023	0,035	0,015	0,011	0,008	0,058	<0,052
23	CuM700	**99,27**	0,490	n.d.	<0,038	0,059	0,011	0,035	<0,023	0,025	0,014	0,014	0,008	0,007	<0,052
RIC I² 245, GIARD 1983, 114: Imperat VII = A.D. 13 (?)															
Group D (regular issues)															
24	MZM18	**99,54**	0,281	n.d.	n.d.	0,049	n.d.	0,037	n.d.	0,028	0,018	0,013	0,006	n.d.	n.d.
25	MZM21	**99,86**	n.d.	n.d.	n.d.	n.d.	n.d.	0,016	n.d.	0,033	0,019	0,011	n.d.	0,017	n.d.
26	MZM29	**99,32**	0,541	n.d.	n.d.	n.d.	n.d.	0,014	n.d.	0,046	0,024	0,012	n.d.	0,007	n.d.
27	MZM30	**99,76**	<0.012	n.d.	n.d.	0,016	0,068	0,083	n.d.	0,024	0,011	0,009	n.d.	n.d.	n.d.
28	MZM31	**95,46**	0,752	**3,25**	0,157	0,039	n.d.	0,073	n.d.	0,145	0,015	0,012	n.d.	0,070	n.d.
29	MZM23	**98,38**	**1,283**	n.d.	n.d.	0,046	0,046	0,157	n.d.	0,030	0,014	0,011	n.d.	0,009	n.d.
30	MBM18	**97,28**	0,981	n.d.	0,722	0,052	0,073	0,128	n.d.	0,699	0,012	0,010	0,007	0,007	n.d.
31	MBM19	**99,03**	0,825	n.d.	n.d.	0,025	n.d.	0,048	n.d.	0,028	0,010	0,009	n.d.	n.d.	n.d.
32	MBM20	**99,71**	<0.012	n.d.	n.d.	n.d.	n.d.	0,015	n.d.	0,105	0,016	0,012	n.d.	0,115	n.d.
33	MBM21	**99,86**	<0.012	n.d.	n.d.	n.d.	n.d.	0,016	n.d.	0,033	0,019	0,011	n.d.	0,017	n.d.
34	MBM22	**99,84**	<0.012	n.d.	n.d.	0,025	n.d.	0,028	n.d.	0,047	n.d.	0,009	n.d.	0,009	n.d.
35	MBM23	**99,86**	<0.012	n.d.	n.d.	n.d.	n.d.	0,021	n.d.	0,046	0,018	0,011	n.d.	n.d.	n.d.
36	AuM12	**97,44**	**1,937**	n.d.	0,153	0,063	0,079	0,191	n.d.	0,037	0,016	0,012	0,009	0,006	0,052
Group E (imitations)															
37	MZM20	**99,88**	<0.012	n.d.	n.d.	n.d.	n.d.	0,019	n.d.	0,028	0,024	0,012	0,007	0,008	n.d.
38	AuM8	**99,55**	<0.012	0,068	0,068	0,022	0,067	0,033	<0,023	0,033	0,009	0,014	0,009	0,005	0,083
RIC I² 237/8 or 245: Imperat V or VII = A.D. 8 (?)/9–13 (?)															
Group D (regular issues)															
39	MZM14	**99,73**	0,031	n.d.	n.d.	n.d.	0,038	0,053	n.d.	0,060	0,022	0,008	n.d.	0,023	n.d.
40	MZM26	**99,08**	0,317	n.d.	0,369	0,045	0,013	0,075	n.d.	0,063	0,011	0,010	n.d.	0,012	n.d.
41	AuM11	**98,69**	**1,085**	n.d.	n.d.	0,013	0,002	0,022	<0,023	0,036	0,018	0,009	0,006	0,059	0,055
Group E (imitations)															
42	MZM25	**94,89**	<0.012	n.d.	**4,972**	0,020	0,021	0,046	n.d.	0,014	0,015	0,009	n.d.	n.d.	n.d.
43	MBM14	**99,66**	<0.012	n.d.	n.d.	0,089	0,043	0,093	n.d.	0,028	0,027	0,011	0,006	n.d.	n.d.
44	MBM15	**99,53**	0,053	n.d.	0,098	0,084	0,033	0,099	n.d.	0,035	0,042	0,009	n.d.	n.d.	n.d.

