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THE EARLY ROMAN IMPERIAL *AES* COINAGE: METAL ANALYSIS AND NUMISMATIC STUDIES*

PART 1

The Chemical Profile of Copper Coins of the Rome Mint from Augustus to Claudius

Contents

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Abbreviations

CARTER 1971	G.F. CARTER, Compositions of Some Copper-Based Coins of Augustus and Tiberius, in: R.H. BRILL (ed.), Science and Archaelogy (Cambridge, MA 1971), pp. 114-130.
CARTER 1978 (a)	G.F. CARTER, Chemical Compositions of Copper-Based Roman Coins. Augustan *Quadrantes*, ca. 9-4 B.C. Advances in Chemistry Series 171, 1978, pp. 347-377.
CARTER 1978 (b)	G.F. CARTER, Precision in the X-Ray Fluorescence Analysis of Sixty-One Augustan *Quadrantes*. Journal of Archaeological Science 5, 1978, pp. 293-300.
CARTER 1984	G.F. CARTER, Chemical Compositions of Copper-Based Roman Coins: Claudian *Quadrantes* A.D. 41-42. Archaeological Chemistry 3, 1984, pp. 311-329.
CARTER 1993	G.F. CARTER, Chemical and Discriminant Analyses of Augustan *Asses*. Journal of Archaeological Science 20, 1993, pp. 101-115.
CARTER 1995/96	G.F. CARTER, The Chronology of Augustan *Asses* and *Quadrantes* Determined from Chemical Compositions. AJN, 7/8, 1995/96, pp. 235-250.
CARTER/BUTTREY 1977	G.F. CARTER/T.V. BUTTREY, Chemical Compositions of Copper-Based Roman Coins, II: Augustus and Tiberius. ANSMN 22, 1977, pp. 49-65.
CARTER/FRURIP 1985	G.F. CARTER/D.J. FRURIP, Discriminant Analysis of the Chemical Compositions and Physical Measurements of 245 Augustan *Quadrantes*. Archaeometry, 27, 1, 1985, pp. 117-126.
CARTER *et al.* 1978	G.F. CARTER/M.H. KIMIATEK/F.J. KLUPACS/J.-B. GIARD, Chemical Compositions of Copper-Based Roman Coins, V. Imitations of Caligula, Claudius, and Nero. RN 1978, pp. 69-88.
CARTER/KING 1980	G.F. CARTER/C.E. KING, Chemical Compositions of Copper-Based Roman Coins, IV. Tiberius to Nero A.D. 34-66; in: METCALF/ODDY 1980, pp. 157-167.
CARTER/METCALF 1988	G.F. CARTER/W.E. METCALF, The Dating of the M. Agrippa *Asses*. NC 148, 1988, pp. 145-147.
CARTER/POWELL 1994	G.F. CARTER/R.R. POWELL, The Chronology of Groups of Dies for Large Issues of Ancient Coins using Mahalanobis Distances. Archaeometry 36, 2, 1994, pp. 277-286.
CRADDOCK 1995	P.T. CRADDOCK, Early Metal Mining and Production (Edinburgh 1995).
DAVIES 1935	O. DAVIES, Roman Mines in Europe (Oxford 1935).
DOMERGUE 1987	Cl. DOMERGUE, Catalogue des mines et des fonderies antiques de la Péninsule Ibérique. Publications de la Casa de Velázquez, Série Archéologie 8 (Madrid 1987).

DOMERGUE 1990	Cl. DOMERGUE, Les mines de la Péninsule Ibérique dans l'Antiquité Romaine. Collection de l'École Française de Rome 127 (Rome 1990).
HALL/METCALF (eds.) 1972	E.T. HALL/D.M. METCALF (eds.), Methods of Chemical and Metallurgical Investigation of Ancient Coinage (London 1972).
HEALY 1978	J.F. HEALY, Mining and Metallurgy in the Greek and Roman World (London 1978).
METCALF/ODDY (eds.) 1980	D.M. METCALF /W.A. ODDY (eds.), Metallurgy in Numismatics 1 (London 1980).
ODDY/COWELL (eds.) 1998	A. ODDY/M. COWELL (eds.), Metallurgy in Numismatics 4 (London 1998).
Projektgruppe Plinius 1985	Projektgruppe Plinius, Plinius der Ältere über Kupfer und Kupferlegierungen. Schriften der Georg-Agricola-Gesellschaft zur Förderung der Geschichte der Naturwissenschaften und der Technik e.V. (Düsseldorf 1985).
SHEPHERD 1993	R. SHEPHERD, Ancient Mining (London/New York 1993).

Abstract

241 copper coins of the Emperors Augustus, Tiberius, Caligula and Claudius from the Rome mint were analysed for bulk chemical composition by electron probe microanalysis (EPMA). The elemental pattern of the copper was used to identify developments in its chemical composition. The analysis illuminated many aspects of the coinage, and above all revealed that over the period the copper used became increasingly pure chemically. Dated and official coinage from the Rome mint was studied, and it was possible to relate undated coins of Tiberius (the DIVVS AVGVSTVS PATER series) to dated Tiberian issues. The Agrippa *asses* were shown to be linked to Caligulan rather than to Tiberian *asses*. Some Claudian imitations may be recycled from late Tiberian *asses*.

1 Introduction and aims

Up to now little attention has been paid to «pure» copper as a metal for Roman Imperial coinage.[1] The discussion of copper in the most recent surveys of metals for coinage[2] has been very brief, and is an apposite reflection of the present state of knowledge and of the low esteem in which the metal is held. This is particularly surprising when one considers that the copper coins which Augustus introduced (the units *as* and *quadrans*) proved to be extremely successful, and that the mass of small change in circulation was, for a long time, characterised by copper coins.

What is more, Roman bronze and brass, of which above all the former was used for the production of a wide range of everyday products and for statues, were normally composed of some 70-90% copper. Thus a better understanding of the characteristic properties of the copper used in coins has implications beyond the coinage itself. Compared with the Imperial coinage, which provides an almost complete documentation of the use of copper, few other objects of unalloyed copper have survived.

As a single phase metal copper provides a particularly good basis for studying the main and trace elemental patterns. The aim of this study is to analyse the copper used in the minting of early Imperial *asses* and *quadrantes* during a politically important period which was also of great significance for the coinage. For example, the elements in the copper used in the moneyers' *asses* and *quadrantes* of Augustus will be examined in order to see whether within their numismatic context they remain uniform, or whether, and how, they change over a period of almost two decades. Individual patterns of trace elements can either be the result of different smelting or refining techniques being used for the raw copper, or of different sources of ore.

Within the context of the early Imperial coinage there are also a number of important numismatic questions to be considered, for example the arrangement of undated coin types, and the relative chronology of particular issues. The work of G.F. Carter has already shown that important information can be expected. Since the 1960s he has published a series of articles on the early Imperial copper

1 Earlier scholars often used the term copper both for unalloyed copper and for the copper alloys bronze and brass, for example H. WILLERS, Geschichte der Römischen Kupferprägung vom Bundesgenossenkrieg bis auf Kaiser Claudius (Leipzig 1909). Although this work is out of date, it is still important in many aspects.

2 H. MOESTA/P.R. FRANKE, Antike Metallurgie und Münzprägung. Ein Beitrag zur Technikgeschichte (Basel/Boston/Berlin 1995), pp. 136-138; P. HAMMER, Metall und Münze (Leipzig/Stuttgart 1993), pp. 104-108; C.H.V. SUTHERLAND, Procurement of *Aes* for Coinage of the Early Empire, in: P. KOS/Ž. DEMO (eds.), Studia Numismatica Labacensia Alexandro Jeločnik oblata (Ljubljana 1988), pp. 27-33; R.G. CARSON, Roman Coinage Metal and Coin Production. NACQTic 10, 1981, pp. 301-313.

and brass coinage,[3] but in numismatic circles these have not yet received the attention they deserve.

In order to counteract problems arising from the fact that finds of early Imperial coins from the Rhineland often include various classes of imitations, it was decided to sample material not from there, but from the centre of the Empire, Rome, where the coins under study were minted. Thanks to the kind support of S. Balbi de Caro, Rome, it was possible to take samples from a selection of some 500 *aes* coins from the large coin collection in the Museo Nazionale Romano in Rome: 28 bronze coins of Octavian of the DIVOS IVLIVS type, as well as 241 copper and 236 brass coins from the Emperors Augustus to Claudius. They all come from the complex of coins found mainly in the last two decades of the 19th century during the construction work on the embankments of the River Tiber within the city of Rome,[4] and which was inventoried at the beginning of this century by S.L. Cesano in the Museo Nazionale Romano. The coins of the Emperors Caligula and Claudius have already been published in the Bollettino di Numismatica,[5] the manuscripts for the Emperors Augustus (including the DIVOS IVLIVS types)[6] and Tiberius[7] are completed, and will also appear in the same journal. The list of the «Greek» coins has also been published.[8]

The coins of the four Emperors could therefore be chosen on the basis of a new catalogue, and in full knowledge of the numismatic questions to be answered. Not only could almost all coin types present be included, but also a number of numismatic peculiarities could be given appropriate consideration. However, in view of the number of samples we were obviously restricted by the availability of financial resources, as well as technical facilities. Although the number of analyses we could carry out does not provide as broad a statistical basis as is desirable given the wide range of coin types and the numismatic questions they raise, nevertheless we feel that the fact that no comparable uniform series of analyses has been conducted to date is justification of our programme.

3 Cf. the works listed in the abbreviations. For a recent survey of metal analysis of ancient coins see M. AMANDRY, Bibliographie commentée des analyses de laboratoire appliquées aux monnaies grecques et romaines de bronze (1972-1998). RBN 145, 1999, pp. 173-183.

4 C. MOCCHEGIANI CARPANO, Il Tevere: Archeologia e commercio. Boll. di Num. 2/3, 1984, pp. 21-81; M.E. BARTOLDI, Antike Münzfunde aus der Stadt Rom (1870-1902). Il problema delle provenienze. Die Fundstellen. Studien zu Fundmünzen der Antike 14 (Berlin 1997) *passim.*

5 *Caligula*: F.E. KOENIG, Roma - Monete dal Tevere. L'imperatore Gaio (Caligola). Boll. di Num. 10, 1988, pp. 21-186. *Claudius*: H.-M. von KAENEL, Roma – Monete dal Tevere. L'imperatore Claudio I. Boll. di Num. 2/3, 1984, pp. 85-325, with a summary of the entire complex.

6 Catalogued by H.-M. VON KAENEL.

7 Catalogued by B. HEDINGER and H. BREM.

8 S. FREY-KUPPER, Monete dal Tevere – I rinvenimenti «greci». Boll. di Num. 25, 1995, pp. 33-73.

In order to be able to put the trace elemental pattern of the copper used in the Rome mint into context, 50 *aes* coins struck at Lugdunum/Lyons during the reign of Augustus were also analysed. G. Rupprecht, Mainz, provided the relevant coins from the large complex of coin finds from Mogontiacum/Mainz. We are preparing a separate publication on the copper from the Lyons altar issues.

2 Mineralogical background

Pliny the Elder (A.D. 23-79) is the main historical source for information about important copper ore locations in Roman times. But his information is neither complete, nor does he differentiate between the purposes for which the copper was used. The *Projektgruppe Plinius*[9] has discussed the mineralogical composition of Pliny's copper ore sources: Cyprus, Euboea, Italy, Spain, Gaul, the German provinces and the Alps. As for metal for coins, Pliny mentions *asses* made of Cypriot copper.[10] In addition to these Roman copper ore sources, other locations which are known to have been exploited in the ancient world, and might still have been of some interest to the Romans, have to be taken into consideration:[11] Britain and the Balkans,[12] Syria, Palestine and the Sinai Peninsula,[13] the Persian Gulf, Asia Minor, as well as Africa (Libya, Algeria, Mauretania, Ethiopia).

Practicable mining[14] and smelting techniques[15] for copper ores always depend greatly on the ore composition, which differs from deposit to deposit. Copper deposits comprise not only the major component copper, but also almost all other elements, and these can occur in various concentrations from percent to trace element range. Depending on the ore types and their particular geochemical conditions and behaviour during formation, specific elements accompanying the copper can dominate. This may produce typical minor and trace elemental patterns which characterise individual ore deposits and ore types,[16] but only to a limited

9 Projektgruppe Plinius 1984, pp. 23-64.

10 Plin. nat. 34,4.

11 RE XI, 2 (1922) 2194-2200 *s.v.* Kupfer (H. BLÜMNER); C. GIARDINO, I metalli nel mondo antico. Introduzione all'archaeometallurgia (Roma/Bari 1998), pp. 115-119.

12 Z.A. STOS-GALE, The Origin of Metals from the Roman-Period Levels of a Site in Southern Poland. Journal of European Archaeology 1.2, 1993, pp. 101-130.

13 Other regions which might have produced copper during Roman times are Fenan, Timna, and Abu Kusheiba.

14 Metallurgical summaries by CRADDOCK 1995; SHEPHERD 1993; DOMERGUE 1990; DOMERGUE 1987; HEALY 1978; DAVIES 1935. For a recent historical survey on Roman mining see J. ANDREAU, Recherches récentes sur les mines à l'époque Romaine, I. Propriété et mode d'exploitation. RN 1989, pp. 86-112 and II. Nature de la main d'œuvre; Histoire des Techniques et de la Production. RN 1990, pp. 85-108.

15 H.-G. BACHMANN, Vom Erz zum Metall (Kupfer, Silber, Eisen) – Die chemischen Prozesse im Schaubild, in: H. STEUER/U. ZIMMERMANN (eds.), Alter Bergbau in Deutschland (Stuttgart 1993), pp. 35-40.

16 The assignment of copper metal to ore source is discussed by R. BOWMAN/A.M. FRIEDMAN/J. LERNER/J. MILSTED, A Statistical Study of the Impurity Occurrences in Copper

extent because the levels of these elements can vary even within the area of a deposit.

Native copper as a source of very pure copper metal has been the subject of often controversial discussion, and the deposition of copper metal on metallic iron out of aqueous solutions was already known to Pliny the Elder, although it probably did not play an important role in the production of copper in the Roman period.[17] If the ore is of oxide character[18] it is easy to obtain metallic copper by a single-stage reduction smelting in which the charge contains ore, fuel, and a low-melting flux. The products are metallic copper and slag.[19] If of sulphide character[20] the ore has to be pre-treated by partial roasting to remove some of the sulphur and to oxidise the copper. A subsequent multi-stage matte smelting procedure[21] has to be applied to this pre-roasted sulphide ore, producing a matte, slag and some metallic copper. During smelting charcoal and fluxing agents are added, the latter improving the formation of slag. If polymetallic mixed sulphide ores are smelted the «pyritic» smelting process[22] by-passes the preliminary roasting, but the multiple matte smelting process is still necessary to obtain a satisfactory yield of copper metal.

The multitude of influences arising from all of these smelting processes significantly alter the primary elemental pattern of the ore.[23] The smelting additions (fuel, fluxes) also introduce unknown contaminations to the ore, and the smelting process greatly influences the volatile elements. Various trace elements parti-

Ores and their Relationship to Ore Types. Archaeometry 17, 2, 1975, pp. 157-163; D. SCHULZ, Zuordnung von Kupfer-Metall zum Ausgangserz. Prähistorische Zeitschrift 58, 1983, pp. 1-14.

17 A useful survey of historical copper production was published by B. NEUMANN, Die Metalle. Geschichte, Vorkommen und Gewinnung nebst ausführlicher Produktions- und Preis-Statistik (Halle 1904).

18 E.g. oxide, carbonate, hydrocarbonate, sulphate, or silicate copper minerals.

19 Intensive studies on archaeometallurgical slags have been presented by H.-G. Bachmann, e.g. H.-G. BACHMANN, Schlacken: Indikatoren archäologischer Prozesse, in: H.W. HENNICKE (ed.), Mineralische Rohstoffe als kulturhistorische Quelle (Hagen 1978), pp. 66-103.

20 E.g. chalcocite (Cu_2S), covellite (CuS), bornite (Cu_5FeS_4), chalcopyrite ($CuFeS_2$), tetrahedrite ($Cu_{12}Sb_4S_{13}$), tennantite ($Cu_{12}As_4S_{13}$), and enargite (Cu_3AsS_4). Ancient literary sources mention the use of «chalcitis», presumably a mixture of various copper and iron sulphide minerals (chalcocite, chalcopyrite, pyrite and markasite).

21 See e.g. CRADDOCK 1995, pp. 156-202.

22 We are grateful to H.-G. Bachmann, Hanau, for information on the «pyritic smelting process», as well as for various references. He found this process being applied in the German Harz Region during medieval times (H.-G. BACHMANN, forthcoming publication).

23 For example manganese in Cypriot Bronze Age copper slags, see N.H. GALE/Z.A. STOS-GALE/G. MALIOTIS/N. ANNETTS, Lead Isotope Data from the Isotrace Laboratory, Oxford: Archaeometry Data Base 4, Ores from Cyprus. Archaeometry 39, 1, 1997, pp. 237-246; also S. STOS-GALE/G. MALIOTIS/N. 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.D. MUHLY (eds.), Metallurgica Antiqua. Der Anschnitt, Beiheft 8 (Bochum 1998), pp. 235-262.

tion between copper metal, matte, and slag.[24] The metallic copper produced from the ore is still very impure and contains only 94-96% copper.[25] It therefore needs to be refined, usually by re-melting.[26] The more often this re-melting is repeated, the purer the metallic copper becomes.

For all these reasons it is extremely difficult to reconstruct ancient smelting and melting processes based on the character of the metal produced. Studies of the provenance of metals based on chemical composition alone only yield satisfying results if used in combination with additional analytical methods, e.g. lead-isotope studies.[27] The consequence is that in order to retrieve information about raw materials from such complex products, we must have sufficient knowledge of the individual stages of the processes and their influence on the chemical behaviour of the material.

The usefulness of chemical investigations for numismatics lies in retrieving information about the character of the coins, for example chemical trends during a defined time period, the quality of the metal produced, the application and quality of refinement techniques, and more practically the assignment of undated coins to dated ones, the identification of imitations, etc.

3 Analytical procedure

Most of the Roman Imperial copper coins investigated to date were subjected to non-destructive surface analysis,[28] sometimes only semi-quantitatively. Traditional analytical methods applied to coins are Atomic Absorption Spectrometry (AAS)[29] and X-Ray Fluorescence Analysis (XRF).[30] Large sets of coin analyses of Roman

[24] R.F. TYLECOTE/H.A. GHAZNAVI/P.J. BOYDELL, Partitioning of Trace Elements Between the Ores, Fluxes, Slags and Metal During the Smelting of Copper. Journal of Archaeological Science 4, 1977, pp. 305-333. Also SCHULZ, op. cit. note 16; A. YAZAWA, Distribution of Various Elements between Copper, Matte and Slag. Erzmetall 33, Nr. 7/8, 1980, pp. 377-382.

[25] So-called «black» or «blister» copper.

[26] For refining and alloying of copper and copper alloys in Roman times see U. ZWICKER/H. GREINER/K.-H. HOFMANN/M. REITHINGER, Smelting, Refining and Alloying of Copper and Copper Alloys in Crucible Furnaces during Prehistoric up to Roman Times, in: P.T. CRADDOCK/M.J. HUGHES (eds.), Furnaces and Smelting Technology in Antiquity. British Museum Occasional Paper 48 (London 1985), pp. 103-115.

[27] The most important study is N.H. GALE/W. GENTNER/G.A. WAGNER, Mineralogical and Geographical Silver Sources of Archaic Greek Coinage, in: METCALF/COWELL (eds.) 1980, pp. 3-49. Recent survey: Z.A. STOS-GALE, Lead Isotope Analysis of Coins – A Review, in: ODDY/COWELL (eds.) 1998, pp. 348-366.

[28] A bibliography on coin analysis until 1998 is given by AMANDRY, op. cit. note 3.

[29] M.J. HUGHES, Atomic Absorption Spectrometry in numismatics, in: ODDY/COWELL 1998, pp. 223-236.

[30] G.F. CARTER, Coin Analyses by Wavelength Dispersive X-Ray Fluorescence (WDXRF), in: ODDY/COWELL (eds.) 1998, pp. 425-442; T. PADFIELD, Analysis of Byzantine Copper Coins by X-ray Methods, in: HALL/METCALF (eds.) 1972, pp. 219-236.

copper-based material were first introduced by Carter and his co-authors, who applied quantitative XRF to the coin surfaces.

Because surface analysis[31] is known to be subject to diverse problems,[32] it was a great advantage for the project presented here, that we were allowed to sample «destructively»,[33] taking uncorroded material from the interior of the object. We sampled 241 copper coins from the Museo Nazionale in Rome by drilling with steel drill bits of 1.0-0.5 mm diameter. This yielded about 50 mg of metal turnings, which were mounted and polished for metallography in the usual manner, and coated with carbon for better conductivity. Coating has the welcome side-effect on metallic samples of protecting them against corrosion.

The analyses were performed at the Institut für Mineralogie, J.W. Goethe-Universität Frankfurt, Germany, applying Electron Probe Microanalysis (EPMA; Jeol Superprobe JXA-8900 RL).[34] For the bulk chemical composition of the samples copper, tin, lead, zinc, iron, manganese, cadmium, cobalt, nickel, arsenic, antimony, silver, gold, bismuth and sulphur were analysed quantitatively with an accelerating voltage of 20 kV and a beam current of 30 nA.[35] The selection of elements followed the practice commonly used in reports on metal analyses of copper-based archaeological objects. Because of the very small size of the turnings it was impossible to scan over a large area, and instead we acquired by point analysis with a beam size of 6 µm. The analysis of each sample was repeated six times on different locations.[36] In this way a total area of 170 μm^2 was analysed. The results presented here correspond to the statistical average of these acquisitions.

In order to monitor the accuracy of our analyses, we regularly ran certified copper metal standards and several multi-analysed copper-based samples, the latter kindly put at our disposal by Haldis Bollingberg, Copenhagen, and Peter Northover, Oxford.

The correction method used for weight percent calculations was ZAF. Due to decreasing total accumulated counts the analytical precision decreases from major

31 Surface polishing or streaking: G.F. CARTER/M.H. KIMIATEK, Comparison of Surface with Interior Compositions of Eight Roman Copper Based Coins. Archaeo-Physika 10, 1979, pp. 82-96; A.A. GORDUS, Streak Analyses, in: HALL/METCALF (eds.) 1972, pp. 127-148.

32 G.F. CARTER, Preparation of Ancient Coins for Accurate X-Ray Fluorescence Analysis. Archaeometry 7, 1964, pp. 106-113; C.E. KING/J.P. NORTHOVER, Ashmolean, British Museum and Neftenbach Hoard Analyses, in: L.H. COPE †/C.E. KING/J.P. NORTHOVER/T. CLAY (eds.), Metal Analyses of Roman Coins Minted under the Empire. British Museum Occasional Paper 120 (London 1997), pp. 69-72; J.P. NORTHOVER, Analysis in the Electron Microprobe and Scanning Electron Microscope, in: ODDY/COWELL (eds.) 1998, pp. 94-113.

33 As KING/NORTHOVER, op. cit. note 32, mention, L.H. Cope already maintained many years ago that destructive examination is the best way to obtain accurate analysis results.

34 The application of EPMA to coins is discussed by NORTHOVER, op. cit. note 32, pp. 69-80.

35 L.H. COPE/R. WARREN, A Comparison of Electron-Probe Microanalysis with other Methods for Determining the Bulk Alloy of Coins, in: HALL/METCALF (eds.) 1972, pp. 238-247.

36 We usually increase the number of repetitions to ten or more if the material is very heterogeneous or has a multi-phase composition.

to trace elements: Typical errors are < 1% relative for the major elements, and approximately 10% relative for the trace elements with concentrations below 200 ppm. However, due to heterogeneous distribution throughout the material analysed the standard deviation of certain elements can be higher than 10%. The calculated detection limits[37] are below 100 ppm for S, Fe, Mn, Ni, Co, between 100 and 200 ppm for Ag, As, Sn, Cu, Sb, Zn. Bi (230 ppm), Pb (380 ppm) and Au (520 ppm) have higher detection limits.

4 The chemical profile of the coins

In this section we will present the results of the analysis, and use them to trace any changes and trends in the behaviour of minor and trace elements in the Roman copper during the period under study. Furthermore, we will look for differences in the chemical composition of various coin types, as well as between coins from the mint of Rome and unofficial imitations. We will refrain from assigning the metal to ore sources as long as lead-isotope studies on this material are not available to us.

The *asses* and *quadrantes* minted at Rome between about 16 B.C. and A.D. 42 analysed here are comprised of almost pure copper, with varying impurities of other elements analysed. Central to our study is the assumption that each coin has its own individual composition, and so we refrain from following the common practice of only presenting statistical averages for coin types or groups. However, we had a large set of data to work with, so that we needed to find a workable basis for the comparison of coin type groups, coin types, and individual specimens. We also felt it was important not just to publish large numbers of data sets alone, but also to present them to the reader in the form of diagrams which can easily be accessed, and which he can compare with his own results.

For this reason we reduced the compositional variety to patterns of certain elements, represented by three relevant elemental groups: tin-sulphur-lead-silver-arsenic-antimony, iron-manganese, and cobalt-nickel. This selection of elements facilitates comparison of the results with other studies on the subject. The patterns were created with reference to the chronology proposed by RIC I^2, using the data for those coin types which are grouped together chronologically and show comparable chemical behaviour. A change from one pattern to the next is said to take place when significant differences in chemical behaviour appear. In the discussion we will refer to coins characterised by the same elemental group pattern as compositional groups.

For each elemental group pattern (EGP) diagrams show the range of concentrations in which the elements occur. A band covers the area into which the element concentrations for the period under consideration can fall, but this does not mean that all coins falling within such a band are identical. Differences in single

37 Detection limits based on 3σ calculations for the matrix of the copper coins taking into account the number of repetitions.

elements can occur which distinguish coins or coin types from others, even when they share the same elemental group pattern.

4.1 Augustus (January 27 B.C. – 19 August A.D. 14)

4.1.1 Numismatic background

There were two separate phases of copper coinage at the Rome mint during the reign of Augustus. Within the so-called moneyers' coinages, which more or less cover the last two decades B.C., *asses* or *quadrantes* were struck a total of eight times; in the late Augustan period *asses* were struck twice.

One of the administrative measures which Augustus carried out during his reign was a reform of the Roman currency.[38] No *aes* had been struck at Rome for several decades when at an uncertain date in or after 23 B.C. the *aes* coinage was completely reformed. The bronze coinage was replaced by a bi-metallic system consisting of brass (*sestertius, dupondius*) and copper (*as, quadrans*), with a fixed tariff between them. This system was to survive for some two and a half centuries.

The new copper and brass issues of Augustus are often referred to as «moneyers' issues», because the coin legends include the names of the moneyers (*IIIviri aere argento auro flando feriundo*). Augustus put new life into the old, traditional office of the *tresviri monetales.*[39] The names of 45 moneyers are recorded on the coinage of Augustus' reign. They were organised into colleges of three, sometimes four, and held office for one year. There names were placed not just on *aes*, but also on gold and silver coins struck at Rome.

There is little doubt about the composition of the individual colleges. In some cases legends confirm the contemporaneity of particular moneyers, while other colleges can be reconstructed with a degree of confidence. On the other hand, the absolute and relative chronologies of the colleges are still a matter of dispute. For example, which college initiated the moneyers' coinage of Augustus, and in which year?

There are two main schools of thought on the sequence and dating of the moneyers' *aes* issues. H. Mattingly,[40] followed more recently by A.M. Burnett,[41] A. Wal-

[38] A. BURNETT, Coinage in the Roman World (London 1987), pp. 53-55; M.H. CRAWFORD, Coinage and Money under the Roman Republic. Italy and the Mediterranean Economy (London 1985), pp. 256-279; RIC I^2, pp. 31-34; J.-B. GIARD, CBN I, Auguste (Paris 1976), pp. 41-43; see also the review by D. MANNSPERGER, Die Münzprägung des Augustus, in: H. BINDER (ed.), *Saeculum Augustum* III. Kunst und Bildersprache (Darmstadt 1991), pp. 348-399.

[39] K. PINK, Die *Triumviri monetales* unter Augustus. NZ 71, 1946, pp. 113-125; C.H.V. SUTHERLAND, The Emperor and the Coinage. Julio-Claudian Studies (London 1976), pp. 9. 12-14. 40.

[40] H. MATTINGLY, BMC I, pp. xciv-cviii.

[41] A.M. BURNETT, The Authority to Coin in the Late Republic and Early Empire. NC 1977, pp. 45-63.

lace-Hadrill[42] and others, suggested that the *aes* coinage began in 23 B.C. with the issues of the moneyers Cn. Piso, L. Naevius Surdinus and C. Plotius Rufus, who struck denominations in brass and copper (*asses*). K. Kraft[43] argued for a different chronology, which was also adopted by C.H.V. Sutherland, J.-B. Giard, and others.[44] They have the coinage start in 19 B.C. with precious metal issues, followed in 18 B.C. by the first *aes* of Q. Aelius Lamia, C. Marcius Censorinus and T. Quinctius Crispinius Sulpicianus, who struck only brass, with no copper. The first copper was then issued in 16 B.C. But it is not only the beginning of the new *aes* coinage that differs in the two chronologies, there are also differences in the arrangement of the subsequent issues. On the basis of a statistical study of his metal analyses, G.F. Carter[45] brought new arguments into play.

In order not to complicate this article with a discussion of the absolute chronology of the moneyers' issues of Augustus, the matter will not be dealt with here, but included in a further study, together with other metal analysis (including so-called 'Numa' *asses*, RIC I^2 391.392) and the results of lead-isotope analyses. It is also pure convention that we have adopted here the arrangement and dating of issues presented in RIC I^2, a procedure which seems all the more acceptable since attention here is focused on the definition and discussion of elemental patterns. Here we only discuss the question of the relative sequence of the moneyers' issues from the viewpoint of chemical analysis.

The late Augustan copper issues are dated by the titulature of Augustus and his adoptive son Tiberius to A.D. 10/11 (RIC I^2 469) and 11/12 (RIC I^2 471). These coins no longer include moneyers' names in their legends.

4.1.2 Coin analysis

A total of 80 Augustan copper coins, 65 moneyers' *asses* and *quadrantes* and 15 late-Augustan *asses*, were analysed (*see Appendices 1-2*).

Under Augustus the chemical composition of the copper clearly distinguishes two periods of minting. The most important characteristics of the material are represented by two elemental group patterns:

42 A. Wallace-Hadrill, Image and Authority in the Coinage of Augustus. JRS 76, 1986, pp. 85-87.

43 K. Kraft, Zur Datierung der römischen Münzmeisterprägung. Mainzer Zeitschrift 46/47,1951/52, pp. 28-35; *id.*, Q. Aelius L. f. Lamia, Münzmeister und Freund des Horaz. JNG 16, 1966, pp. 23-31.

44 RIC I^2, pp. 31-34 and 61-78, also C.H.V. Sutherland, Roman History and Coinage 44 BC – AD 69 (Oxford 1987), pp. 33-34; Giard, op. cit. note 38; C.M. Kraay, Die Münzfunde von Vindonissa (bis Trajan). Veröffentlichungen der Gesellschaft Pro Vindonissa 5 (Basel 1962) pp. 29-31. Kraay later returned to the arrangement suggested in BMC (23 B.C.), cf. C.H.V. Sutherland/C.M. Kraay, Catalogue of Coins of the Roman Empire in the Ashmolean Museum I, Augustus (c. 31 B.C. - A.D.14) (Oxford 1975) text to pls. 12-17. The sequence proposed by Kraft was adopted for the FMRD volumes, as well as by H. Chantraine, Die antiken Fundmünzen von Neuss. Gesamtkatalog der Ausgrabungen 1955-1978. Novaesium VIII. Limesforschungen 20 (Berlin 1982) pp. 17-18.

45 Carter 1995/96.

Elemental group pattern I (EGP I)

EGP I (*Figure 1*) represents the earlier copper issues under Augustus (16 – 4 B.C.):

- Sn-S-Pb-Ag-As-Sb group: tin, sulphur, and lead can be detected, but are just as often below the detection threshold. Whereas the levels of tin and sulphur, if detectable, remain very constant, lead can scatter over a wide range. Silver, arsenic, and antimony vary and scatter within one tenth power. Normally antimony is most important, followed by silver and then arsenic.
- Fe-Mn group: iron is always present in larger quantities than manganese. The range in which both elements scatter is quite wide.
- Co-Ni group: nickel is always present, cobalt is predominantly below the detection limit.

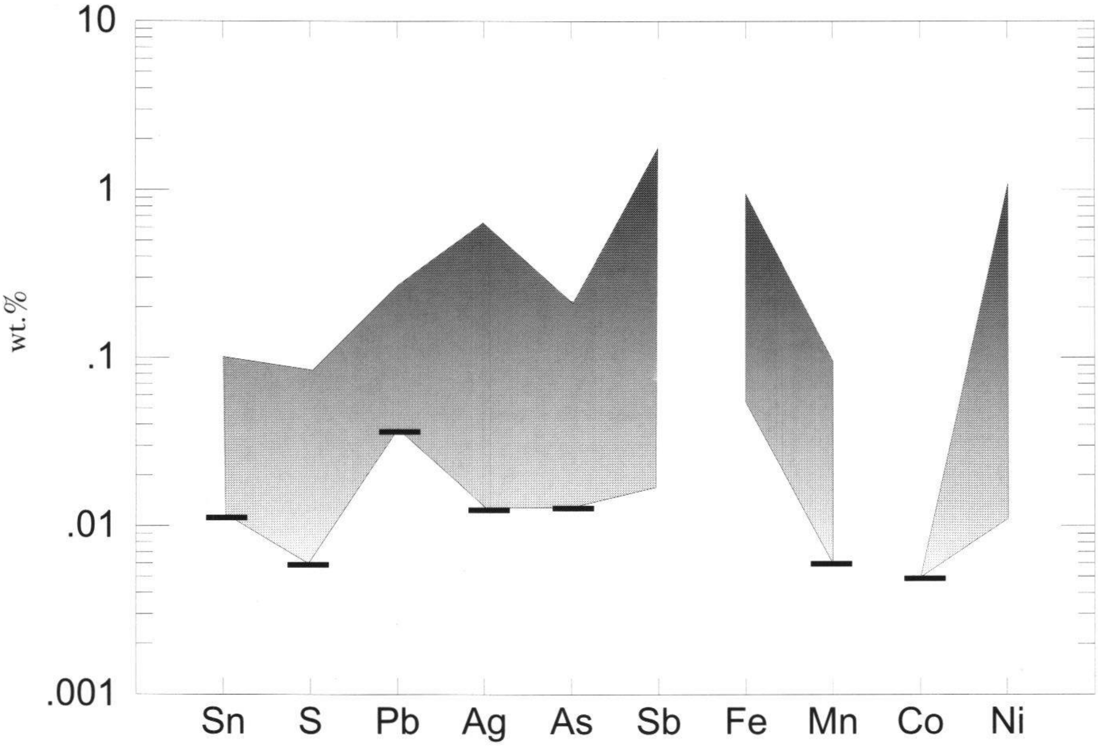

Figure 1: Elemental group pattern I (EGP I). The diagram displays the most characteristic elements, based on the representative Augustan groups 1-8. Bars indicate values below the detection limits of the elements.

Elemental group pattern II (EGP II)

EGP II (*Figure 2*) presents an elemental pattern typical of the late Augustan copper coinage (A.D. 10-12):

- Sn-S-Pb-Ag-As-Sb group: tin, sulphur, lead, and arsenic are below detection limits. Silver and antimony scatter in a much narrower range than in EGP I.
- Fe-Mn group: the behaviour of iron and manganese is generally the same as in EGP I. Only the range within which iron and manganese scatter is narrower than before.
- Co-Ni group: The major difference to EGP I is that besides nickel, cobalt is also regularly detectable.

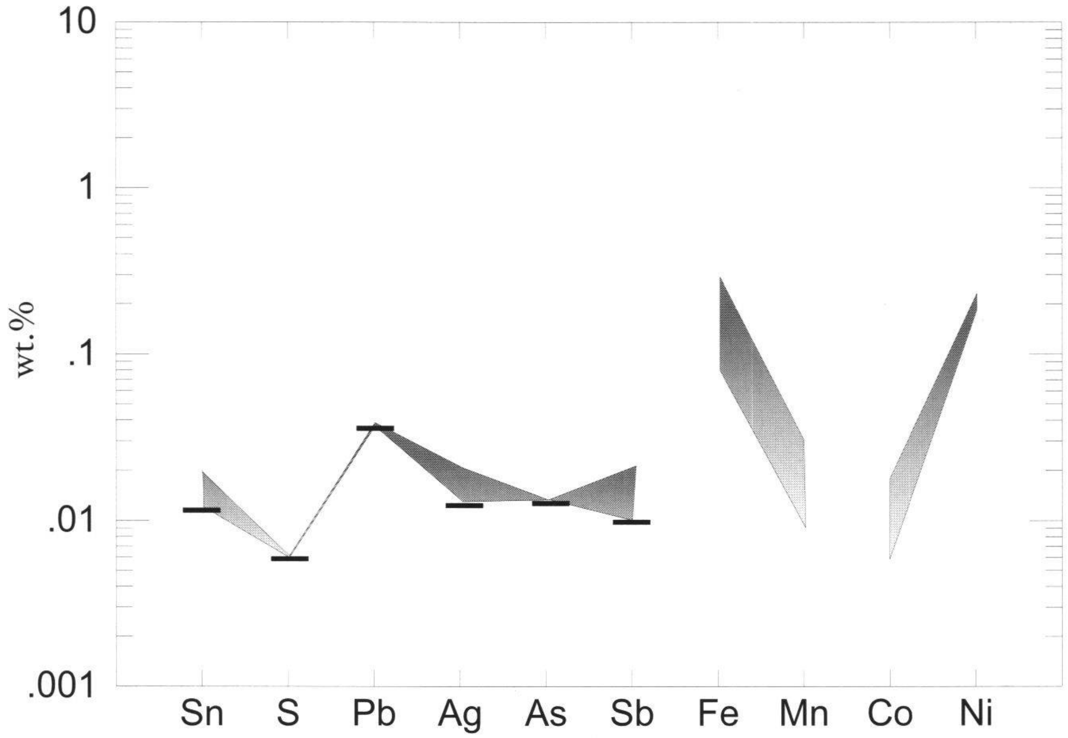

Figure 2: Elemental group pattern II (EGP II). The diagram displays the most characteristic elements, based on Augustan group 9. Bars indicate values below the detection limits of the elements.

4.1.3 Numismatic questions

1 Of the first issues of *asses*, i.e. of Gallus, Celer and Lupercus (group 1) and Piso, Surdinus and Rufus (group 2): What is the composition of the elemental pattern of the copper of the individual moneyers? Are the values homogeneous, and how do they relate to those for the *asses* of the other moneyers in the same college? Is the copper used in the two issues chemically different?

The *asses* of group 1 are all characterised by EGP I. The three moneyers struck coins with homogeneous copper, and the *asses* of the individual moneyers are not distinguishable from each other on the basis of the chemical composition.

As for the *asses* of group 2, the college produced copper coins characterised by EGP I, although the *asses* struck by Piso are chemically distinct from the others in having higher and therefore detectable amounts of cobalt. No differences can be found between the issues of Surdinus and Rufus.

2 The same questions apply to the *asses* and *quadrantes* of the next moneyers (groups 3–8).

The *quadrantes* of Lamia, Silius and Annius (group 3) are characterised by EGP I. No chemical distinction can be made between the three moneyers' copper. The *quadrantes* of Pulcher, Taurus and Regulus (group 4) are also characterised by

EGP I. Chemical distinction is not possible between the moneyers, nor between the two groups of *quadrantes.*

As for group 6, the *asses* of Silianus and Quinctilianus are not distinguishable and are characterised by EGP I, whereas Messalla's coins differ in having detectable cobalt contents. The *asses* of Agrippa, Otho and Tullus (group 5) are also characterised by EGP I, and again only Otho's copper is different with detectable cobalt values. Coins of Otho and Messalla are chemically distinct from the issues of their respective colleges.

The *quadrantes* of Apronius, Galus, Messalla and Sisenna (group 7) are homogeneous in composition (EGP I), and no distinction can be made between the moneyers. The *quadrantes* of Bassus, Capella, Blandus and Catullus (group 8) are also homogeneous in composition (EGP I). No distinction can be made between the moneyers, nor between the two groups of *quadrantes.*

3 Do the elemental patterns for the individual coin types and emissions remain stable, or can a relative chronology be deduced from characteristic developments of the copper in the eight separate issues?

Changes in chemical composition towards purer material can be observed which might suggest a relative sequence of *asses* and *quadrantes* of groups 1, 2, 3, 4, 7 and 8, whereas groups 5, 6, 9 and 10 cannot be fitted into this trend. A progressive and significant decrease in the impurity of the copper used can be seen in the development of the Sn-S-Pb-Ag-As-Sb group of EGP I, which reveals a steady reduction of almost all elements (*see Appendix 2*). The improvement in the purification of the copper is most obvious from group 1 to group 4.

Significant for all four groups of *quadrantes* is the fact that the silver:nickel ratio is much higher than for the *asses* (*quadrantes*: average 2.8 Ag:Ni, *asses*: average < 1 Ag:Ni), which suggests that all *quadrantes* might belong to one large single compositional group.

As for the *asses,* groups 5, 6, 9 and 10 have higher Ni:Sb ratios (groups 5 and 6: average 3.4 Ni:Sb; groups 9 and 10: average 9.4 Ni:Sb, all other Augustan copper *asses* <1). Presumably the group 5 and 6 *asses* are chemically related to the late Augustan *asses* rather than to the *asses* of groups 1 and 2. However, as far as the arrangement of the coinage is concerned, this need not suggest a close chronological relationship between groups 5 and 6 on one hand, and 9 and 10 on the other.

The separation of the Augustan coinage into three sets of groups[46] is most obvious in the nickel:antimony relationship which is displayed in *Figure 3*: (a) Augustan *asses,* groups 1 and 2, (b) Augustan *quadrantes,* groups 3, 4, 7 and 8, (c) Augustan *asses,* groups 5, 6, 9 and 10.

46 See also CARTER 1993; CARTER 1978 (a); CARTER 1978 (b); CARTER/BUTTREY 1977.

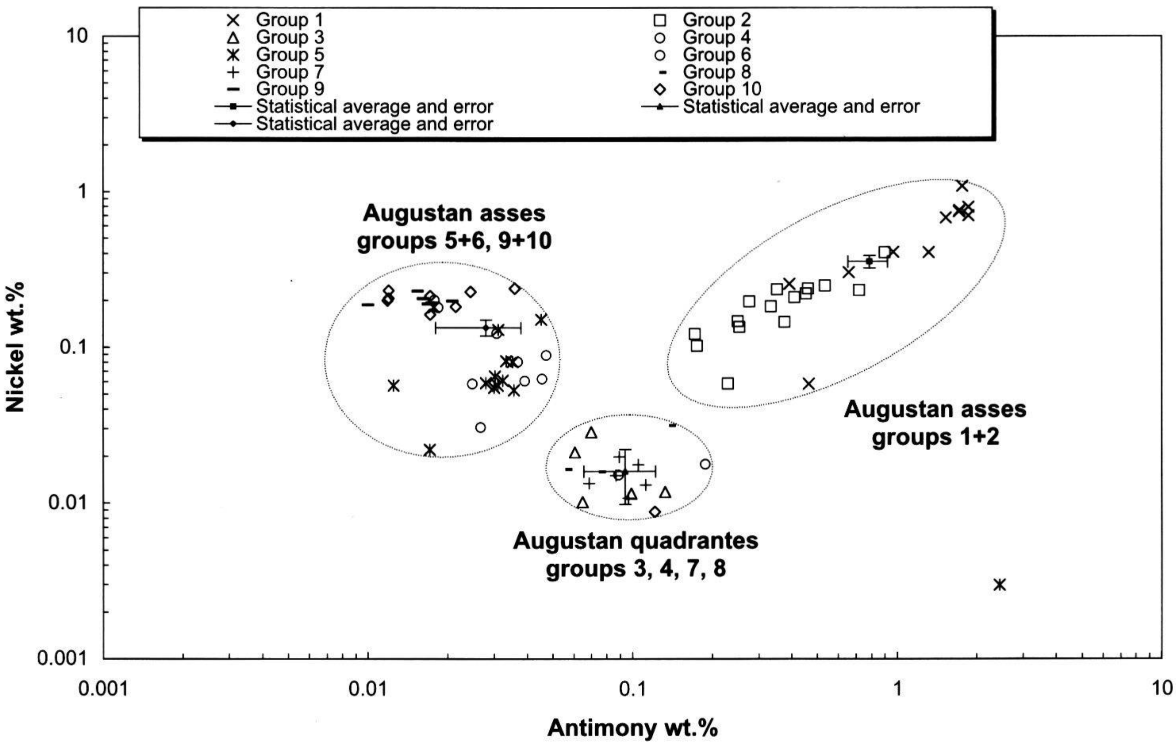

Figure 3: Division of Augustan *asses* and *quadrantes* into three compositional groups on the basis of antimony and nickel contents. Each data point represents the statistical average of six analysis repetitions for a sample. The error bars indicate the calculated range of error for each of the three compositional groups.