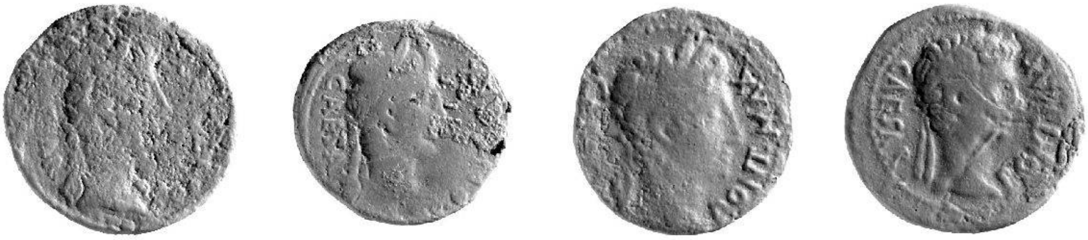
Table 2: Lead and copper isotope ratios of the Lyons altar series analysed by MC-ICP-MS

[STD= Standard Deviation; n.a.= element not analysed, * = no data available]

Sample		$^{206}Pb/^{204}Pb$	STD	$^{207}Pb/^{204}Pb$	STD	$^{208}Pb/^{204}Pb$	STD	$^{208}Pb/^{206}Pb$	STD	$^{207}Pb/^{206}Pb$	STD	$\delta^{65}Cu$ (‰)	STD
Lyons altar series I (RIC I^2 230)													
Group A or B													
1	MZM9	18,42826	0,00344	15,64737	0,00031	38,51527	0,00694	2,09001	0,00002	0,84915	0,00010	-0,03	0,02
2	MZM12	18,19444	0,00049	15,63297	0,00038	38,23238	0,00098	2,10132	0,00006	0,85924	0,00001	0,03	0,02
3	MBM3	18,34194	0,00023	15,63710	0,00022	38,36741	0,00060	2,09179	0,00002	0,85253	0,00001	-0,01	0,02
4	MBM4	18,38231	0,00103	15,64697	0,00099	38,51830	0,00250	2,09540	0,00003	0,85120	0,00001	-0,02	0,02
5	MBM5	18,38795	0,00050	15,64913	0,00057	38,54763	0,00113	2,09635	0,00005	0,85105	0,00002	-0,05	0,02
6	MBM24	18,47421	0,00017	15,66624	0,00018	38,64684	0,00057	2,09193	0,00002	0,84801	0,00000	0,01	0,01
Group B													
7	MBM2	18,37052	0,00025	15,63415	0,00036	38,46304	0,00116	2,09374	0,00004	0,85105	0,00001	0,01	0,01
8	MZM2	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
9	MZM5	18,38900	0,00040	15,64497	0,00044	38,54079	0,00119	2,09586	0,00003	0,85078	0,00001	-0,05	0,02
10	MZM6	18,37773	0,00196	15,63118	0,00013	38,43603	0,00367	2,09145	0,00003	0,85055	0,00008	0,01	0,03
11	MBM1	18,44534	0,00058	15,64685	0,00060	38,50133	0,00185	2,08732	0,00004	0,84828	0,00001	0,09	0,01
Group A or B													
12	MZM10	18,39272	0,00026	15,65929	0,00025	38,49671	0,00083	2,09304	0,00002	0,85139	0,00000	-1,20	0,02
13	MZM1	18,40787	0,00046	15,65087	0,00031	38,55922	0,00101	2,09471	0,00002	0,85023	0,00001	-0,04	0,02
14	AuM9	18,46752	0,00189	15,66956	0,00224	38,58107	0,00611	2,08903	0,00012	0,84849	0,00003	n.a.	n.a.
Group C (imitations)													
15	MBM13	18,20417	0,00044	15,63328	0,00045	38,24257	0,00137	2,10077	0,00004	0,85878	0,00001	0,96	0,02
16	MZM3	18,50921	0,00034	15,63939	0,00032	38,59238	0,00099	2,08504	0,00002	0,84495	0,00001	-0,52	0,02
17	MZM8	18,38842	0,00018	15,61585	0,00020	38,35794	0,00060	2,08598	0,00002	0,84922	0,00000	0,05	0,02
18	MZM4	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	-0,08	0,03
19	AuM5	18,19556	0,00059	15,63213	0,00075	38,22726	0,00239	2,10090	0,00006	0,85911	0,00001	n.a.	n.a.