Figure 4 displays the trend of better copper purification for these groups based on the sequence presented in RIC I². Between groups 1, 2, 3, 4, 7, 8 and groups 5, 6, 9, and 10 a compositional caesura is observable, after which the copper gets less pure as far as nickel and arsenic are concerned.

4 Many scholars link the introduction of the moneyers' issues to the moneyer Piso, and date it to 23 B.C. In this context we must ask whether the relative sequence of groups 1 and 2 should not in fact be reversed, for if the chemical composition suggests a different sequence from that proposed by RIC I², this would confirm that Piso's college did indeed come first.

The separation of Augustan *asses* and *quadrantes* into three compositional groups indicates a close link between groups 1 and 2. Looking at the overall trend of purification, and the fact that group 1 contains much higher amounts of impurities than group 2, the sequence proposed by RIC I², that is group 1 – group 2, is very likely.

5 Does the copper used in Rome for the moneyers' issues have a different elemental pattern from the copper used in the mint at Lugdunum/Lyons for the *asses* of the first Altar Series (RIC I² 230), which were struck between 12 and 3 B.C.?

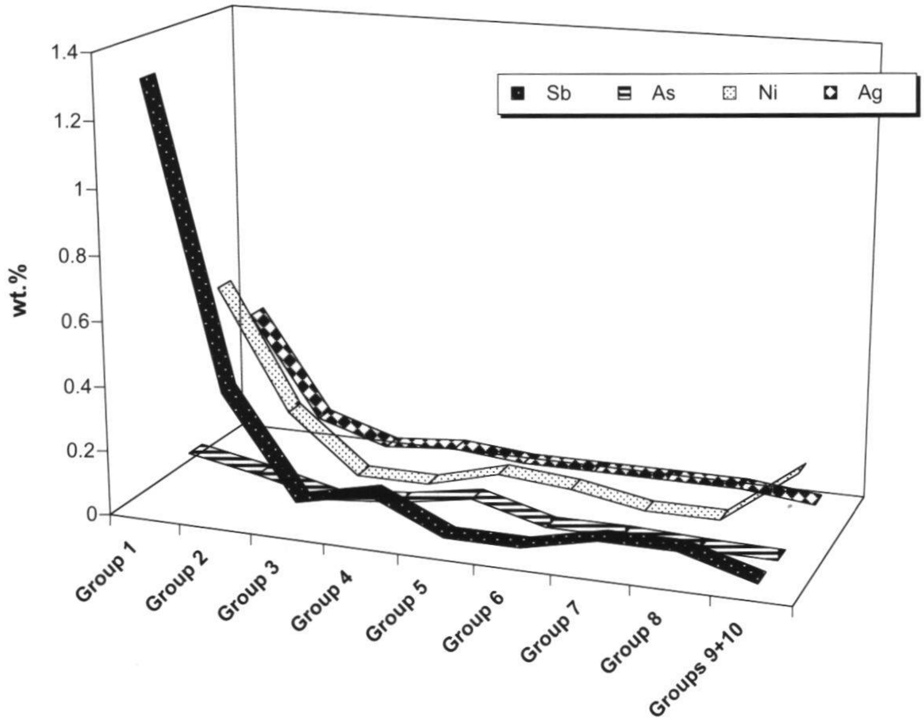

Figure 4: Sequence of Augustan coins from 16 B.C. to A.D. 12 based on RIC I². Each data point represents the statistical average of the respective group.

Chemically the copper issued at Lugdunum is different from Augustan copper coinage minted at Rome during the same period (groups 3-8). The major differences in the Lugdunum copper are the much higher concentration of tin, and also higher values for silver, arsenic and antimony.[47] It is also rich in sulphur, iron, cobalt and nickel, and the scatter of tin, silver, arsenic, antimony, iron and nickel is remarkably wide. The discussion of our analysis of the Lugdunum copper coins will be the subject of a forthcoming report.

6 How homogeneous is the copper of the two late-Augustan issues (groups 9 and 10), and how does it compare with that used in the earlier moneyers' issues?

The two late Augustan issues of *asses* differ in sulphur content, but all other elements are characterised by EGP II. Presumably the high sulphur content of RIC I² 471 (*Figure 5*) might have been a result of a «dirty» charge of copper from which the sulphur was not completely removed during smelting. Sulphur residues are indicators of sulphide copper ore charges.[48] The difference of groups 9 and 10 to

47 Values are comparable to Augustan *asses* from Rome of groups 1 and 2.

48 The drilling can distort the microstructural information of the copper metal, otherwise one would possibly be able to observe sulphidic inclusions under the metallographic microscope.

the previous issues (groups 1, 2, 3, 4, 7, 8) is made clear in the difference between EGP I and EGP II. Groups 9 and 10 belong to the same compositional group as groups 5 and 6 (*Figure 3*).

A comparison of the copper of the ten groups of coin types reveals significant continuous quantitative changes in composition from the early through to the late Augustan copper coinage. Whereas in EGP I, with the exception of the coins of the moneyers Piso, Otho and Messalla, cobalt is below the detection limit, coins characterised by EGP II contain detectable amounts of the element.

We can observe a rapid improvement in the purification of the Augustan copper, reflected in a decrease in silver, antimony and nickel levels,[49] which also have a narrower scatter in later issues. Furthermore, our data would support the correction of the relative sequence for the *quadrantes* that Carter/Frurip 1985 and Carter 1995/96 had proposed against that in RIC I²: groups 1-2-4-3-7-8-5-6-9-10. However, we would not go so far as to actually want to re-arrange the issues, for we

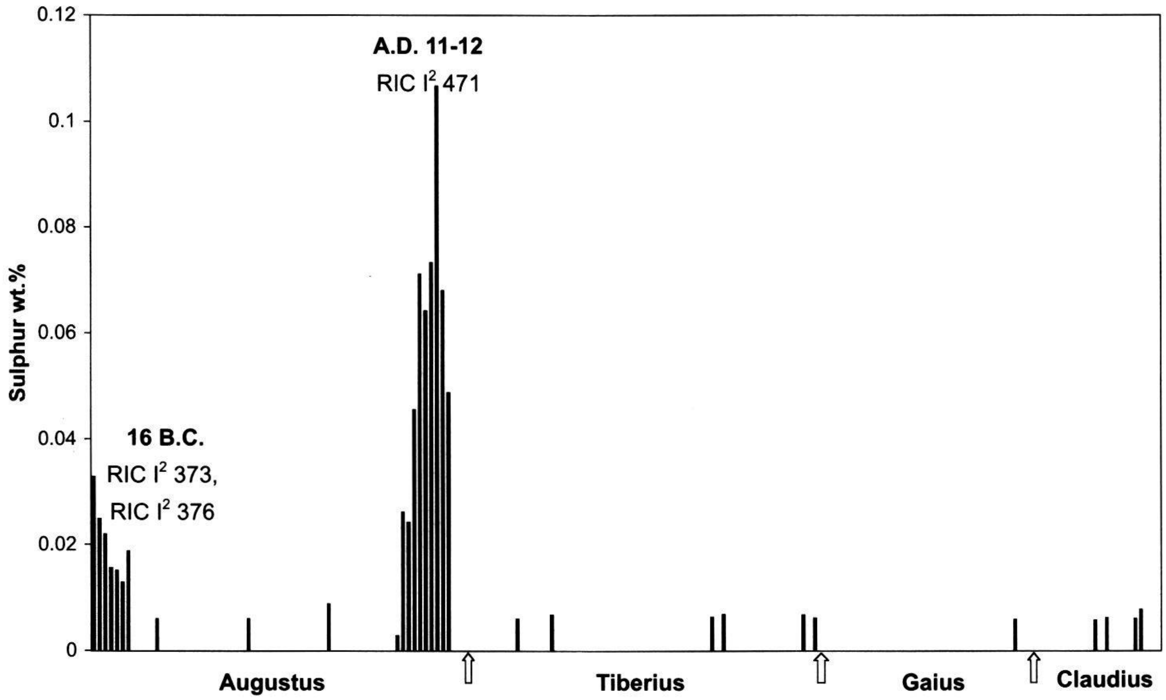

Figure 5: Sulphur contents of copper coins from Augustus to Claudius. Two very early issues (RIC I² 373, 376) and one very late issue (RIC I² 471) of Augustus are significantly sulphur rich. Each column represents the statistical average of six analysis repetitions.

49 As previously discussed by CARTER 1993.

feel that the generally low concentration of the elements in these groups is insufficient to have been of significance for the production process or the coins produced.

Carter 1993, Carter 1978 (a), Carter 1978 (b), and Carter/Buttrey 1977, provide important reference material for our analysis of Augustan *asses* and *quadrantes*.[50] Plotted into our elemental group patterns[51] they match our data as regards the overall picture of Augustan *asses* and *quadrantes*, as well as in the detailed compositional differences we found.

Our results suggest significant possibilities for a resumption of the numismatic discussion of the organisation and sequence of the Augustan moneyers' issues. However, we feel that it would be inappropriate to pursue the discussion further without considering the corresponding brass issues, or without lead-isotope analysis, work on which we have already started.

4.2 Tiberius (17[?] September 14 – 16 March 37)

4.2.1 Numismatic background[52]

During the reign of Tiberius only one copper denomination, the *as*, was struck at Rome. We do not find *quadrantes* again until the Emperors Caligula and Claudius. The copper issues of Tiberius consist of dated and undated types, and the sequence of the former provides important information about the structure of his entire copper coinage.

The *tribunicia potestas* dates in the coin legends of Tiberius indicate that copper was struck at the beginning of his reign in 15/16 (TR P XVII), then in 22/23 (TR P XXIIII)[53] and finally at the end of his reign in 34/35 (TR P XXXVI), 35/36 (TR P XXXVII) and 36/37 (TR P XXXVIII). In addition he produced four undated types, all of which have the head of the deified Augustus with radiate crown and the legend DIVVS AVGVSTVS PATER on the obverse. The reverse types of the latter are:

1 S C, woman sitting r. («seated Livia», RIC I² 72),
2 S C, Altar and PROVIDENT (RIC I² 81),
3 S C, eagle on globe (RIC I² 82) and
4 S C, winged thunderbolt (RIC I² 83).

[50] Deviations of single elements presented in the above publications from our EGPs are due to the different limitations of the analytical methods used.

[51] The same method was adopted for the data of Tiberius, Caligula and Claudius. We also included data from G.F. Carter/H. Razi, Chemical Composition of Copper-Based Coins of the Roman Republic, 217-31 B.C. Advances in Chemistry Series 220, 1989, pp. 213-227.

[52] We are indebted to B. Hedinger and H. Brem, Winterthur, who prepared the catalogue of the coins of Tiberius from the Tiber inventoried in the Museo Nazionale Romano, Rome, for information.

[53] The type RIC I² 41 (20/21) is dubious. No examples are among the finds from the Tiber.

Although the coin legends do not mention the minting authority, the portraits, style and occurrence in finds of these coin types clearly point to a Tiberian date for the DIVVS AVGVSTVS PATER *asses*. However, their exact dating has been the subject of continued discussion.

C.H.V. Sutherland laid the foundation for the classification of these issues, even if his arguments are still not generally accepted. His study, published in 1941,[54] was based on systematic observations of the style and fabric of the DIVVS AVGVSTVS PATER coins, and comparison with the dated Tiberian emissions, and his conclusions differed from those proposed in RIC,[55] BMC[56] and other studies.[57] He differentiated three groups of emissions, and related them to the dated copper issues. The *asses* with the «seated Livia» on the reverse (RIC I^2 72) he placed together with the issues of 15/16, the *Providentia asses* (RIC I^2 81) with those of 22/23, and both those with eagle on globe (RIC I^2 82) and winged thunderbolt (RIC I^2 83) on the reverse with the copper coinages of 34-37. On the basis of the large size of the issue, as is indicated by the frequency with which they occur in coin finds,[58] he suggested that the *Providentia* type was struck over a longer period (until 30?). Sutherland returned to discuss the date of the DIVVS AVGVSTVS PATER issues on several occasions,[59] most recently presenting the same arrangement without modification in the second edition of RIC I,[60] published in 1984.

However other suggestions have been made for the relative and absolute chronology of the DIVVS AVGVSTVS PATER issues. For example, in the German Fundmünzen corpora (FMRD) the arrangement of the first edition of RIC was, and still is used. The two issues which Sutherland identified as late-Tiberian, eagle on globe (RIC I^2 82) and winged thunderbolt (RIC I^2 83) are dated to early in his reign (14/15 and 16-22), while the *Providentia* type is simply placed «after 22» (i.e. 22-37). H. Chantraine[61] has discussed this chronology, and preferred it to Suther-

54 C.H.V. SUTHERLAND, Divus Augustus Pater. A Study in the *Aes* Coinage of Tiberius. NC 1941, pp. 97-116.

55 RIC I, pp. 93-96.

56 BMC I, pp. cxxxi–cxl.

57 Among others L. LAFFRANCHI, RIN 23, 1910, pp. 21-31; E.A. SYDENHAM, NC 1917, pp. 258-278.

58 For a review of the frequency of DIVVS AVGVSTVS PATER coins see C. RODEWALD, Money in the Age of Tiberius (Manchester 1976), p. 149. His figures are no longer up to date, but still give a good impression of the relative proportions involved. – There are some 1200 *aes* coins for Tiberius among the finds from the Tiber inventoried in the Museo Nazionale Romano, Rome. They include some 70 examples of the «seated Livia» type, 460 of the *Providentia* type and about 110 each of the eagle on globe and winged thunderbolt reverses.

59 Among others C.H.V. SUTHERLAND, Coinage in Roman Imperial Policy 31 B.C.–A.D. 68 (London 1951), pp. 86-88; *id.*, The Emperor and the Coinage. Julio-Claudian Studies (London 1976), pp. 102.110. In both works Sutherland dates the *Providentia asses* to 22-28.

60 RIC I^2, pp. 88. 98-99.

61 CHANTRAINE, op. cit. note 44, pp. 22-23.

land's. In his publication of the coins from the legionary fortress at Vindonissa C.M. Kraay[62] distinguished different groups of *Providentia asses* on the basis on style, flan and fabric.[63] One he attributed to Rome, the other to «a provincial mint». Furthermore, on the basis of overstrikes of the *Providentia* type on *asses* of Caligula, he was able to demonstrate that the type continued to be struck in local workshops into the reign of Caligula. J.-B. Giard[64] and H.-M. von Kaenel[65] noted further examples of such overstrikes, and interpreted them in the context of the regional and local imitations of copper coins which are typical of the western provinces during the reign of Claudius. This connection with the particular conditions of the Claudian period has since been confirmed by additional material, and any discussion of the chronology of the *Providentia* type must take this into account. Apart from the identification of the issues actually struck at Rome itself, it is the coin finds from Rome and Italy which are particularly relevant to the question under discussion, for few coins struck outside of Rome were in circulation in the area, in stark contrast to the finds from the western provinces.

An alternative date, exclusively in the final years of Tiberius' reign, has been proposed by a number of authors. M.P. Charlesworth[66] and others[67] have drawn attention to the particular relevance of the Imperial *Providentia* in connection with the overthrow of the Praetorian Prefect Sejanus in the autumn of 31, and have linked the dedication of the *Ara Providentiae Augustae* with this event. Such an altar is recorded in the Acts of the Arval Brethren for 38,[68] and although the date of its dedication is recorded[69] the year is not. In spite of this J.-P. Martin,[70] and follow-

62 Kraay, op. cit. note 44, p. 34.

63 So already in M. Grant, The Pattern of Official Coinage in the Early Empire, in: R.A.G. Carson/C.H.V. Sutherland (eds.), Essays in Roman Coinage presented to Harold Mattingly (Oxford 1956), p. 108.

64 J.-B. Giard, Pouvoir central et libertés locales. Le monnayage en bronze de Claude avant 50 après J.-C. RN 1970, pp. 48-51; *id.*, La pénurie de petite monnaie en Gaule au début du Haut-Empire. Journal des Savants, Avril-Juin 1975, pp. 82-102.

65 H.-M. von Kaenel, Die Fundmünzen aus Avenches, I. Von den Anfängen bis Titus. SNR 51, 1972, pp. 113-117.

66 M.P. Charlesworth, *Providentia* and *Aeternitas.* Harvard Theological Review 29, 1936, pp. 110 -113.

67 E.g. M. Grant, Roman Anniversary Issues. An Exploratory Study of the Numismatic and Medallic Commemoration of Anniversary Years 49 B.C.–A.D. 375 (Cambrigde 1950), pp. 62-64. For a different date (22-30) M. Grant, Roman Imperial Money (London/Edinburgh 1954), p. 316, pl. VIII, 3.

68 On the new fragments of the Acts of the Arval Brethren cf. J. Scheid, *Commentarii Fratrum Arvalium qui supersunt.* Les copies épigraphiques des protocoles annuels de la confrérie Arvale (21 av.–304 ap. J.-C.). Recherches archéologiques à la Magliana. Roma Antica 4 (Rome 1998), pp. 28-35, no. 12.

69 26 June; this can only refer to the anniversary of the adoption of Tiberius by Augustus on 26 June A.D. 4.

70 J.-P. Martin, *Providentia deorum.* Recherches sur certains aspects religieux du pouvoir impérial romain. Collection de l'École Française de Rome 61 (Rome 1982), pp. 103-133. 432.

ing him J.-B. Giard[71] have proposed that the *Providentia asses* were struck between late 31/early 32 and the end of Tiberius' reign. J.-B. Giard also adopted C.H.V. Sutherland's late dating of both eagle on globe (RIC I^2 82) and winged thunderbolt (RIC I^2 83) types, with the result that his chronology sees a massive copper coinage in the closing years of Tiberius, including not just the DIVVS AVGVSTVS PATER *asses*, but also the dated issues of 34-37. However, not just this imbalance, but also more importantly his uncritical approach to the epigraphic and numismatic sources[72] make his arrangement unlikely.

W. Szaivert produced a very different arrangement for the *Providentia asses* in his reconstruction of the coinage of Tiberius.[73] However, his suggestion that the type was struck in the years 16/17 – 22 is methodically dubious. Independently of this, and with reference to a newly found fragment of the Acts of the Arval Brethren, W. Trillmich[74] interprets *Providentia* as Augustus' prudence in arranging for Tiberius to succeed him and proposes an early Tiberian date (from 14) for the *Providentia asses*. M. Bergmann has recently analysed the DIVVS AVGVSTVS PATER issues in a broader historical and contextual study.[75]

An exciting new find, the *Senatus consultum de Cn. Pisone Patre*,[76] now confirms that the *Ara Providentiae* was already in existence by 19, and must in fact be a few years older. It is possible, but not proven, that the altar was even dedicated late in Augustus' reign. This leads W. Eck to suggest that the *Providentia asses* were struck early in Tiberius' reign. We will revert to this issue later in our discussion of the analytical results.

Summing up the state of the discussion of the chronology of the undated DIVVS AVGVSTVS PATER issues, it is notable that no broadly-based *numismatic* study of the material has been made. C.H.V. Sutherland's collection of data, published in 1941 and heavily restricted by the outbreak of the Second World War, still forms the basis to this day. But opportunities were also missed to bring other arguments into the discussion. Not only has no attempt been made to systematically analyse the occurrence of DIVVS AVGVSTVS PATER coins in military and civilian settlements, there has also been no study undertaken of reliable sealed archaeological deposits containing such *asses* which might throw light on their chronology.

71 J.-B. GIARD, CBN II. De Tibère à Néron (Paris 1988), pp. 24. 54-55.
72 The same applies to R.T. SCOTT, PROVIDENT AVG. Historia 31, 1982, pp. 436-459.
73 W. SZAIVERT, Die Münzprägung der Kaiser Tiberius und Caius (Caligula) 14/41. Moneta Imperii Romani 2/3 (Vienna 1984), pp. 37-38.
74 W. TRILLMICH, Münzpropaganda, in: M. HOFTER *et al.* (eds.), Kaiser Augustus und die verlorene Republik. Exhibition catalogue Berlin 1988 (Mainz 1988), pp. 527-528 no. 376.
75 M. BERGMANN, Die Strahlen der Herrscher. Theomorphes Herrscherbild und politische Symbolik im Hellenismus und in der römischen Kaiserzeit (Mainz 1998), pp. 102-108.
76 W. ECK/A. CABALLOS/F. FERNÁNDEZ, Das *senatus consultum de Cn. Pisone Patre*. Vestigia 48 (Munich 1996), pp. 44. 199-201.

4.2.2 Coin analysis

A total of 72 Tiberian copper coins were analysed, 37 dated and 35 undated (*see Appendices 3-4*).

The chemical composition allows the division of Tiberian *asses* into three sets of groups: group 1 is characterised by EGP II and has no detectable cobalt present;[77] group 2 contains exceptional high nickel values,[78] as well as cobalt in low but detectable amounts. Such high levels of nickel, which are an important characteristic of this group, are found earlier only in Augustan *asses* from group 2, and groups 9 and 10. Tiberian groups 3-5 are characterised by increased levels of elements such as antimony and silver.[79] They further contain cobalt in low but detectable amounts. In contrast to Carter/King 1980 we found no positive correlation between antimony and tin.[80] Group 3-5 *asses* of Tiberius are characterised by a third elemental group pattern:

Elemental group pattern III (EGP III)
EGP III (*Figure 6*) is to some extent a mixture of EGP I and EGP II: the Sn-S-Pb-Ag-As-Sb ratios and levels are reminiscent of EGP I, cobalt is always present at levels above the detection limit (up to 0.014 wt.%). The silver:nickel ratio is quite different from EGP I, and has increased (2-7 Ag:Ni; EGP I *asses* 1.6 - < 1 Ag:Ni), while iron scatters in a much broader range than in EGP II.

4.2.3 Numismatic questions

1 Does the copper of the various *dated* coinages (groups 1 – 5) reveal individual elemental patterns? If so, do they remain the same, or do they vary and how?

For dated Tiberian copper issues, the coins of the five groups are in themselves quite homogeneous in chemical composition. Three main compositional groups can be distinguished (*Figure 7*): (a) group 1 (early Tiberian), (b) group 2 (mid-Tiberian), and (c) groups 3-5 (late Tiberian). Group 1 is characterised by EGP II, as is group 2, with the exception of remarkably high nickel levels. Groups 3-5 are characterised by EGP III.

[77] As observed previously by CARTER 1971.
[78] Also described for Tiberian *asses* of 22/23 by CARTER/BUTTREY 1977 and CARTER 1971.
[79] CARTER 1971 described this increase in levels of elements for iron and nickel also, a result that we can not confirm with our data.
[80] The correlation between antimony and tin is reported to be an effect of segregation by J.P. NORTHOVER/V. RYCHNER, Bronze analysis: Experience of a Comparative Programme, in: C. MORDANT/M. PERNOT/V. RYCHNER (eds.), L'Atelier du bronzier en Europe du XX^{e} siècle avant notre ère. I. Les analyses de composition du métal: Leur apport à l'archéologie de l'âge du bronze (Paris 1998), pp. 19-40.

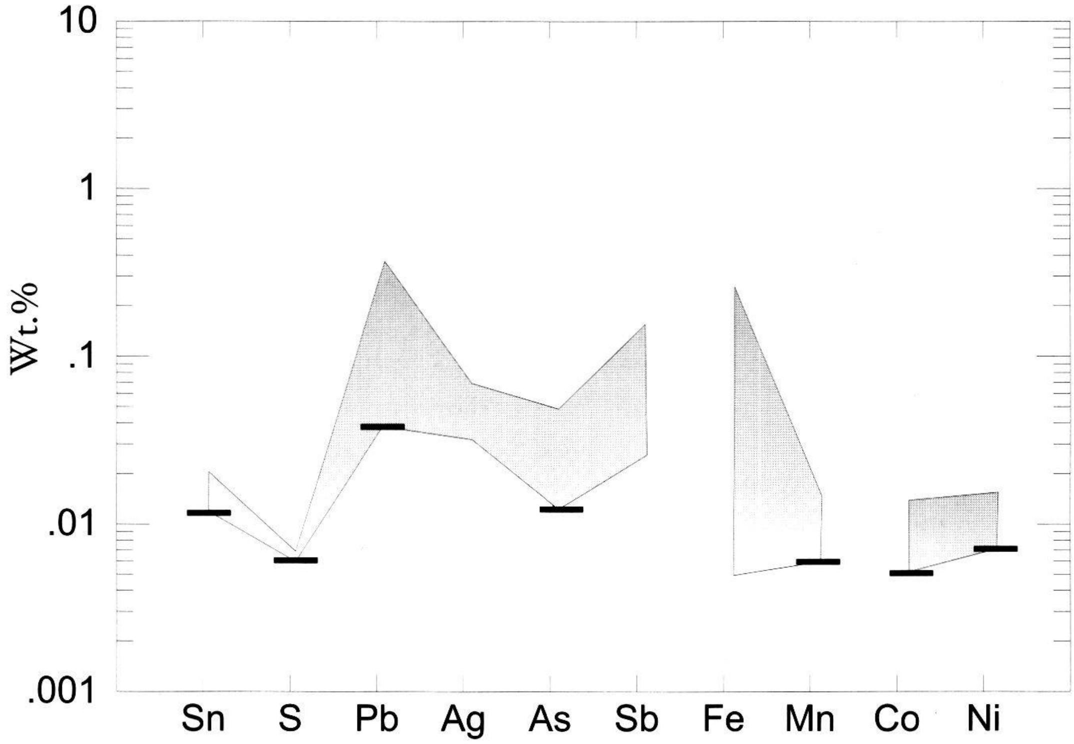

Figure 6: Elemental group pattern III (EGP III). The diagram displays the most characteristic elements, based on the Tiberian groups 3-5. Bars indicate values below the detection limits of the elements.

2 How does the elemental pattern of the first Tiberian copper issues of 15/16 (group 1) compare with that of the last coinages of Augustus?

Group 1 differs chemically from the late Augustan coinage in its nickel values: they are much lower for the Tiberian (average: 0.01 wt.% Ni) than for the late Augustan (groups 9 and 10) copper coins (average: 0.16 wt.% Ni).

3 Does the copper of the four *undated* DIVVS AVGVSTVS PATER types (groups 6 – 8) reveal individual elemental patterns? If so, are they consistent, or do they vary?

The four analysed undated DIVVS AVGVSTVS PATER types differ clearly in chemical composition, and can be separated into three main compositional groups: (a) group 6, (b) group 7, and (c) groups 8 and 9 (for details *see Appendix 4*).

4 Can the copper of the undated DIVVS AVGVSTVS PATER types be connected with the copper of the dated issues on the basis of their elemental patterns? Is it possible to draw conclusions on the relative and absolute chronology of the undated DIVVS AVGVSTVS PATER types?

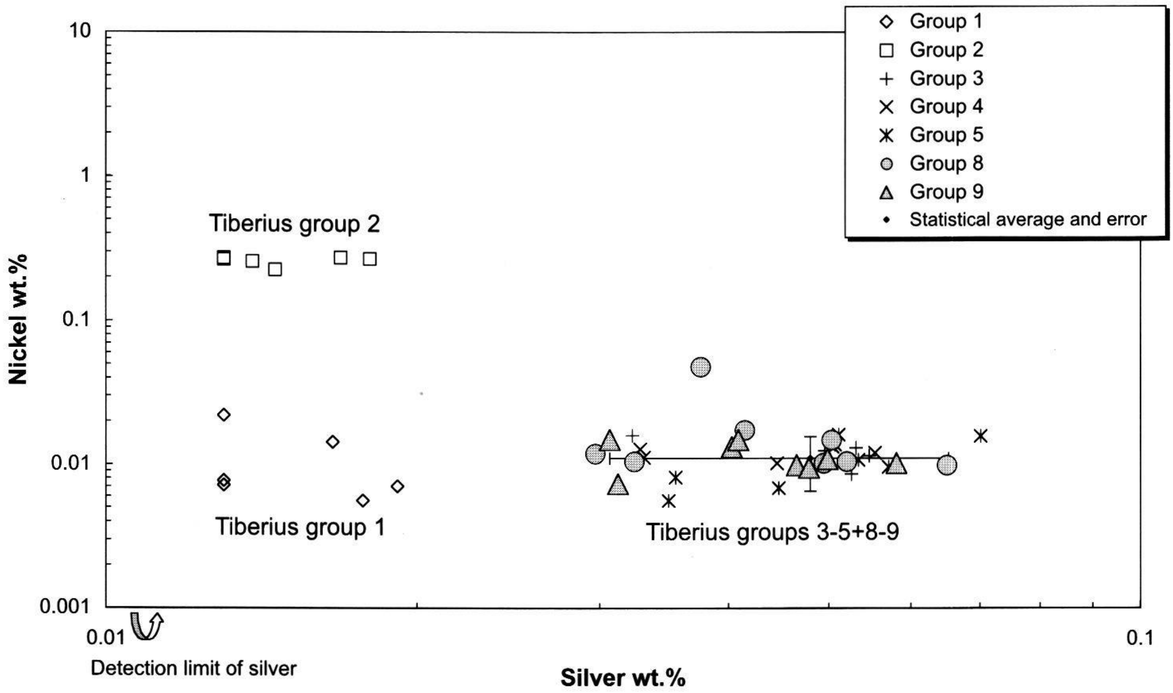

Figure 7: Relation of undated Tiberian coins of groups 8 and 9 to dated Tiberian coin groups. For groups 1 (15/16) and 2 (22/23) only those data points are displayed which fall above the detection limit of silver (>0.013 wt.% Ag). Each data point represents the statistical average of six analysis repetitions, and the error bars for groups 3-5 are shown. Even taking into account the fact that the standard deviation of silver is high, groups 8 and 9 best match groups 3-5, rather than group 1 or group 2.

Among the DIVVS AVGVSTVS PATER types we could identify three main compositional groups. As for the relationship between the undated and the dated Tiberian copper coinage, group 6 («seated Livia») is comparable to dated Tiberian *asses* of 15/16, and group 7 (*Providentia asses*) to *asses* of 22/23 (*Figure 8*). The few analyses of the two types by Carter/Buttrey 1977 (RIC I^2 72 and 81) linked them both to Tiberian coins of 22/23. This we could show to be true of the *Providentia* type (RIC I^2 81) as is indicated by their high nickel values, but not for the «seated Livia» type (RIC I^2 72), which corresponds to Tiberian coins of 15/16 rather than 22/23.

Although the *Providentia asses* are chemically closely linked to the dated issues of 22/23, we should be careful with the assumption that this was their exact date of issue. Some could be later as our next chronological point of reference are the dated issues of 34/37.

Groups 8 and 9 are most likely related to issues of 34-37 (*Figure 7*), as like the late Tiberian groups 3-5 they are characterised by EGP III.

4.3 Caligula (18 March 37 – 24 January 41)

4.3.1 Numismatic background

The chronology of the copper coinage of the short reign of Caligula provides little controversy. There were a large number of dated coin types, which enable us to reconstruct with certainty a total of five emissions of *asses* and/or *quadrantes*. C.H.V. Sutherland's arrangement[81] was recently updated by the present author in an article in this journal,[82] where further details can be found.

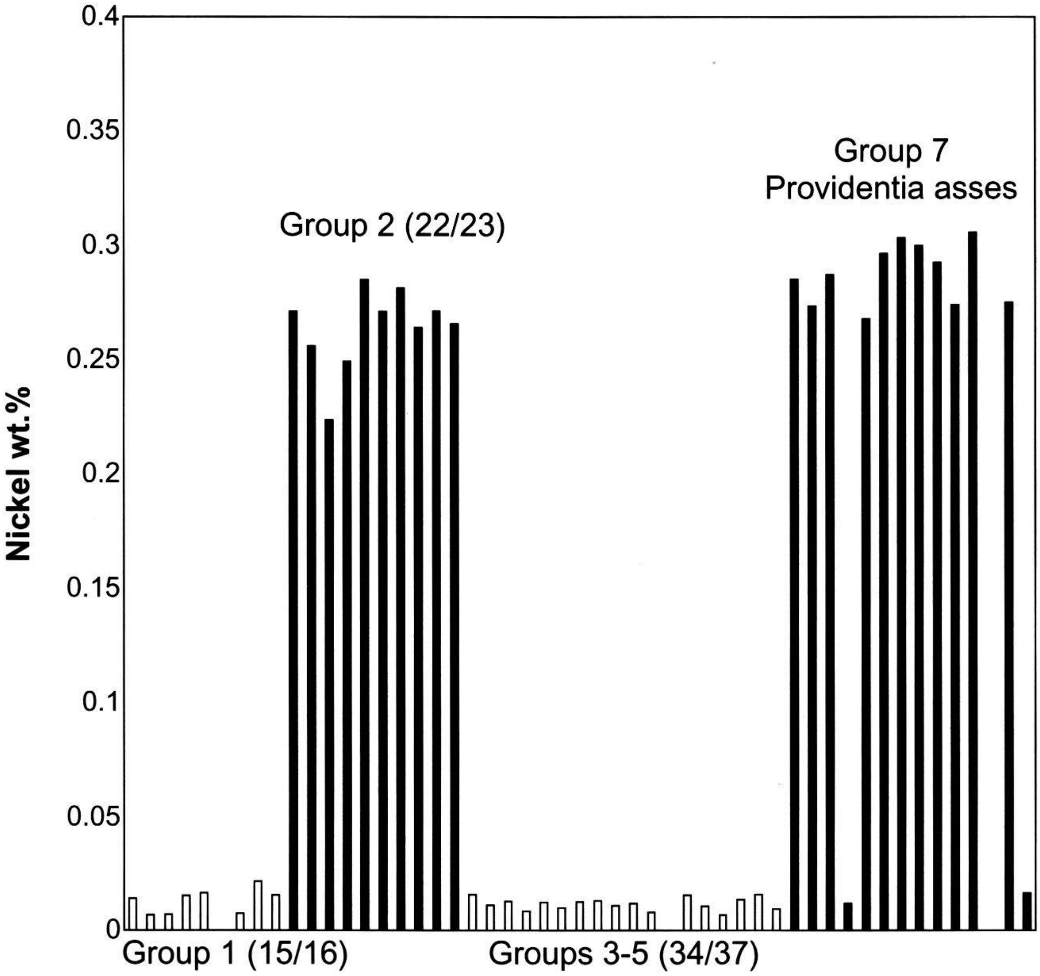

Figure 8: Relationship of *Providentia asses* and Tiberian *asses* of A.D. 22-23. The group 2 *asses* and the *Providentia asses* have similarly high nickel levels (up to 0.3 wt.%). Earlier and later (dated) Tiberian issues contain much less nickel (<0.05 wt.%). Each column represents the statistical average for nickel of six analysis repetitions.

81 RIC I², pp. 102-112.

82 H.-M. von Kaenel, Die Organisation der Münzprägung Caligulas. SNR 66, 1987, pp. 135-156.

Important for an understanding of the copper coinage of Caligula is the fact that the striking of imitations of *asses* in local or regional «mints» did not first start during the reign of Claudius, but already under Caligula. The proportion of imitations of Caligula among the finds from Vindonissa[83] and other sites in the Rhineland and Gaul is by no means insignificant. On the other hand, at Rome few copper coins are found which can be identified as irregular on the basis of style, weight or fabric.[84]

The attribution of the large numbers of so-called Agrippa *asses*[85] to Caligula was long disputed, but is now generally accepted and has been confirmed more recently by metal analyses.[86] These coins do not name a minting authority in their legend, but only the name and title of Agrippa, the grandfather of Caligula, who died in 12 B.C. Nevertheless, it is still uncertain whether the Agrippa *asses* were struck in just one single large issue, or, as is more probable, in the course of the three dated issues of *asses*.

We must also differentiate between those Agrippa *asses* struck at the mint of Rome, which are of interest to us here, and the products of local «mints» in the western provinces. Several groups can be differentiated on the grounds of style, weight and fabric.[87] As with the DIVVS AVGVSTVS PATER issues, no detailed study of the Agrippa *asses* has been carried out.

4.3.2. Coin analysis

A total of 42 copper coins struck during the reign of Caligula were analysed: 29 coins struck in the name of the Emperor himself, and 13 Agrippa *asses* (*see Appendices 5-6*).

Elemental group pattern IV (EGP IV)

The copper of Caligulan coins is exceptionally pure, reflected in a new elemental pattern (EGP IV, *Figure 9*) which is characterised by concentrations below detection limits of tin, sulphur, lead, silver, arsenic and cobalt. This is the major difference to EGP I and II. Iron and manganese are detectable but scatter randomly, just as in earlier patterns. As a result antimony and nickel are the only elements of real relevance for EGP IV. Antimony values are very constant (narrow range of scatter), and are comparable to those of late Augustan (groups 9 and 10) or early Tiberian copper. Nickel does not scatter much either, and its values are comparable to Augustan groups 4 and 5, and Tiberian copper coins (except group 2).

83 Kraay, op. cit. note 44, p. 36.
84 Koenig, op. cit. note 5, pp. 30-32.
85 RIC I 32 (Tiberius); BMC I, p. cxl (Tiberius); J. Nicols, The Chronology and Significance of the M. Agrippa Asses. ANSMN 19, 1974, pp. 65-86; Chantraine, op. cit. note 44, pp. 18-20; RIC I², pp. 89. 105. 112 no. 58 (Caligula).
86 Carter/Metcalf 1988.
87 Cf. for example Kraay, op. cit. note 44, pp. 34-35, and Giard, La pénurie, op. cit. note 64, pl. III, as well as the material from the Tiber, Koenig, op.cit. note 5, pp. 35-41 and pp. 115-173. nos. 250-543.

4.3.2 Numismatic questions

1 Does the copper of the various *dated* coinages reveal consistent individual elemental patterns? If so, do they remain the same during this brief reign, or do they vary and does the copper used for the *asses* have the same elemental pattern as the *quadrantes*?

The dated groups of coins of Caligula are – with few exceptions (group 1) – very homogeneous in composition. The variable iron content of the various groups might be just a natural scattering. As for chronological developments, no chemical trend can be observed. The copper used for minting the Caligulan *asses* and *quadrantes* was chemically identical.

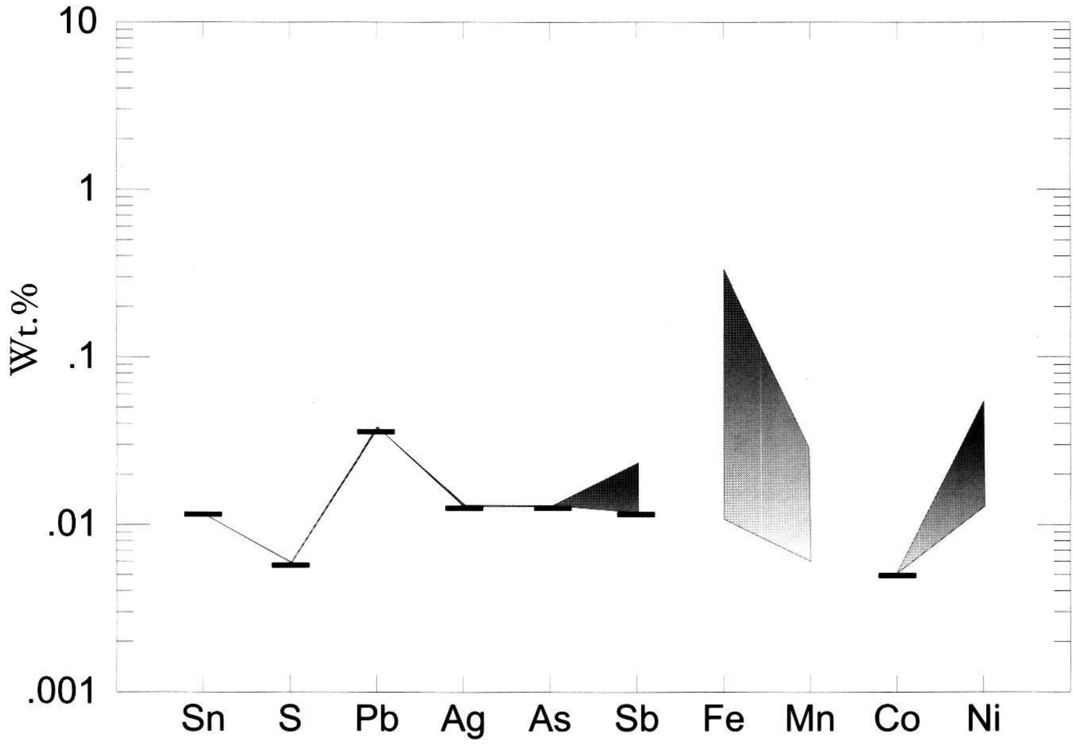

Figure 9: Elemental group pattern IV (EGP IV). The diagram displays the most characteristic elements, based on the representative Caligulan groups 3-5. Bars indicate values below the detection limits of the elements.

2 How does the elemental pattern of the first copper issues (group 1) compare with that of the last coinages of Tiberius (group 5)?

The comparison of the very first Caligulan issues with late Tiberian *asses* reveals major differences in composition, which allow them to be distinguished from each other: Tiberian group 5 coins contain higher values for lead, silver, arsenic, antimony and cobalt than Caligulan group 1 coins.

3 Of the undated Agrippa *asses* (group 6): Is the elemental pattern for this coin type consistent and homogeneous, or can groups be identified? Does it confirm their attribution to the reign of Caligula?

Apart from TM 375 all the undated *asses* of Agrippa analysed belong to one compositional group, and no additional distinction can be made that would differentiate them further. The chemical composition of the *asses* of Agrippa analysed corresponds with Caligulan rather than with late Tiberian issues (*Figure 10*).

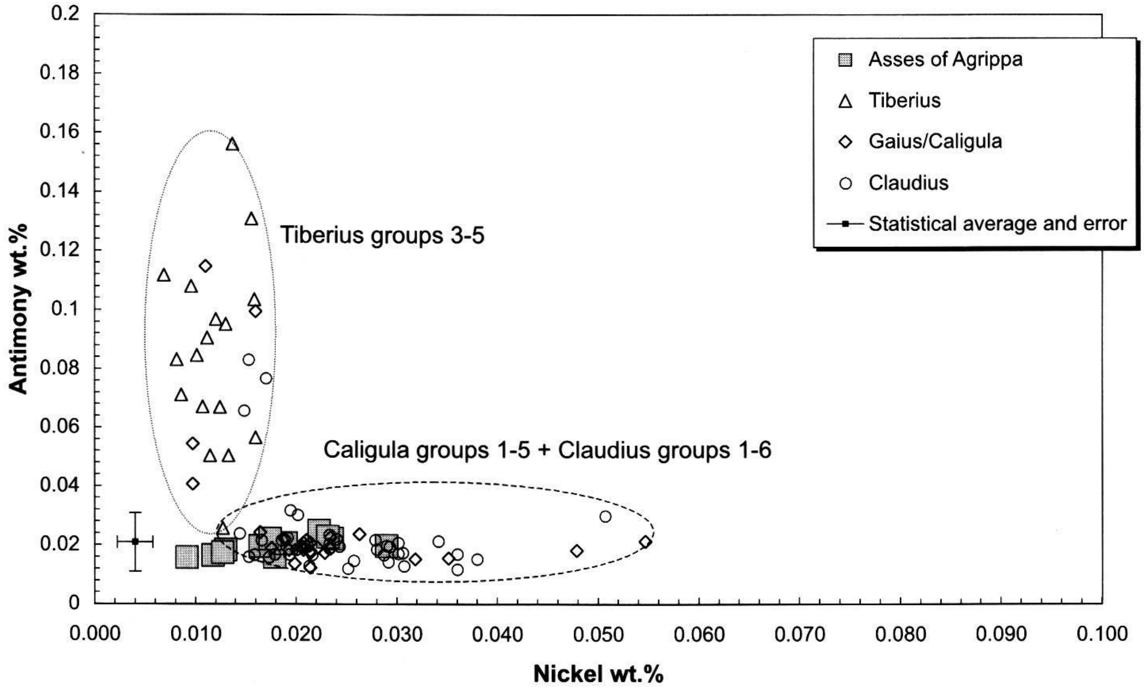

Figure 10: Relation of Agrippa *asses* to dated *asses*. The Agrippa *asses* fall within the range of Caligulan *asses* of groups 1-5 rather than the late Tiberian *asses* (groups 3-5). Each data point represents the statistical average of six analysis repetitions, and the analytical error is represented by error bars that were calculated for the *asses* of Agrippa. The latter can in some cases be higher due to the heterogeneous distribution of the element.