Lyons altar series II													
RIC I² 233, GIARD 1983, 95													
Group D (regular issues)													
20	AuM10	18,33856	0,00346	15,64079	0,00310	38,37821	0,00841	2,09268	0,00004	0,85290	0,00002	n.a.	n.a.
Group E (imitation)													
21	AuM6	18,19440	0,00107	15,63167	0,00112	38,22684	0,00309	2,10105	0,00008	0,85915	0,00002	n.a.	n.a.
RIC I² 237/8, GIARD 1983, 101.105.109: Imperator V = A.D. 8(?)/9–10													
Group D (regular issues)													
22	CuM701	18,51346	0,00127	15,74336	0,00249	38,83396	0,00571	2,09747	0,00017	0,84691	0,00008	n.a.	n.a.
23	CuM700	18,52047	0,00076	15,78113	0,00130	38,98058	0,00288	2,10459	0,00008	0,84856	0,00004	n.a.	n.a.
RIC I² 245, GIARD 1983, 114: Imperat VII = A.D. 13 (?)													
Group D (regular issues)													
24	MZM18	18,34602	0,00040	15,62603	0,00040	38,32844	0,00083	2,08920	0,00002	0,85174	0,00001	1,15	0,03
25	MZM21	18,20785	0,00076	15,63476	0,00039	38,24580	0,00139	2,10055	0,00006	0,85865	0,00001	n.a.	n.a.
26	MZM29	18,42230	0,00535	15,65574	0,00413	38,49469	0,01032	2,08957	0,00009	0,84983	0,00006	-0,12	0,01
27	MZM30	18,21413	0,00130	15,63701	0,00111	38,25905	0,00247	2,10052	0,00002	0,85859	0,00001	-5,73	0,01
28	MZM31	18,15097	0,00084	15,63370	0,00085	38,24268	0,00229	2,10692	0,00005	0,86132	0,00001	-2,17	0,01
29	MZM23	18,22966	0,00010	15,63768	0,00009	38,27590	0,00023	2,09965	0,00001	0,85782	0,00001	0,11	0,01
30	MBM18	18,20853	0,00046	15,63464	0,00049	38,23517	0,00149	2,09985	0,00004	0,85864	0,00001	0,01	0,02
31	MBM19	18,19434	0,00040	15,63490	0,00056	38,22772	0,00184	2,10108	0,00006	0,85933	0,00001	-1,53	0,02
32	MBM20	18,41140	0,00153	15,63075	0,00084	38,42003	0,00260	2,08675	0,00004	0,84897	0,00003	0,06	0,02
33	MBM21	18,68321	0,00110	15,64867	0,00073	38,63897	0,00223	2,06811	0,00003	0,83758	0,00002	-0,04	0,01
34	MBM22	18,20241	0,00039	15,63284	0,00048	38,24161	0,00157	2,10091	0,00004	0,85883	0,00001	-1,61	0,01
35	MBM23	18,37419	0,00031	15,62546	0,00034	38,37799	0,00112	2,08869	0,00004	0,85040	0,00001	-0,05	0,01
36	AuM12	18,20318	0,00059	15,63914	0,00067	38,25345	0,00131	2,10152	0,00005	0,85915	0,00002	n.a.	n.a.

Group E (imitations)													
37	MZM20	18,49966	0,01930	15,68662	0,01437	38,62889	0,03639	2,08809	0,00030	0,84794	0,00012	0,10	0,02
38	AuM8	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
RIC I^2 237/8 or 245: Imperat V or VII = A.D. 8 (?)/9–13 (?)													
Group D (regular issues)													
39	MZM14	18,71230	0,00104	15,66163	0,00086	38,67620	0,00208	2,06689	0,00002	0,83697	0,00001	-0,01	0,02
40	MZM26	18,17950	0,00036	15,63535	0,00051	38,25652	0,00194	2,10438	0,00007	0,86005	0,00001	1,74	0,02
41	AuM11	18,20676	0,00038	15,63198	0,00043	38,22010	0,00122	2,09921	0,00004	0,85858	0,00001	n.a.	n.a.
Group E (imitations)													
42	MZM25	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
43	MBM14	18,19717	0,00077	15,63126	0,00061	38,23056	0,00145	2,10091	0,00003	0,85899	0,00001	1,03	0,02
44	MBM15	18,19741	0,00047	15,63435	0,00049	38,23668	0,00126	2,10122	0,00002	0,85915	0,00000	0,38	0,02



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