4 Is the elemental pattern of the coin regarded as an imitation (TM 375) different to that of the other issues?

The imitation of an Agrippa *as* is comparable in silver, arsenic and antimony with Tiberian issues of groups 3-5, but the low level of iron was not observed in any of the latter. This coin might have been produced from recycled copper coins, maybe of late Tiberian origin.

The coins analysed confirmed the high purity of Caligulan coins and the differences in chemical composition to late Tiberian issues that had previously been indicated in the analyses published by Carter/King 1980. All groups are characterised by EGP IV, which make them difficult to distinguish. The results obtained by Carter/King best match our Caligulan group 1 copper coins in detail (zinc, silver and lead contents). However, in contrast to them we could not find any chemical differences between *quadrantes* and *asses*.

As for the Agrippa *asses*, Carter/King 1980 and Carter/Metcalf 1988 assigned nine of them on the basis of their chemical composition to the Rome mint under Caligula. The broader statistical basis of analyses of coins from Rome presented here confirms the presumption that the Agrippa *asses* cannot have been struck under Tiberius, but under Caligula/Claudius.[88]

Three published imitations of Agrippa *asses*[89] differ in zinc, tin, lead, silver and antimony content from the imitation (TM 375) we analysed, which is best matched by late Tiberian *asses* of groups 3-5. This parallels the results of Carter/King 1980, who suggested that the three imitations they analysed had been re-struck from official (late) Tiberian coins.

4.4 Claudius (25 January 41 – 13 October 54)

4.4.1 Numismatic background

The soundest basis for the arrangement of the coinage of Claudius is the review of the typology of the *aes* issues of the Rome mint presented in the second edition of the first volume of RIC[90] by C.H.V. Sutherland. Revisions and additions by the present author are to be found in his study of the coinage of this Emperor,[91] which should be consulted for further details and discussion.

The *aes* coinage of Claudius can be divided into two main groups on the basis of the coin legends. The normal formula for the Imperial titulature on both the brass denominations and on the copper *as* has only one variation, the use of the honorary title *Pater Patriae*. This was adopted by Claudius towards the end of the first year of his reign, on 12 January 42.[92] Coins with the Imperial titulature without this title must therefore belong to the period between 25 January 41 and 12 January 42, while those with *Pater Patriae* can be dated to after 12 January 42.

The Claudian *as* coinage was regularly organised, and consisted of few types. The three types with the reverses *Minerva* (RIC I^2 100. 116), *Constantia* (RIC I^2 95. 111) and *Libertas* (RIC I^2 97. 113) were struck twice, once without and once with

88 As we will discuss in the following chapter, we are unable to distinguish chemically between Caligulan and Claudian copper.

89 Carter/King 1980, pp. 164-165.

90 RIC I^2, pp. 126-130.

91 H.-M. von Kaenel, Münzprägung und Münzbildnis des Claudius. AMuGS 9 (Berlin 1986), pp. 22-32.

92 J. Scheid, Nouvelles données sur les avènements de Claude, de Septime Sévère et de Gordien III. Bulletin de la Société Nationale des Antiquaires de France 1988, pp. 361-364; *id.*, op. cit. note 68, pp. 45-46 no. 17.

the title *Pater Patriae* in the Emperor's name, while *asses* in the name of Germanicus, the brother of Claudius, were struck only once (RIC I^2 106), with *Pater Patriae.*

The Imperial titulature used indicates that *quadrantes* were issued on two occasions during Claudius' reign, with two types being used each time (obv. *modius* and PNR-hand with scales). The first emission (RIC I^2 84. 85) dates to the period from his accession to late 41, the second to the year 42. The latter must have been struck from the very beginning of the year 42, for their legend mentions Claudius' second consulate which he assumed on 1 January (RIC I^2 88. 89), but did not yet include the title *Pater Patriae* which was granted him a few days later, and which was immediately included in the coin legend (RIC I^2 90. 91). As was usual the Emperor held the office of consul for only a short time, and was then proclaimed consul designate for his third consulate on 1 January 43. There are no *aes* coins with legends that mention this or any other consulate, thus the well-dated *quadrantes* confirm that copper was struck twice at the Rome mint, in the first and second years of his reign.

A frequent bone of contention is the question of whether the coinage of *aes* was really suspended in the second year of Claudius' reign, or whether it was continued in the following years with unchanged Imperial titulature. Doubts have often been expressed as to whether it is really possible that no *aes* was struck at the capital until not just the end of Claudius' reign, but even longer until 62.[93] The matter is further complicated by the fact that *aes* coins without and with the title *Pater Patriae* are present in quite unequal numbers in coin finds. Copper and brass coins with *Pater Patriae* are much less common than those without.

As had others before him, C.H.V. Sutherland in RIC I^2 accordingly extended the period of emission of copper coins without the title *Pater Patriae* to around 50 (?), and placed the issues with the title in the years 50–54. In his study the present author[94] went into the matter in detail, and a critical examination of the various arguments led to a different conclusion, that all copper issues from the Rome mint were indeed struck in the first two years of Claudius' reign, and that thereafter no more *aes* was struck for him there. If the large numbers of imitations are excluded and only the coins relevant to the question – that is those which were definitely struck in Rome – are taken into account, then the proportion of coins without and with the title *Pater Patriae* is very different: they are more or less equally common. Only the regular coins struck at Rome are important for a discussion of the organisation and chronology of the official *aes* coinage of Claudius. The numerous copies in brass («many» in Rome and Italy, «few» in the western provinces) and copper («few» in Rome and Italy, «very many» in the western provinces) are, both chronologically and functionally, a different matter, albeit of great importance for the history of the coinage.

93 RIC I^2, p. 158 (Nero).
94 Cf. von Kaenel, op.cit. note 91, pp. 220-233.

Any consideration of the brass and copper coinages of Caligula and Claudius must take into account the testimony of Cassius Dio,[95], who states that the Senate decided in 43 to melt down the *aes* coins with the portrait of the much-hated emperor Caligula. The empress Messalina is reputed to have used the metal for statues of the actor Mnester. The matter has, however, been the subject of frequent discussion,[96] and so it seems sensible to see whether the analyses conducted here throw any light on the problem.

4.4.2 Coin analysis

A total of 47 copper coins of Claudius were analysed: 11 *quadrantes*, 16 *asses* without *Pater Patriae* in their legend, and 20 *asses* with (*see Appendices 7-8*).

The Claudian copper is as chemically pure as the Caligulan. No major differentiation can be made, and the Claudian copper is still characterised by EGP IV.

4.4.3 Numismatic questions

1 The *quadrantes* (groups 1 - 3): Are the elemental patterns for the copper used in the two emissions consistent in each case?

The Claudian *quadrantes* are composed of homogeneous copper chemically characterised by EGP IV. No trends can be identified, nor further differentiations made.

2 The *asses* without *Pater Patriae* (group 4): Are the elemental patterns for the copper used for the three types *Minerva, Constantia* and *Libertas* consistent in each case? Is the elemental pattern the same as for the *quadrantes*?

The *asses* without the title *Pater Patriae* are homogeneous and characterised by EGP IV. They are comparable to the Claudian *quadrantes*. The three coin types *Minerva, Constantia,* and *Libertas* without the title *Pater Patriae* can not be further distinguished on the basis of their chemical composition.

3 What is the relationship between the elemental pattern of the copper issues of 41/42 (groups 1 – 4) and that of the last copper emission of Caligula (January 41, group 5)?

Claudian *asses* and *quadrantes* dating to A.D. 41/42 do not differ chemically from the latest emission of Caligula.

95 Cassius Dio 60,22,3.

96 Most recently in detail R. WOLTERS, *Nummi Signati.* Untersuchungen zur römischen Münzprägung und Geldwirtschaft. Vestigia 49 (Munich 1999), pp. 144-169.

4 The *asses* with *Pater Patriae* (group 5): Are the elemental patterns for the copper used for the three types *Minerva, Constantia* and *Libertas* consistent in each case?

The *asses* with the title *Pater Patriae* are a chemically heterogeneous group. Most of the coins follow EGP IV, but a few differ in single elements (zinc, lead). No further differentiation can be made.

5 The *asses* for Germanicus (group 6): Is the elemental pattern different to or the same as that for the other *asses* with *Pater Patriae*?

The Germanicus *asses* are comparable in composition to the zinc-free *asses* with the title *Pater Patriae.*

6 Is the elemental pattern for the coins without *Pater Patriae* different to that for those with?

The copper coins without and with the title *Pater Patriae* are chemically comparable, apart from the few coins that contain zinc.

7 Is the elemental pattern of the *asses* which are classified as imitations (TM 442; 443; 444; 447; 448; 452) different to that of the copper coinage of Claudius?

The six imitations are clearly of two different compositional patterns, in both cases copper with impurities. TM 442, 447, 448, and 452 have higher levels of silver, arsenic and antimony, and less nickel than Claudian *asses*, and therefore suggest that recycled late Tiberian *asses* (34/37) were re-used, whereas TM 443 and 444 are presumably of copper which had been contaminated with brass (*see Appendix 8*).

8 Does the elemental pattern provide any useful clues for the discussion of the supposed melting down of coins of Caligula under Claudius?

Since the elemental patterns of Caligulan and Claudian copper coins are not distinguishable, chemical composition cannot contribute to the discussion of whether Caligulan copper coins were melted down and re-struck under Claudius.

Our analyses confirm the findings of Carter/King 1980, that Caligulan and Claudian copper does not differ in chemical composition. Extensive analyses of some 100 *quadrantes* from 41/42 corresponding to our groups 1-3 were presented by Carter 1984. He split them into two compositional groups,[97] but no such differentiation can be made on the basis of our data.

Due to the high purity of the copper used for group 41#B Carter 1984 suggested that native copper was used. However, we would hesitate to distinguish native copper from copper smelted from oxide or sulphide ore on the basis of chemical

[97] Carter's group 41#A comprises *quadrantes* from 41, which he found to be relatively low in iron and nickel, and high in silver, antimony and sometimes also lead. His group 41#B comprises coins from 41/42, all of which are reported to have moderate amounts of iron and nickel, the highest copper concentrations known for Roman coins, and the lowest silver, tin, antimony and lead concentrations known for Roman copper-based coins.

composition. Neither the level nor the pattern of impurities in metallic copper are reliable indicators of native copper.[98]

6 Conclusions

The copper of the Rome mint reveals a significant decrease in the levels of silver, arsenic, antimony and nickel (*Figure 4*), a trend which is most noticeable for the Augustan copper from groups 1 and 2 to groups 3 and 4. Subsequent Augustan, and all dated Tiberian groups continue this trend, but now variations in certain elements such as sulphur, silver, nickel or cobalt occur, which sometimes run contrary to the general trend. The level of nickel is significantly higher where the values for antimony, silver, and arsenic are low; if antimony, silver, and arsenic are high, nickel is low (*Figure 11*). Finally, under Caligula and Claudius the copper was chemically very much purer than at any other time during the period under study, and usually contained less than 1 wt.% impurities.

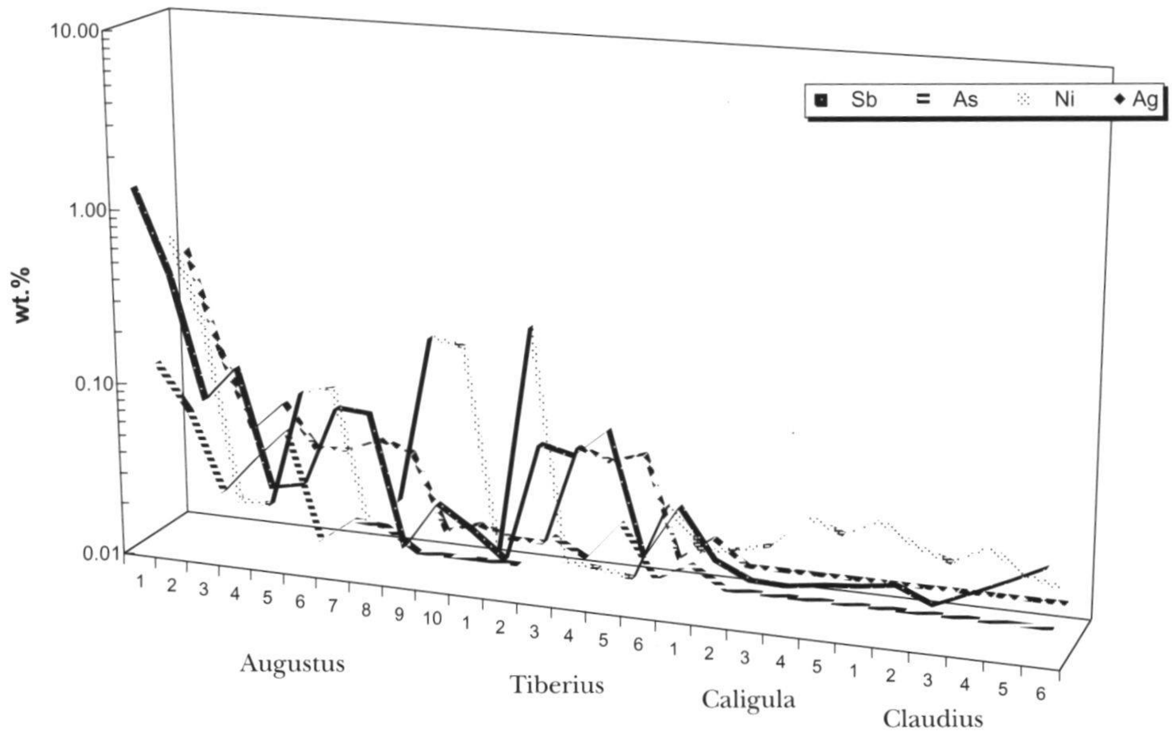

Figure 11: Overall chemical development of Roman copper used for coinage from Augustus to Claudius. The diagram shows a trend to increased purification as well as changes in material. X-axis: coin groups. Each data point represents the statistical average of all analyses of the respective group.

98 R. Maddin/T. Stech Wheeler/D. Muhly, Distinguishing Artifacts Made of Native Copper. Journal of Archaeological Science 7, 1980, pp. 211-225.

The increasing purity of the copper metal from the Rome mint during the reign of Augustus can be assumed to be (a) a direct reflection of the raw material and (b) a result of improved smelting, refining and melting processes.

The copper used for the first moneyers' issues of Augustus (group 1) has significant impurities of antimony and arsenic, which are characteristics of fahlore type ores.[99] The copper of group 2 looks chemically different and is purer. It was possibly produced from other types of ore than the fahlore which may have been used for group 1. One indication for a switch to other ore sources could be the first occurrence of cobalt in *asses* of Piso (group 2), and later in those of Otho (group 5) and Messalla (group 6). However, as we stated above, it is almost impossible to answer questions of provenance on the basis of chemical composition alone, and so we will not pursue the matter of the cobalt levels further here.

In this context we should bear in mind that it was with the issues of group 1 that the Imperial copper coinage was introduced, and that at this time the Rome mint had no experience at all in the production of copper coins. As for the fahlore, it occurs in various ore deposits in different locations, but is also found in the Alpine region. Pliny[100] mentions the «sallustian» copper from the Western Alps which was «*non longi et ipsum aevi*», and A. Wallace-Hadrill has identified Sallustius Crispus, a close friend of Augustus, as «*the owner of the new copper mine in the Val d'Aosta which provided bullion for the new issues*».[101] Our analyses could provide support for this thesis, but reliable conclusions can only be reached with the help of lead-isotope analysis.

With the copper of groups 3 and 4 of Augustus a high standard of purity was already reached. This was such that minor compositional variations no longer had any influence on the physical and mechanical properties required of copper to strike coins.

As for the extraction of the copper from the ore, presumably experience will have revealed how to treat the ore charge in order to obtain very pure metal. This could have been achieved by improving the pre-roasting of sulphide ores, increasing the smelting temperature, and by single or multiple re-melting of the metal produced in order to eliminate unwanted impurities. This would mean that there was a deliberate process of refining raw smelted metal which contributed to the high purity of the copper.[102] It is also possible that high quality metal was produced especially to be supplied to the mint of Rome.

99 We are grateful to Zofia Stos-Gale, Oxford, and Hans-Gert Bachmann, Hanau, for their comments on our results.

100 Plin. nat. 34,3.

101 WALLACE-HADRILL, op. cit. note 42, p. 87.

102 Pliny the Elder informs us about the techniques for refining copper metal, and its different qualities. He states that refined copper from Gaul did not match copper from Capua (Italy, Campania) in quality, due to differences in techniques of refining; cf. Plin. nat. 34, 94-96.

With groups 3 and 4 sufficient knowledge had been gained to produce copper of high purity, and subsequent variations in the late Augustan and Tiberian period have to be differentiated from the effects of smelting and refining (*Figure 11*). Augustan copper coins have either increased silver and antimony levels (groups 7, 8) or nickel (groups 5, 6, 9, 10). Tiberian copper either contains more silver, antimony and arsenic (groups 3-5), or nickel (groups 2, 6). We assume that during this period two different sources of raw material or ore from distinct locations were accessed alternately, and that the chemical patterns of the ores were so marked that advanced smelting and refining techniques could not completely erase them.

The high sulphur content of the late Augustan issue (group 10) can only be accounted for by «dirty» copper, which derived from the smelting of sulphide ore from which the sulphur had not been successfully removed.

The high purity of Caligulan and Claudian copper mirrors the high standard of smelting and refining techniques achieved during the preceding decades, and also the improved knowledge of which available raw material sources were ideal for the production of the copper coins.

The chemical analysis of the copper coins from Rome has shown that great advances in knowledge and skill were made in the field of copper technology during the period under study. The manufacture of copper coins was a difficult process that required good knowledge of the raw materials used, and the ability to control its quality both by selecting the most reliable metal sources and through the refining process. Since it is difficult to assign the copper used for coin production to individual ore sources and types on the grounds of chemical composition alone, our next step will be to incorporate lead-isotope analysis into the chemical data. We hope that we will then be able to trace the sources of raw material which played such an important role in the production of early Imperial copper coinage.

Zusammenfassung

241 Kupfermünzen der Kaiser Augustus, Tiberius, Caligula und Claudius aus der Münzstätte Rom wurden mit der Elektronenstrahlmikrosonde (EPMA) auf ihre chemische Zusammensetzung hin analysiert. Anhand des Elementmusters des Kupfers werden Veränderungen in der chemischen Zusammensetzung über den gegebenen Zeitraum beschrieben. Die Analysen beleuchten verschiedene Aspekte der Münzprägung und zeigen insbesondere, dass zunehmend spurenelementärmeres Kupfer Verwendung fand. Referenzgruppen, die anhand von datierten Emissionen erstellt wurden, erlauben es, undatierte Emissionen, insbesondere die DIVVS AVGVSTVS PATER-Serien des Tiberius, einzuordnen. Für die sogenannten Agrippa-Asse konnte bestätigt werden, dass sie nicht unter Tiberius, sondern unter Caligula geprägt worden sind. Bestimmte Imitationen claudischer Kupfermünzen dürften aus wiederverwendeten spättiberischen Assen bestehen.

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Appendices

1 Electron probe microanalysis results for the Augustan copper coins. Each analysis represents the statistical average of six acquisition runs (repetitions). Results in weight percent. As = *as*, Qd = *quadrans*, n.d. = not detected. In the column «Total»: * = normed to 100%.

2 Spider diagrams of Augustan copper coins of groups 1 to 10. Note that some low concentrations of elements fall below detection limits that are indicated in the Figures of the EGP's.

3 Electron probe microanalysis results for the Tiberian copper coins. Each analysis represents the statistical average of six acquisition runs (repetitions). Results in weight percent. As = *as*, n.d. = not detected.

4 Spider diagrams of Tiberian copper coins of groups 1 to 9. Note that some low concentrations of elements fall below detection limits that are indicated in the Figures of the EGP's.

5 Electron probe microanalysis results for the Caligulan copper coins. Each analysis represents the statistical average of six acquisition runs (repetitions). Results in weight percent. As = *as*, Qd = *quadrans*, n.d. = not detected. In the column Sample: (Imit.) = Imitation.

6 Spider diagrams of Caligulan copper coins of groups 1 to 6. Note that some low concentrations of elements fall below detection limits that are indicated in the Figures of the EGP's.

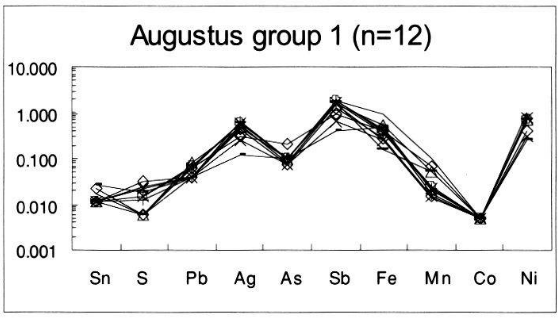
7 Electron probe microanalysis results for the Claudian copper coins. Each analysis represents the statistical average of six acquisition runs (repetitions). Results in weight percent. As = *as*, Qd = *quadrans*, n.d. = not detected. In the column Total: * = normed to 100%, in the column Sample: (Imit.) = Imitation.

8 Spider diagrams of Claudian copper coins of groups 1 to 6. Note that some low concentrations of elements fall below detection limits that are indicated in the Figures of the EGP's.

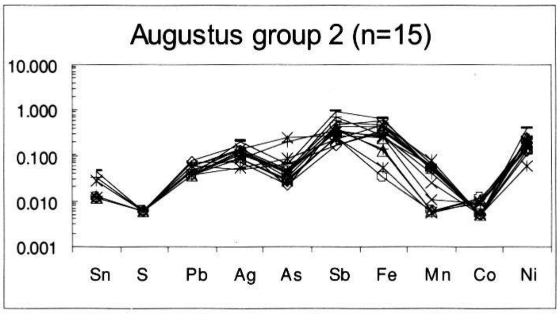
9 Concordance of analysis nos. (TM...) and inventory nos. of the Museo Nazionale Romano, Rome (in brackets; K = cat. no. F.E. KOENIG, Boll. di Num. 10, 1988, pp. 57-179; vK = cat. no. H.-M. VON KAENEL, Boll. di Num. 2/3, 1984, pp. 113-324).

Augustus

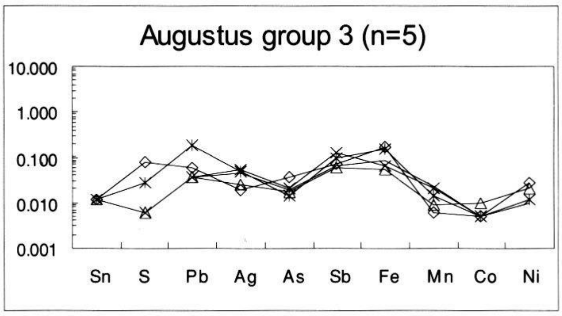
Group	RIC I[2]	Sample	Denomination	Cu	Sn	Zn	Pb	Ag	As	Sb	Bi	S	Ni	Co	Mn	Fe	Cd	Au	Total
1	373	TM 55	As	97.3	<0.012	n.d.	<0.038	0.469	0.074	1.319	<0.023	0.033	0.406	<0.005	0.016	0.287	<0.016	n.d.	100.00
16 B.C.	373	TM 56	As	96.9	<0.012	n.d.	<0.038	0.518	0.084	1.533	<0.023	0.025	0.678	<0.005	0.014	0.255	<0.016	n.d.	100.00
	373	TM 57	As	89.5	3.158	n.d.	5.214	0.092	0.236	0.465	<0.023	0.011	0.058	0.017	0.021	0.030	<0.016	n.d.	98.85
	373	TM 58	As	98.3	<0.012	n.d.	0.038	0.262	0.074	0.658	<0.023	0.022	0.304	<0.005	0.015	0.264	<0.016	n.d.	100.00
	376	TM 69	As	96.3	<0.012	n.d.	0.061	0.579	0.104	1.728	0.050	0.016	0.758	<0.005	0.022	0.386	<0.016	n.d.	100.00
	376	TM 70	As	96.2	<0.012	n.d.	0.071	0.574	0.100	1.870	<0.023	0.015	0.699	<0.005	0.026	0.413	<0.016	n.d.	100.00
	376	TM 71	As	96.1	<0.012	<0.015	<0.038	0.653	0.102	1.865	<0.023	0.013	0.795	<0.005	0.017	0.437	<0.016	n.d.	100.00
	376	TM 72	As	98.6	0.028	n.d.	<0.038	0.117	0.096	0.392	<0.023	0.019	0.255	<0.005	0.020	0.483	<0.016	n.d.	100.00
	379	TM 84	As	96.5	<0.012	0.025	0.066	0.573	0.100	1.723	<0.023	<0.006	0.744	<0.005	0.050	0.161	<0.016	n.d.	*100.00
	379	TM 85	As	97.5	0.022	n.d.	0.061	0.296	0.207	0.968	<0.023	<0.006	0.410	<0.005	0.068	0.405	n.d.	n.d.	*100.00
	379	TM 86	As	95.4	0.017	n.d.	0.040	0.511	0.098	1.769	<0.023	<0.006	1.085	<0.005	0.097	0.937	<0.016	n.d.	*100.00
	379	TM 89	As	96.4	<0.012	n.d.	0.080	0.513	0.097	1.568	<0.023	<0.006	0.747	<0.005	0.052	0.529	<0.016	n.d.	*100.00
2	382	TM 166	As	99.3	<0.012	n.d.	<0.038	0.129	0.032	0.409	<0.023	<0.006	0.210	0.011	<0.006	0.121	<0.016	n.d.	100.20
15 B.C.	382	TM 167	As	98.9	<0.012	n.d.	0.061	0.139	0.236	0.276	<0.023	<0.006	0.197	0.009	0.011	0.241	<0.016	n.d.	100.10
	382	TM 168	As	99.5	<0.012	n.d.	<0.038	0.089	0.028	0.250	<0.023	<0.006	0.147	0.010	0.006	0.056	n.d.	n.d.	100.09
	382	TM 169	As	99.4	<0.012	n.d.	<0.038	0.086	0.031	0.253	<0.023	<0.006	0.135	0.012	<0.006	0.033	<0.016	n.d.	100.00
	382	TM 170	As	99.0	0.033	n.d.	0.049	0.090	0.206	0.377	<0.023	<0.006	0.146	0.009	<0.006	0.133	<0.016	n.d.	100.04
	385	TM 115	As	99.1	0.045	n.d.	0.062	0.049	0.064	0.175	<0.023	<0.006	0.102	<0.005	0.059	0.364	<0.016	n.d.	*100.00
	386	TM 119	As	97.7	<0.012	<0.015	<0.038	0.207	0.064	0.899	<0.023	0.006	0.407	<0.005	0.050	0.617	<0.016	n.d.	*100.00
	386	TM 120	As	99.1	<0.012	n.d.	0.071	0.070	0.024	0.172	<0.023	<0.006	0.122	<0.005	0.062	0.320	<0.016	n.d.	*100.00
	386	TM 121	As	98.3	<0.012	n.d.	0.079	0.166	0.021	0.462	<0.023	<0.006	0.239	<0.005	0.065	0.606	<0.016	n.d.	*100.00
	386	TM 122	As	98.9	<0.012	n.d.	<0.038	0.113	0.039	0.353	<0.023	<0.006	0.235	<0.005	0.061	0.256	<0.016	n.d.	*100.00
	386	TM 177	As	98.6	<0.012	n.d.	<0.038	0.106	0.043	0.334	<0.023	<0.006	0.183	<0.005	0.026	0.267	<0.016	n.d.	99.55
	389	TM 133	As	99.0	0.028	n.d.	<0.038	0.053	0.089	0.229	<0.023	<0.006	0.059	<0.005	0.078	0.480	n.d.	n.d.	*100.00
	389	TM 134	As	98.6	<0.012	n.d.	<0.038	0.113	0.045	0.452	<0.023	<0.006	0.222	<0.005	0.050	0.429	<0.016	n.d.	*100.00
	389	TM 135	As	98.5	0.013	n.d.	0.058	0.124	0.046	0.719	<0.023	<0.006	0.233	<0.005	0.039	0.283	<0.016	n.d.	*100.00
	389	TM 136	As	98.4	<0.012	n.d.	0.047	0.136	0.051	0.534	<0.023	<0.006	0.249	<0.005	0.053	0.462	<0.016	<0.052	*100.00
3	420	TM 40	Qd	99.5	<0.012	n.d.	0.058	0.020	0.037	0.070	<0.023	0.082	0.029	<0.005	<0.006	0.163	<0.016	<0.052	100.00
9 B.C.	420	TM 41	Qd	99.7	<0.012	n.d.	0.039	0.044	0.019	0.065	<0.023	<0.006	0.010	<0.005	0.023	0.083	<0.016	n.d.	100.00
	420	TM 156	Qd	99.9	<0.012	n.d.	<0.038	0.026	0.017	0.061	<0.023	<0.006	0.021	0.010	0.009	0.055	<0.016	n.d.	100.10
	422	TM 42	Qd	99.6	<0.012	n.d.	<0.038	0.052	0.021	0.133	<0.023	<0.006	0.012	n.d.	0.021	0.063	<0.016	n.d.	100.00
	422	TM 43	Qd	99.4	<0.012	n.d.	0.180	0.051	0.014	0.099	<0.023	0.027	0.012	<0.005	0.014	0.154	<0.016	n.d.	100.00
4	423	TM 173	Qd	99.4	0.016	n.d.	<0.038	0.073	0.056	0.188	<0.023	<0.006	0.018	0.010	<0.006	0.294	<0.016	n.d.	100.07
8 B.C.	425	TM 174	Qd	99.8	<0.012	n.d.	<0.038	0.045	0.015	0.089	<0.023	<0.006	0.015	0.011	0.006	0.042	<0.016	n.d.	100.11
5	428	TM 105	As	99.2	<0.012	n.d.	<0.038	0.013	0.050	0.013	<0.023	<0.006	0.057	<0.005	0.078	0.583	<0.016	n.d.	*100.00
7 B.C.	429	TM 151	As	99.4	0.047	n.d.	0.040	0.062	0.064	0.030	<0.023	<0.006	0.065	<0.005	0.053	0.241	<0.016	n.d.	*100.00
	431	TM 144	As	99.5	<0.012	n.d.	0.040	<0.013	0.070	0.033	<0.023	<0.006	0.081	0.026	0.079	0.133	<0.016	n.d.	*100.00
	431	Tm 145	As	99.2	0.016	n.d.	0.054	0.023	0.027	0.031	<0.023	<0.006	0.130	<0.005	0.076	0.394	<0.016	n.d.	*100.00
	431	TM 146	As	99.4	0.032	n.d.	<0.038	0.073	0.143	0.036	<0.023	<0.006	0.053	<0.005	0.047	0.154	n.d.	n.d.	*100.00
	431	TM 147	As	98.8	0.104	n.d.	0.059	0.025	0.117	0.045	<0.023	<0.006	0.151	0.008	0.067	0.638	<0.016	n.d.	*100.00
	432	TM 148	As	99.6	<0.012	n.d.	<0.038	0.053	<0.013	0.030	<0.023	<0.006	0.055	<0.005	0.070	0.143	<0.016	n.d.	*100.00
	432	TM 149	As	99.6	<0.012	n.d.	<0.038	<0.013	<0.013	0.018	<0.023	<0.006	0.181	<0.005	0.068	0.098	<0.016	n.d.	*100.00
	435	TM 106	As	99.7	<0.012	n.d.	<0.038	0.039	<0.013	0.032	<0.023	0.006	0.061	<0.005	0.050	0.113	<0.016	n.d.	*100.00
	435	TM 107	As	99.4	0.030	n.d.	<0.038	0.025	0.050	0.028	<0.023	<0.006	0.059	<0.005	0.071	0.368	<0.016	n.d.	*100.00
	435	TM 108	As	99.3	0.038	n.d.	0.249	0.070	0.051	0.031	<0.023	<0.006	0.057	<0.005	0.063	0.109	<0.016	n.d.	*100.00
	436	TM 109	As	99.6	0.016	<0.015	<0.038	<0.013	0.020	0.017	<0.023	<0.006	0.022	<0.005	0.049	0.219	<0.016	n.d.	*100.00
	436	TM 110	As	99.4	0.033	0.048	<0.038	0.044	0.081	0.035	<0.023	<0.006	0.081	<0.005	0.038	0.191	<0.016	n.d.	*100.00
6	437	TM 90	As	99.5	<0.012	n.d.	<0.038	0.015	<0.013	0.018	<0.023	<0.006	0.181	<0.005	0.065	0.185	<0.016	n.d.	*100.00
6 B.C.	437	TM 91	As	99.6	<0.012	n.d.	<0.038	0.039	0.019	0.031	<0.023	<0.006	0.124	<0.005	0.073	0.082	<0.016	n.d.	*100.00
	437	TM 92	As	99.3	<0.012	n.d.	<0.038	<0.013	<0.013	0.018	n.d.	0.009	0.202	<0.005	0.087	0.340	<0.016	n.d.	*100.00
	439	TM 123	As	99.5	0.016	n.d.	<0.038	0.045	<0.013	0.039	<0.023	<0.006	0.061	<0.005	0.070	0.246	<0.016	n.d.	*100.00
	439	TM 124	As	99.2	<0.012	n.d.	<0.038	0.061	0.014	0.047	<0.023	<0.006	0.089	<0.005	0.066	0.435	<0.016	n.d.	*100.00
	439	TM 125	As	99.7	<0.012	n.d.	<0.038	0.029	<0.013	0.025	<0.023	<0.006	0.059	n.d.	0.053	0.143	<0.016	n.d.	*100.00
	439	TM 126	As	99.7	0.015	n.d.	<0.038	0.030	<0.013	0.027	<0.023	<0.006	0.031	<0.005	0.053	0.081	<0.016	n.d.	*100.00
	441	TM 159	As	99.7	<0.012	n.d.	<0.038	0.046	<0.013	0.037	<0.023	<0.006	0.081	0.011	<0.006	0.151	<0.016	n.d.	100.05
	441	TM 160	As	99.7	0.012	n.d.	<0.038	0.042	0.017	0.046	<0.023	<0.006	0.063	0.011	<0.006	0.164	<0.016	n.d.	100.04
7	443-464	TM 59	Qd	99.6	<0.012	n.d.	<0.038	0.044	0.015	0.097	<0.023	0.032	0.011	<0.005	0.018	0.113	<0.016	n.d.	100.00
5 B.C.	443-464	TM 60	Qd	99.6	<0.012	n.d.	0.051	0.055	0.020	0.112	<0.023	0.007	0.013	<0.005	0.019	0.074	<0.016	n.d.	100.00
	443-464	TM 74	Qd	99.6	<0.012	n.d.	0.038	0.056	0.018	0.089	<0.023	<0.006	0.020	<0.005	0.082	0.107	<0.016	n.d.	*100.00
	443-464	TM 75	Qd	99.6	<0.012	n.d.	<0.038	0.035	0.019	0.087	<0.023	<0.006	0.015	<0.005	0.063	0.113	<0.016	n.d.	*100.00
	443-464	TM 76	Qd	99.0	<0.012	n.d.	0.271	0.030	0.023	0.105	<0.023	<0.006	0.018	<0.005	0.067	0.440	<0.016	n.d.	*100.00
	443-464	TM 157	Qd	99.3	<0.012	n.d.	0.044	0.026	<0.013	0.069	<0.023	<0.006	0.013	<0.005	<0.006	0.391	<0.016	n.d.	99.90
8	465-468	TM 61	Qd	99.5	<0.012	n.d.	<0.038	0.031	<0.013	0.075	<0.023	<0.006	0.016	<0.005	0.033	0.245	<0.016	n.d.	100.00
4 B.C.	465-468	TM 114	Qd	99.3	0.013	n.d.	0.065	0.029	0.025	0.139	<0.023	0.006	0.032	<0.005	0.055	0.314	<0.016	n.d.	*100.00
	465-468	TM 158	Qd	99.7	<0.012	n.d.	0.047	0.047	0.014	0.056	<0.023	<0.006	0.017	0.011	<0.006	0.114	<0.016	n.d.	99.99
9	469	TM 180	As	99.3	<0.012	n.d.	<0.038	<0.013	<0.013	0.021	<0.023	<0.006	0.199	0.008	0.017	0.167	<0.016	n.d.	99.71
A.D. 10/11	469	TM 181	As	99.3	<0.012	n.d.	<0.038	<0.013	<0.013	0.016	<0.023	<0.006	0.207	0.007	0.011	0.269	<0.016	n.d.	99.83
	469	TM 182	As	99.3	<0.012	n.d.	<0.038	<0.013	n.d.	0.015	<0.023	<0.006	0.231	0.018	0.018	0.126	<0.016	n.d.	99.77
	469	TM 183	As	99.6	<0.012	n.d.	<0.038	0.020	<0.013	0.017	<0.023	<0.006	0.190	0.009	0.014	0.126	<0.016	n.d.	100.00
	469	TM 184	As	99.5	<0.012	n.d.	<0.038	<0.013	<0.013	0.010	<0.023	<0.006	0.188	0.006	0.009	0.080	<0.016	n.d.	99.87
	469	TM 185	As	99.2	<0.012	n.d.	<0.038	0.020	<0.013	0.017	<0.023	<0.006	0.193	0.013	0.030	0.295	<0.016	n.d.	99.82
10	471	TM 31	As	99.6	<0.012	n.d.	<0.038	<0.013	<0.013	0.012	<0.023	0.026	0.200	0.006	0.012	0.110	<0.016	n.d.	100.00
A.D. 11/12	471	TM 32	As	99.7	<0.012	n.d.	<0.038	0.013	<0.013	0.022	<0.023	0.024	0.182	<0.005	0.012	0.010	<0.016	n.d.	100.00
	471	TM 33	As	99.6	<0.012	n.d.	<0.038	0.014	<0.013	0.036	<0.023	0.046	0.239	0.006	0.006	0.062	<0.016	n.d.	100.07
	471	TM 34	As	98.9	0.016	n.d.	<0.038	0.016	<0.013	0.017	<0.023	0.071	0.214	0.019	<0.006	0.526	<0.016	n.d.	99.88
	471	TM 35	As	99.5	<0.012	n.d.	<0.038	0.017	0.015	<0.012	<0.023	0.064	0.206	0.006	<0.006	0.166	<0.016	<0.052	100.00
	471	TM 36	As	99.4	0.013	<0.015	0.047	0.021	<0.013	0.017	<0.023	0.073	0.163	0.013	0.010	0.179	<0.016	<0.052	100.00
	471	TM 37	As	98.5	<0.012	n.d.	<0.038	0.015	<0.013	0.024	<0.023	0.107	0.227	0.016	0.008	1.048	<0.016	<0.052	100.00
	471	TM 38	As	97.6	<0.012	n.d.	<0.038	0.016	<0.013	<0.012	<0.023	0.068	0.231	0.018	0.007	1.611	<0.016	n.d.	99.63
	471	TM 39	As	99.7	<0.012	n.d.	<0.038	0.026	0.018	0.121	<0.023	0.049	0.009	<0.005	<0.006	0.019	<0.016	n.d.	100.00



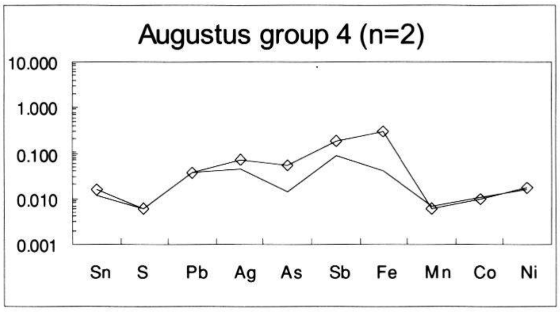
Asses of the college of Gallus/Celer/Lupercus (16 B.C.) are characterised by EGP I, with the highest values for elements other than copper of all Augustan groups. One coin of Lupercus (TM 84) is different from the others with a detectable zinc content of 0.03 wt.%. One coin of Gallus (TM 57) has lead and tin levels of some 5% and 3%, and therefore differs from the rest of the group. This coin is not included in the diagram.



Asses of the college of Piso/Surdinus/Rufus (15 B.C.), or more precisely the coins of the moneyers Surdinus and Rufus, are characterised by EGP I. The element levels are significantly lower than in group 1. The coins of Piso, however, are the earliest to have detectable amounts of cobalt, although all other elements stay within EGP I.

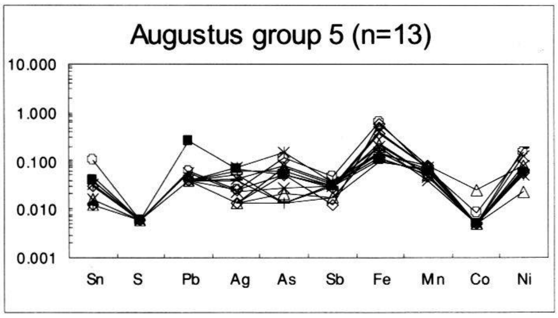


Quadrantes of the college of Lamia/Silius/Annius (9 B.C.) are characterised by EGP I, with even lower values for the elements analysed. Only one coin (TM 156) differs in containing a detectable level of cobalt, although all other elements stay within EGP I.

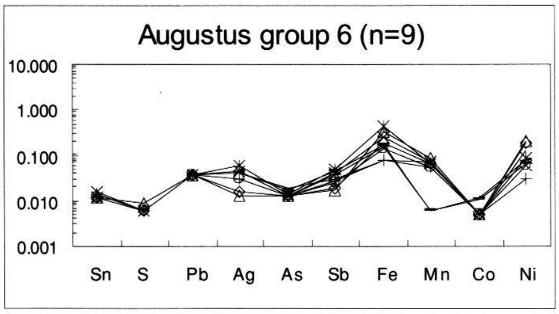


Quadrantes of the college of Pulcher/Taurus/Regulus (8 B.C.) are characterised by EGP I. The values are comparable to group 3 quadrantes, and have not decreased further.

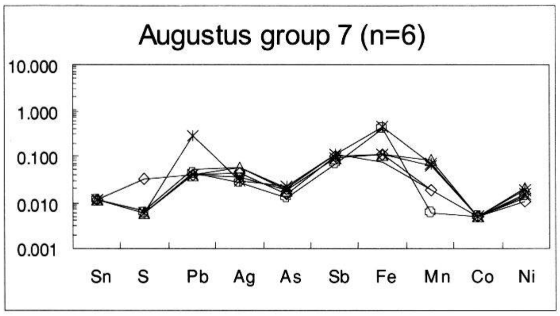
Each data point represents the mean value of six analysis repetitions, aquired from six different locations of the sample. The Y-axis of diagrams is weight percent. Note the detection limits of the elements displayed in the figures of the EGP's and the data tables.



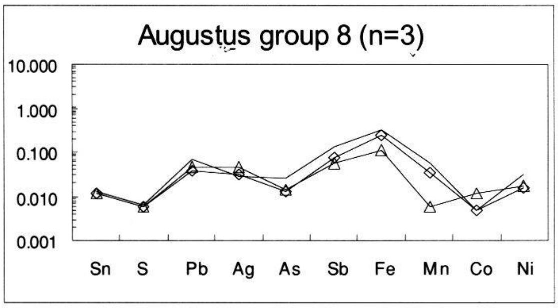
Asses of the college of Agrippa/Otho/Tullus (7 B.C.) are characterised by the overall picture of EGP I, but the arsenic:antimony ratio differs, and the level of arsenic is higher than that of antimony. The values for iron, manganese and nickel have increased slightly towards the values for coins of group 2. Two coins of Otho have detectable amounts of cobalt, but otherwise Otho's copper pattern remains within EGP I.



Asses of the college of Silianus/Quinctilianus/Messalla (6 B.C.). The coins of the moneyers Silianus and Quinctilianus are characterised by EGP I. The values of silver, arsenic and antimony have decreased to the lowest detectable values. Iron, manganese and nickel are as high as in groups 2 and 5, although iron and manganese scatter less. The coins of Messalla contain significant levels of cobalt (~0.01 wt.% Co). Manganese is below the detection limit.

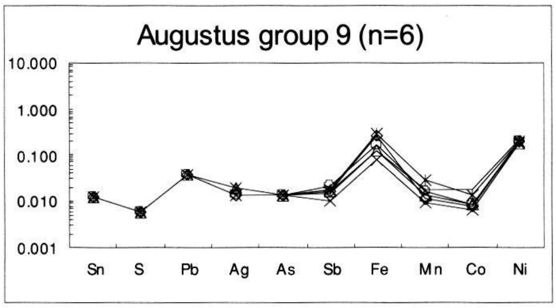


Quadrantes of the college of Apronius/Galus/Messalla/Sisenna (5 B.C.) are characterised by EGP I. In one single coin (TM 157) manganese is below the detection limit. The element values are comparable to groups 3 and 4.

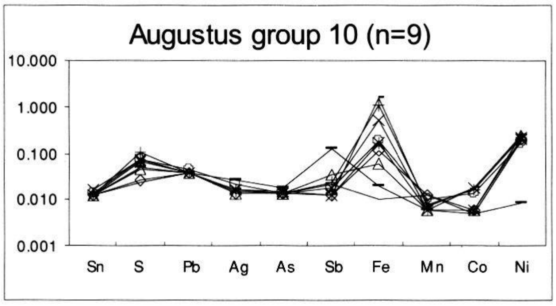


Quadrantes of the college of Bassus/Capella/Blandus/Catullus (4 B.C.) are characterised by EGP I, with element values comparable to groups, 3, 4 and 7. Again, one single coin (TM 158) has a detectable cobalt content.

Each data point represents the mean value of six analysis repetitions, aquired from six different locations of the sample. The Y-axis of diagrams is weight percent. Note the detection limits of the elements displayed in the figures of the EGP's and the data tables.



Asses (A.D. 10-11) are characterised by EGP II, with tin, sulphur, lead and arsenic below detection limits. Silver and antimony are still present, but are very close to their detection limits. Cobalt is detectable in all coins in this group analysed. The value for nickel is as high as in *quadrantes* earlier than group 7.

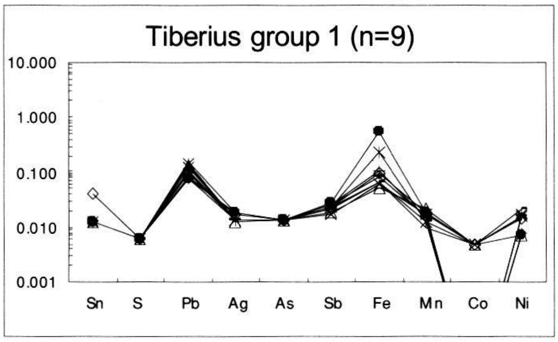


Asses (A.D. 11-12) are characterised by EGP II, but contain unusually high sulphur levels, even higher than in group 1 copper. In addition, iron scatters over a remarkably wide range of two tenth power.

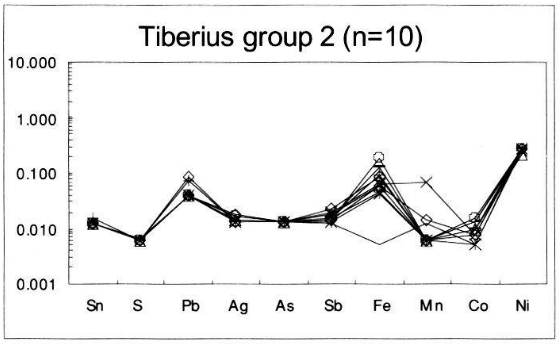
Each data point represents the mean value of six analysis repetitions, aquired from six different locations of the sample. The Y-axis of diagrams is weight percent. Note the detection limits of the elements displayed in the figures of the EGP's and the data tables.

Tiberius

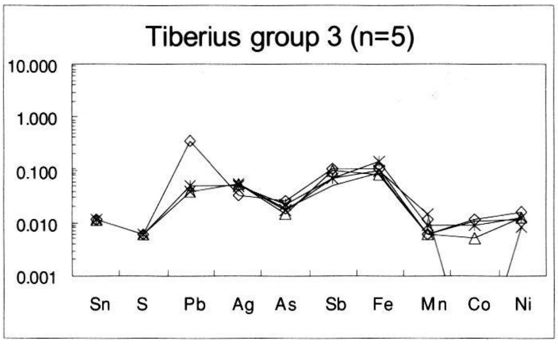
Group	RIC I[2]	Sample	Denomination	Cu	Sn	Zn	Pb	Ag	As	Sb	Bi	S	Ni	Co	Mn	Fe	Cd	Au	Total
1	33	TM 226	As	95.81	0.041	3.323	0.081	0.017	<0.013	0.024	<0.023	0.006	0.014	<0.005	0.018	0.096	<0.016	n.d.	99.44
15/16	33	TM 227	As	99.12	<0.012	n.d.	0.148	0.019	<0.013	0.023	<0.023	<0.006	0.007	<0.005	0.010	0.066	<0.016	n.d.	99.42
	34	TM 228	As	99.16	<0.012	n.d.	0.131	0.013	<0.013	0.019	<0.023	<0.006	0.007	<0.005	0.022	0.050	<0.016	n.d.	99.43
	34	TM 229	As	99.33	<0.012	n.d.	0.126	<0.013	<0.013	0.017	<0.023	<0.006	0.015	<0.005	0.017	0.058	<0.016	n.d.	99.59
	34	TM 230	As	99.07	<0.012	n.d.	0.139	<0.013	<0.013	0.023	<0.023	<0.006	0.017	n.d.	0.012	0.230	<0.016	n.d.	99.53
	35	TM 231	As	98.70	<0.012	n.d.	0.077	0.018	<0.013	0.028	<0.023	<0.006	<0.007	n.d.	0.019	0.562	<0.016	n.d.	99.43
	35	TM 232	As	99.18	<0.012	n.d.	0.077	0.013	<0.013	0.025	<0.023	<0.006	0.008	n.d.	0.015	0.101	<0.016	n.d.	99.43
	36	TM 233	As	98.98	<0.012	n.d.	0.095	<0.013	<0.013	0.021	<0.023	<0.006	0.022	<0.005	0.013	0.067	<0.016	n.d.	99.22
	36	TM 234	As	99.37	<0.012	n.d.	0.104	0.013	<0.013	0.025	<0.023	<0.006	0.016	n.d.	0.016	0.079	<0.016	n.d.	99.65
2	44	TM 235	As	98.91	<0.012	n.d.	0.087	0.013	<0.013	0.014	<0.023	<0.006	0.271	0.008	0.014	0.060	<0.016	n.d.	99.40
22/23	44	TM 236	As	99.43	<0.012	n.d.	<0.038	0.014	<0.013	0.012	<0.023	0.006	0.256	<0.005	0.012	<0.005	<0.016	n.d.	99.76
	44	TM 237	As	99.40	<0.012	n.d.	<0.038	0.015	<0.013	0.018	<0.023	<0.006	0.224	0.009	<0.006	0.058	<0.016	n.d.	99.76
	44	TM 238	As	98.88	<0.012	n.d.	<0.038	<0.013	<0.013	0.019	<0.023	<0.006	0.249	0.008	0.069	0.060	<0.016	n.d.	99.32
	44	TM 239	As	99.43	<0.012	n.d.	<0.038	<0.013	<0.013	0.013	<0.023	<0.006	0.285	<0.005	<0.006	0.043	<0.016	n.d.	99.81
	45	TM 240	As	99.20	<0.012	n.d.	<0.038	0.017	<0.013	0.015	<0.023	<0.006	0.271	0.015	<0.006	0.186	<0.016	n.d.	99.73
	45	TM 241	As	99.00	0.016	n.d.	0.076	<0.013	<0.013	0.016	<0.023	<0.006	0.281	0.013	<0.006	0.090	<0.016	n.d.	99.52
	45	TM 242	As	99.36	<0.012	n.d.	<0.038	0.013	<0.013	0.015	<0.023	0.007	0.264	0.013	<0.006	0.046	<0.016	n.d.	99.73
	45	TM 243	As	99.23	<0.012	n.d.	<0.038	<0.013	<0.013	0.015	<0.023	<0.006	0.272	0.010	<0.006	0.126	<0.016	n.d.	99.69
	45	TM 244	As	99.25	<0.012	n.d.	<0.038	0.018	<0.013	0.022	<0.023	<0.006	0.266	0.007	<0.006	0.088	<0.016	n.d.	99.67
3	52	TM 257	As	99.13	<0.012	n.d.	0.364	0.032	0.027	0.104	<0.023	<0.006	0.016	0.011	<0.006	0.108	<0.016	n.d.	99.82
34/35	52	TM 258	As	99.64	<0.012	n.d.	<0.038	0.055	0.019	0.050	<0.023	<0.006	0.011	0.010	<0.006	0.087	<0.016	n.d.	99.92
	53	TM 245	As	99.45	<0.012	n.d.	<0.038	0.053	0.015	0.095	<0.023	<0.006	0.013	<0.005	<0.006	0.081	<0.016	n.d.	99.74
	53	TM 246	As	99.36	<0.012	n.d.	<0.038	0.053	0.018	0.071	<0.023	<0.006	0.009	n.d.	0.015	0.100	<0.016	n.d.	99.66
	53	TM 263	As	99.49	<0.012	n.d.	0.048	0.050	0.021	0.067	<0.023	<0.006	0.012	0.009	0.009	0.139	<0.016	n.d.	99.87
4	58	TM 247	As	99.39	<0.012	n.d.	<0.038	0.045	0.015	0.085	<0.023	<0.006	0.010	<0.005	<0.006	0.093	<0.016	n.d.	99.67
35/36	58	TM 248	As	99.69	<0.012	n.d.	<0.038	0.033	<0.013	0.026	<0.023	<0.006	0.013	<0.005	<0.006	0.019	<0.016	n.d.	99.82
	59	TM 249	As	99.31	<0.012	n.d.	<0.038	0.050	<0.013	0.050	<0.023	<0.006	0.013	n.d.	<0.006	0.239	<0.016	n.d.	99.72
	59	TM 250	As	99.46	<0.012	n.d.	<0.038	0.033	0.017	0.090	<0.023	<0.006	0.011	<0.005	<0.006	0.048	<0.016	n.d.	99.69
	59	TM 252	As	99.68	0.012	n.d.	0.072	0.055	0.021	0.097	<0.023	<0.006	0.012	0.010	0.007	0.136	<0.016	n.d.	100.11
5	64	TM 253	As	99.87	<0.012	n.d.	0.054	0.036	0.032	0.083	<0.023	<0.006	0.008	0.010	<0.006	0.066	<0.016	n.d.	100.18
36/37	64	TM 254	As	99.73	<0.012	n.d.	<0.038	0.035	0.034	0.101	<0.023	0.006	<0.007	0.011	0.006	<0.005	<0.016	n.d.	99.95
	64	TM 255	As	99.47	<0.012	n.d.	0.221	0.070	0.021	0.131	<0.023	<0.006	0.016	0.009	0.007	0.016	<0.016	n.d.	99.97
	64	TM 256	As	99.71	<0.012	n.d.	0.048	0.053	0.008	0.067	<0.023	0.007	0.011	0.011	<0.006	0.034	<0.016	n.d.	99.96
	65	TM 259	As	99.64	<0.012	n.d.	<0.038	0.045	0.033	0.112	<0.023	<0.006	0.007	0.011	0.006	0.075	<0.016	n.d.	99.96
	65	TM 260	As	99.59	0.021	n.d.	0.038	0.051	0.048	0.156	<0.023	<0.006	0.014	0.014	<0.006	0.105	<0.016	n.d.	100.05
	65	TM 261	As	99.69	<0.012	n.d.	<0.038	0.051	0.018	0.057	<0.023	<0.006	0.016	0.009	0.008	0.237	<0.016	n.d.	100.10
	65	TM 262	As	99.52	<0.012	n.d.	0.059	0.057	0.019	0.108	<0.023	<0.006	0.010	0.010	<0.006	0.065	<0.016	n.d.	99.87
6	72	TM 264	As	99.83	<0.012	n.d.	<0.038	0.020	<0.013	0.020	<0.023	<0.006	0.011	0.009	<0.006	0.081	<0.016	n.d.	100.01
undated	72	TM 265	As	99.85	<0.012	n.d.	<0.038	<0.013	<0.013	0.019	<0.023	<0.006	0.017	0.011	0.009	0.012	<0.016	n.d.	99.95
	72	TM 266	As	99.79	<0.012	n.d.	<0.038	<0.013	<0.013	0.026	<0.023	<0.006	0.091	0.011	<0.006	0.102	<0.016	n.d.	100.05
	72	TM 267	As	99.96	<0.012	n.d.	<0.038	<0.013	<0.013	0.018	<0.023	<0.006	0.023	0.009	0.020	0.082	<0.016	n.d.	100.15
	72	TM 268	As	99.74	<0.012	n.d.	<0.038	<0.013	0.015	0.021	<0.023	<0.006	0.011	0.012	0.008	0.103	<0.016	n.d.	99.95
7	81	TM 269	As	99.63	<0.012	n.d.	<0.038	<0.013	<0.013	<0.012	<0.023	<0.006	0.285	0.020	<0.006	0.046	<0.016	n.d.	100.07
undated	81	TM 270	As	99.55	<0.012	n.d.	<0.038	<0.013	<0.013	0.016	<0.023	<0.006	0.274	0.027	0.014	0.078	<0.016	n.d.	99.98
	81	TM 271	As	99.47	<0.012	n.d.	<0.038	<0.013	<0.013	0.023	<0.023	<0.006	0.287	0.017	0.012	0.036	<0.016	n.d.	99.87
	81	TM 272	As	98.15	0.684	0.837	0.077	0.025	0.041	0.085	<0.023	<0.006	0.012	0.009	<0.006	0.013	<0.016	n.d.	99.95
	81	TM 273	As	99.52	<0.012	n.d.	<0.038	<0.013	<0.013	0.019	<0.023	<0.006	0.268	0.022	0.010	0.091	<0.016	n.d.	99.97
	81	TM 274	As	99.63	<0.012	n.d.	<0.038	0.018	<0.013	0.017	<0.023	<0.006	0.297	0.019	0.011	0.019	<0.016	n.d.	100.03
	81	TM 275	As	99.45	<0.012	n.d.	<0.038	<0.013	<0.013	0.017	<0.023	<0.006	0.303	0.036	<0.006	0.287	<0.016	n.d.	100.14
	81	TM 276	As	99.44	<0.012	n.d.	<0.038	0.016	<0.013	<0.012	<0.023	<0.006	0.300	0.030	<0.006	0.155	<0.016	n.d.	99.98
	81	TM 277	As	99.55	<0.012	n.d.	<0.038	<0.013	<0.013	0.017	<0.023	<0.006	0.293	0.023	0.006	0.080	<0.016	n.d.	100.00
	81	TM 278	As	99.36	<0.012	n.d.	<0.038	<0.013	<0.013	0.020	<0.023	<0.006	0.274	0.020	<0.006	0.099	<0.016	n.d.	99.82
	81	TM 279	As	99.38	<0.012	n.d.	<0.038	<0.013	<0.013	0.013	<0.023	<0.006	0.306	0.028	<0.006	0.050	<0.016	n.d.	99.81
	81	TM 280	As	99.88	<0.012	n.d.	<0.038	0.015	<0.013	0.042	<0.023	<0.006	<0.007	0.011	<0.006	<0.005	<0.016	n.d.	100.01
	81	TM 281	As	99.56	<0.012	n.d.	<0.038	<0.013	<0.013	0.017	<0.023	<0.006	0.275	0.020	<0.006	0.038	<0.016	n.d.	99.96
	81	TM 282	As	99.44	<0.012	n.d.	0.103	0.043	0.041	0.099	<0.023	<0.006	0.017	0.005	0.008	0.041	<0.016	n.d.	99.81
8	82	TM 283	As	99.14	<0.012	n.d.	0.219	0.041	0.018	0.106	<0.023	<0.006	0.017	n.d.	0.009	0.094	<0.016	n.d.	99.67
undated	82	TM 284	As	99.06	<0.012	n.d.	0.187	0.065	0.014	0.056	<0.023	<0.006	0.010	n.d.	0.006	0.110	<0.016	n.d.	99.53
	82	TM 285	As	99.24	<0.012	n.d.	0.107	0.038	0.044	0.104	<0.023	<0.006	0.048	<0.005	0.007	0.102	<0.016	n.d.	99.71
	82	TM 286	As	99.18	<0.012	n.d.	0.064	0.049	0.024	0.148	<0.023	<0.006	0.010	<0.005	0.008	0.061	<0.016	n.d.	99.56
	82	TM 287	As	99.20	<0.012	n.d.	0.123	0.030	0.016	0.065	<0.023	<0.006	0.012	n.d.	0.009	0.055	<0.016	n.d.	99.53
	82	TM 288	As	99.41	<0.012	n.d.	0.114	0.032	<0.013	0.053	<0.023	<0.006	0.010	n.d.	0.006	0.042	<0.016	n.d.	99.69
	82	TM 289	As	99.23	<0.012	n.d.	0.101	0.052	0.016	0.113	<0.023	<0.006	0.010	<0.005	0.009	0.049	<0.016	n.d.	99.60
	82	TM 290	As	99.35	<0.012	n.d.	0.115	0.050	0.017	0.073	<0.023	<0.006	0.015	n.d.	0.012	0.079	<0.016	n.d.	99.73
9	83	TM 291	As	99.11	0.012	n.d.	0.106	0.058	0.044	0.147	<0.023	<0.006	0.010	n.d.	0.007	0.059	<0.016	n.d.	99.56
undated	83	TM 292	As	98.73	<0.012	n.d.	0.316	0.040	0.029	0.094	<0.023	0.007	0.013	n.d.	0.024	0.133	<0.016	n.d.	99.40
	83	TM 293	As	99.05	<0.012	n.d.	0.107	0.047	0.024	0.111	<0.023	<0.006	0.010	<0.005	0.008	0.083	<0.016	n.d.	99.45
	83	TM 294	As	99.36	<0.012	n.d.	0.097	0.031	0.021	0.066	<0.023	0.006	0.007	<0.005	0.011	0.022	<0.016	n.d.	99.63
	83	TM 295	As	99.30	<0.012	n.d.	0.094	0.041	0.019	0.078	<0.023	<0.006	0.015	<0.005	0.007	0.110	<0.016	n.d.	99.68
	83	TM 296	As	99.06	0.012	n.d.	0.104	0.050	0.025	0.126	<0.023	<0.006	0.011	n.d.	0.016	0.019	<0.016	n.d.	99.44
	83	TM 297	As	99.50	<0.012	n.d.	<0.038	0.031	0.018	0.067	<0.023	<0.006	0.015	<0.005	0.007	0.016	<0.016	n.d.	99.68
	83	TM 298	As	99.37	<0.012	n.d.	<0.038	0.048	0.032	0.115	<0.023	<0.006	0.009	<0.005	0.022	0.101	<0.016	n.d.	99.75



Asses (15/16) are characterised by EGP II except one coin (TM 226), which contains high zinc and tin levels. Lead is present in fairly high amounts (about 0.1 wt.% Pb). Nickel contents are low compared to the late Augustan coin type groups, and cobalt is below the detection limit.

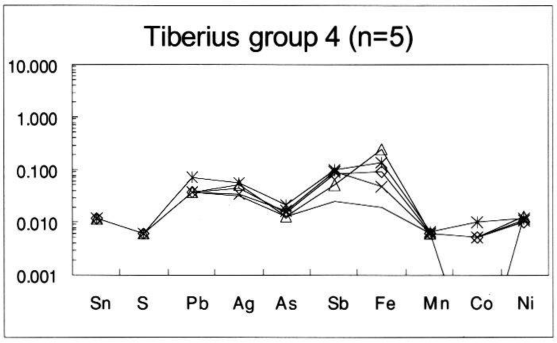


Asses (22/23) are characterised by EGP II, except for manganese that is usually below the detection limit. Typical of this group are significantly high nickel values with a small range of scatter (0.22-0.28 wt.% Ni), indeed as high as in some Augustan coins from group 2.

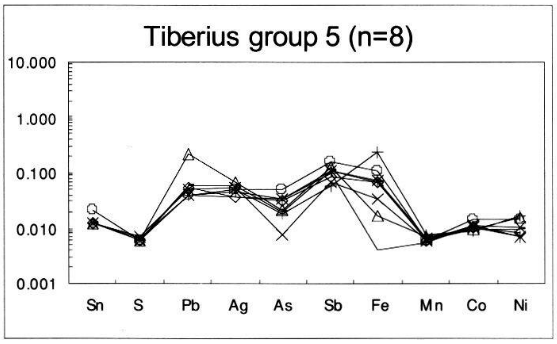


Asses (34/35) are characterised by EGP III with detectable levels of cobalt present and a high silver-nickel ratio.

Each data point represents the mean value of six analysis repetitions, aquired from six different locations of the sample. The Y-axis of diagrams is weight percent. Note the detection limits of the elements displayed in the figures of the EGP's and the data tables.

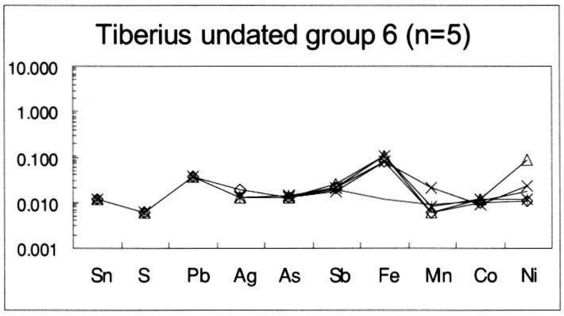


Asses (35/36) are related to group 3.

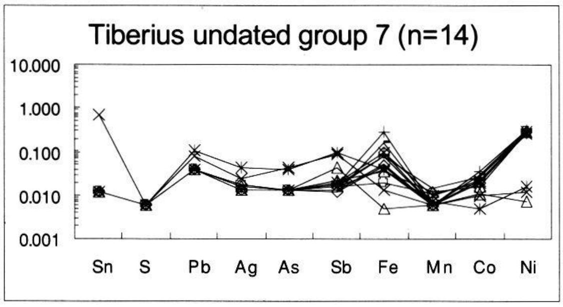


Asses (36/37) are related to groups 3 and 4.

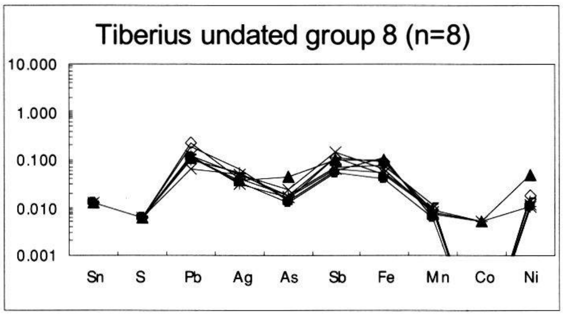
Each data point represents the mean value of six analysis repetitions, aquired from six different locations of the sample. The Y-axis of diagrams is weight percent. Note the detection limits of the elements displayed in the figures of the EGP's and the data tables.



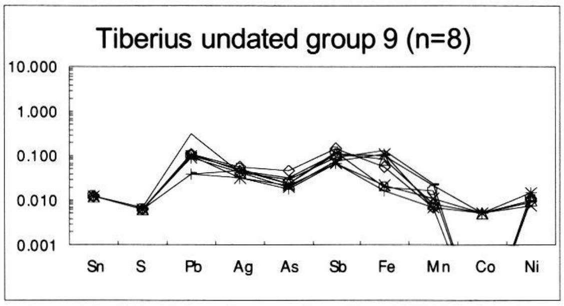
«Seated Livia» asses (undated) again correspond to EGP II, and are comparable to the early dated Tiberian *asses* (group 1). Cobalt is detectable in these *asses* (0.009-0.012 wt.% Co), whereas in early dated Tiberian *asses* cobalt is below detection limit.



Providentia asses (undated) conform to EGP II. The nickel values are significantly high (around 0.3 wt.%) and comparable to Tiberius group 2.



«Eagle on globe» asses (undated) are very homogeneous and their patterns follow EGP III (groups 3-5). Only cobalt diverges (< 0.005 wt.% Co, EGP III usually up to 0.014 wt.% Co). The increased silver:nickel ratio (3.8 Ag:Ni) is also typical of the dated Tiberian groups 3-5 (2.0-6.5 Ag:Ni).

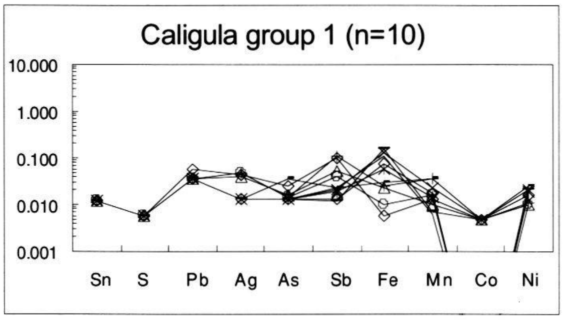


«Winged thunderbolt» asses (undated) are very homogeneous and their patterns follows EGP III (groups 3-5). Only cobalt diverges (< 0.005 wt.% Co, EGP III usually up to 0.014 wt.% Co). The increased silver:nickel ratio (3.8 Ag:Ni) is also typical of the dated Tiberian groups 3-5 (2.0-6.5 Ag:Ni).

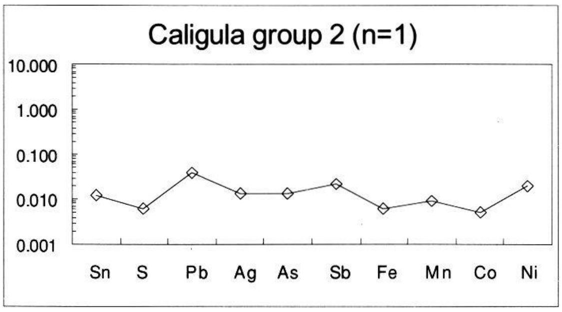
Each data point represents the mean value of six analysis repetitions, aquired from six different locations of the sample. The Y-axis of diagrams is weight percent. Note the detection limits of the elements displayed in the figures of the EGP's and the data tables.

Caligula

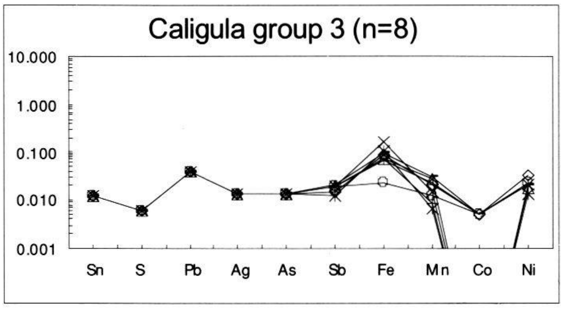
Group	RIC I[2]	Sample	Denomination	Cu	Sn	Zn	Pb	Ag	As	Sb	Bi	S	Ni	Co	Mn	Fe	Cd	Au	Total
1	35	TM 307	As	99.4	<0.012	0.098	0.057	0.043	0.025	0.099	<0.023	<0.006	0.016	<0.005	0.013	0.006	<0.016	n.d.	99.75
37/38	35	TM 308	As	99.6	<0.012	n.d.	<0.038	<0.013	<0.013	0.023	<0.023	<0.006	0.023	n.d.	0.006	0.106	<0.016	n.d.	99.82
	35	TM 309	As	99.3	<0.012	0.237	<0.038	0.039	0.015	0.054	<0.023	<0.006	0.010	<0.005	0.010	0.023	n.d.	n.d.	99.67
	35	TM 310	As	99.6	<0.012	n.d.	<0.038	<0.013	<0.013	0.021	<0.023	<0.006	0.021	<0.005	0.022	0.131	<0.016	n.d.	99.81
	38	TM 312	As	99.5	<0.012	n.d.	<0.038	<0.013	<0.013	0.018	<0.023	<0.006	0.019	n.d.	0.014	0.057	<0.016	n.d.	99.68
	38	TM 313	As	99.6	<0.012	n.d.	<0.038	0.048	0.015	0.041	<0.023	<0.006	0.010	n.d.	0.016	0.010	<0.016	n.d.	99.76
	38	TM 314	As	99.4	<0.012	n.d.	<0.038	0.049	0.014	0.115	<0.023	<0.006	0.011	<0.005	0.037	0.024	<0.016	n.d.	99.66
	38	TM 315	As	99.3	<0.012	n.d.	<0.038	<0.013	0.036	0.024	<0.023	<0.006	0.026	<0.005	0.035	0.030	<0.016	n.d.	99.48
	38	TM 316	As	99.7	<0.012	n.d.	<0.038	<0.013	<0.013	0.012	<0.023	<0.006	0.021	<0.005	0.007	0.159	<0.016	n.d.	99.96
	38	TM 317	As	99.7	<0.012	n.d.	<0.038	<0.013	<0.013	<0.012	<0.023	<0.006	0.016	n.d.	0.017	0.075	<0.016	n.d.	99.82
2	39	TM 318	Qd	99.6	<0.012	n.d.	<0.038	<0.013	<0.013	0.022	<0.023	<0.006	0.019	<0.005	0.009	0.006	<0.016	n.d.	99.74
39																			
3	43	TM 321	As	99.4	<0.012	n.d.	<0.038	<0.013	<0.013	0.015	<0.023	<0.006	0.032	<0.005	0.021	0.087	<0.016	n.d.	99.58
40	43	TM 322	As	99.6	<0.012	n.d.	<0.038	<0.013	<0.013	0.018	<0.023	<0.006	0.021	<0.005	0.023	0.064	<0.016	n.d.	99.79
	43	TM 323	As	99.5	n.d.	n.d.	<0.038	<0.013	<0.013	0.019	<0.023	<0.006	0.018	n.d.	0.029	0.073	<0.016	n.d.	99.65
	45	TM 329	Qd	99.7	<0.012	n.d.	<0.038	<0.013	<0.013	0.019	<0.023	<0.006	0.021	n.d.	0.015	0.158	<0.016	n.d.	99.92
	45	TM 330	Qd	99.8	<0.012	n.d.	<0.038	<0.013	<0.013	<0.012	<0.023	<0.006	0.013	n.d.	0.006	0.106	<0.016	n.d.	99.94
	47	TM 334	As	99.6	<0.012	n.d.	<0.038	<0.013	<0.013	0.019	<0.023	<0.006	0.022	<0.005	0.012	0.023	<0.016	n.d.	99.69
	47	TM 335	As	99.5	<0.012	n.d.	<0.038	<0.013	<0.013	0.019	<0.023	<0.006	0.021	n.d.	0.009	0.076	<0.016	n.d.	99.66
	47	TM 336	As	99.5	<0.012	n.d.	<0.038	<0.013	<0.013	0.022	<0.023	<0.006	0.021	<0.005	0.029	0.092	<0.016	n.d.	99.68
4	52	TM 346	Qd	99.4	0.015	n.d.	<0.038	<0.013	<0.013	0.018	<0.023	<0.006	0.021	n.d.	0.012.	0.337	<0.016	n.d.	99.86
40	52	TM 347	Qd	99.6	<0.012	n.d.	<0.038	<0.013	<0.013	0.021	<0.023	<0.006	0.055	n.d.	0.021	0.126	<0.016	n.d.	99.84
	52	TM 348	Qd	99.7	<0.012	n.d.	<0.038	<0.013	<0.013	0.014	<0.023	<0.006	0.020	<0.005	0.013	0.064	<0.016	n.d.	99.80
5	50	TM 340	As	99.6	<0.012	n.d.	<0.038	<0.013	<0.013	0.017	<0.023	<0.006	0.023	n.d.	0.013	0.021	<0.016	n.d.	99.73
41	50	TM 341	As	99.7	<0.012	n.d.	<0.038	<0.013	<0.013	0.021	<0.023	<0.006	0.021	<0.005	0.011	0.049	<0.016	n.d.	99.80
	50	TM 342	As	99.8	<0.012	n.d.	<0.038	<0.013	<0.013	0.017	<0.023	<0.006	0.021	<0.005	0.015	0.011	<0.016	n.d.	99.86
	50	TM 343	As	99.6	n.d.	n.d.	<0.038	<0.013	<0.013	0.019	<0.023	<0.006	0.023	n.d.	0.021	0.047	<0.016	n.d.	99.73
	54	TM 350	As	99.9	<0.012	n.d.	<0.038	<0.013	<0.013	0.018	<0.023	<0.006	0.048	n.d.	0.013	0.025	<0.016	n.d.	100.03
	54	TM 351	As	99.7	<0.012	n.d.	<0.038	<0.013	<0.013	0.024	<0.023	<0.006	0.016	<0.005	0.011	0.050	<0.016	n.d.	99.87
	/ 41	TM 367	Qd	99.8	<0.012	n.d.	<0.038	<0.013	<0.013	0.016	<0.023	<0.006	0.035	n.d.	0.008	0.035	<0.016	n.d.	99.89
6	58	TM 368	As	99.7	<0.012	n.d.	<0.038	<0.013	<0.013	0.018	<0.023	<0.006	0.013	<0.005	0.010	0.035	<0.016	n.d.	99.80
ındated	58	TM 369	As	99.6	<0.012	n.d.	<0.038	<0.013	<0.013	0.016	<0.023	<0.006	0.018	<0.005	0.022	0.078	<0.016	n.d.	99.80
	58	TM 370	As	99.4	<0.012	n.d.	<0.038	<0.013	<0.013	0.016	<0.023	<0.006	0.009	<0.005	0.015	0.160	<0.016	n.d.	99.63
	58	TM 371	As	99.5	<0.012	n.d.	<0.038	<0.013	<0.013	0.017	<0.023	<0.006	0.012	<0.005	0.013	0.087	<0.016	n.d.	99.73
	58	TM 372	As	99.8	<0.012	n.d.	<0.038	<0.013	<0.013	0.020	<0.023	<0.006	0.016	<0.005	0.007	0.190	<0.016	n.d.	100.03
	58	TM 373	As	99.4	<0.012	n.d.	<0.038	<0.013	<0.013	0.022	<0.023	<0.006	0.024	<0.005	0.014	0.229	<0.016	n.d.	99.75
	58	TM 374	As	99.7	<0.012	n.d.	<0.038	<0.013	<0.013	0.021	<0.023	<0.006	0.019	<0.005	0.011	0.054	<0.016	n.d.	99.88
	58	TM 375 (Imit.)	As	99.3	<0.012	n.d.	<0.038	0.038	0.020	0.150	<0.023	<0.006	0.015	<0.005	<0.006	<0.005	<0.016	n.d.	99.55
	58	TM 376	As	99.4	<0.012	n.d.	<0.038	<0.013	<0.013	0.020	<0.023	<0.006	0.029	<0.005	0.007	0.062	<0.016	n.d.	99.56
	58	TM 377	As	99.9	<0.012	n.d.	<0.038	<0.013	<0.013	0.025	<0.023	<0.006	0.022	<0.005	0.008	0.046	<0.016	n.d.	100.06
	58	TM 378	As	99.9	<0.012	n.d.	<0.038	<0.013	<0.013	0.022	<0.023	<0.006	0.017	n.d.	0.019	0.074	<0.016	n.d.	100.02
	58	TM 379	As	99.7	<0.012	n.d.	<0.038	<0.013	<0.013	0.018	<0.023	<0.006	0.013	<0.005	0.007	0.036	<0.016	n.d.	99.81
	58	TM 380	As	99.9	<0.012	n.d.	<0.038	<0.013	<0.013	0.023	<0.023	<0.006	0.023	<0.005	0.008	0.031	<0.016	n.d.	100.02



Asses (37/38) are partly characterised by EGP IV. TM 313; 314; 315 (all RIC I[2] 38) have higher levels of silver, arsenic and antimony. Four *asses* struck for Germanicus (all RIC I[2] 35) were analysed with group 1. Two of them (TM 308; 310) are characterised by EGP IV, two others (TM 307; 309) have different compositions (high zinc content [> 0.1 wt.%], silver, arsenic and antimony above detection limits). One coin (TM 309), which is remarkable in having a small flan, has an unusually high zinc value (0.23 wt.%) and a high lead value. All other elements are characterised by EGP IV.

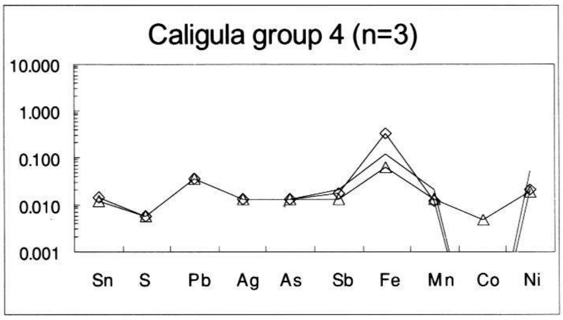


Quadrans (39). Only one coin was analysed. It is characterised by EGP IV. The iron content is lower than that of manganese. This single coin analysis provides no further information for the general discussion of Caligulan coins.

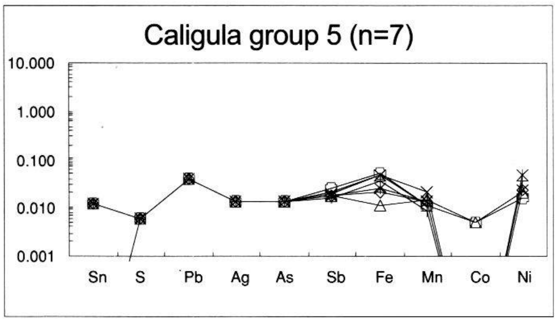


Asses and *quadrantes* (40) are characterised by EGP IV.

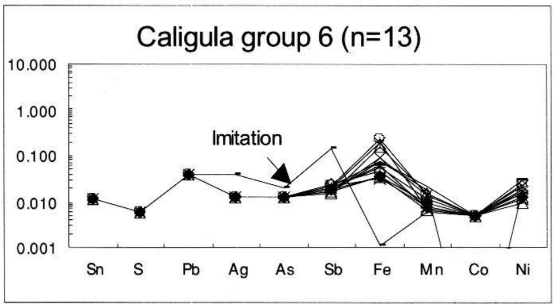
Each data point represents the mean value of six analysis repetitions, aquired from six different locations of the sample. The Y-axis of diagrams is weight percent. Note the detection limits of the elements displayed in the figures of the EGP's and the data tables.



Quadrantes (March-December 40) are characterised by EGP IV. One of the three coins analysed (TM 346) has a detectable level of tin (0.015 wt.%), though this value is still close to the detection limit.



Asses and *quadrans* (January 41) are characterised by EGP IV.

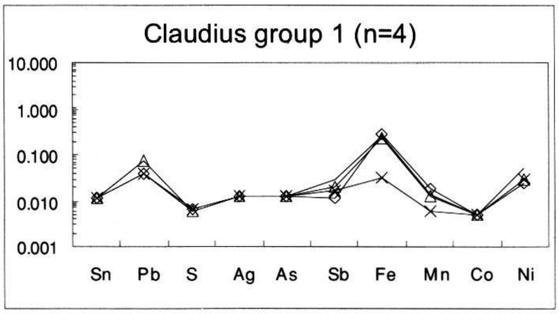


Asses of Agrippa, form a very homogeneous group and fit EGP IV perfectly: tin, sulphur, lead, silver, antimony and cobalt are all below detection limits. Antimony and nickel values correspond to those found in the dated issues of Caligula. One imitation (TM 375) was analysed, which is rich in silver, arsenic, and antimony. Iron, manganese, and cobalt are detectable, but below detection limits. The value for nickel is as low as in the Caligulan copper coins analysed (0.009-0.029 wt.% Ni, Caligulan dated coins: 0.010-0.048 wt.%).

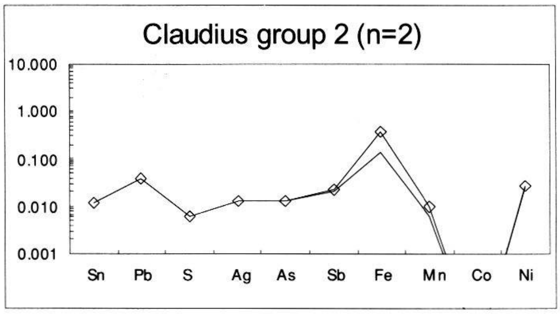
Each data point represents the mean value of six analysis repetitions, aquired from six different locations of the sample. The Y-axis of diagrams is weight percent. Note the detection limits of the elements displayed in the figures of the EGP's and the data tables.

Claudius

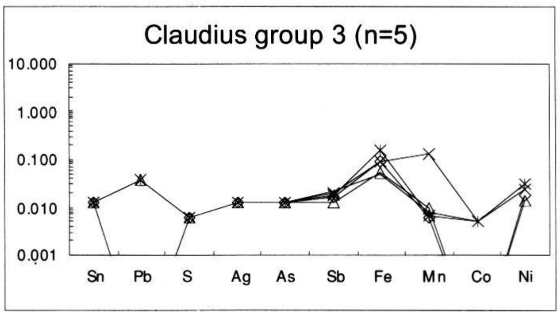
Group	RIC I[2]	Sample	Denomination	Cu	Sn	Zn	Pb	Ag	As	Sb	Bi	S	Ni	Co	Mn	Fe	Cd	Au	Total
1	84	TM 453	Qd	99.0	<0.012	n.d.	<0.038	<0.013	<0.013	0.012	<0.023	0.006	0.025	<0.005	0.019	0.287	n.d.	n.d.	99.40
41	84	TM 454	Qd	99.0	<0.012	n.d.	<0.038	<0.013	<0.013	0.030	<0.023	0.006	0.051	<0.005	0.014	0.249	<0.016	n.d.	99.41
	85	TM 455	Qd	99.1	<0.012	n.d.	0.073	<0.013	<0.013	0.020	<0.023	<0.006	0.029	<0.005	0.012	0.242	<0.016	n.d.	99.53
	85	TM 456	Qd	99.3	<0.012	n.d.	<0.038	<0.013	<0.013	0.017	<0.023	0.006	0.030	<0.005	0.006	0.032	<0.016	n.d.	99.41
2	88	TM 457	Qd	99.5	<0.012	n.d.	<0.038	<0.013	<0.013	0.022	<0.023	<0.006	0.028	n.d.	0.010	0.385	<0.016	n.d.	*100.00
42	89	TM 458	Qd	99.3	<0.012	n.d.	<0.038	<0.013	<0.013	0.020	<0.023	<0.006	0.023	n.d.	0.006	0.135	n.d.	n.d.	99.53
3	90	TM 513	Qd	99.4	<0.012	n.d.	n.d.	<0.013	<0.013	0.016	<0.023	<0.006	0.017	n.d.	<0.006	0.094	<0.016	n.d.	99.56
42	90	TM 514	Qd	99.4	<0.012	n.d.	n.d.	<0.013	<0.013	0.022	<0.023	<0.006	0.024	<0.005	0.008	0.049	<0.016	n.d.	99.55
	90	TM 515	Qd	99.2	<0.012	n.d.	<0.038	<0.013	<0.013	<0.012	<0.023	0.006	0.014	n.d.	0.009	0.054	<0.016	n.d.	99.32
	91	TM 516	Qd	99.1	<0.012	n.d.	<0.038	<0.013	<0.013	0.019	<0.023	0.006	0.024	<0.005	0.134	0.091	<0.016	n.d.	99.42
	91	TM 517	Qd	99.3	<0.012	n.d.	<0.038	<0.013	<0.013	0.017	<0.023	<0.006	0.031	<0.005	0.007	0.157	<0.016	n.d.	99.51
4	95	TM 445	As	99.4	<0.012	n.d.	<0.038	<0.013	<0.013	0.019	<0.023	0.006	0.023	<0.005	0.010	0.055	<0.016	n.d.	99.58
41/42	95	TM 446	As	99.5	n.d.	n.d.	<0.038	<0.013	<0.013	0.015	<0.023	0.006	0.038	n.d.	0.013	0.079	<0.016	n.d.	99.65
	95	TM 447 (Imit.)	As	99.5	<0.012	n.d.	<0.038	0.033	0.014	0.043	<0.023	0.006	0.010	<0.005	0.007	0.013	<0.016	n.d.	99.61
	95	TM 448 (Imit.)	As	99.3	<0.012	n.d.	<0.038	0.034	0.027	0.085	<0.023	<0.006	0.011	<0.005	0.006	0.105	<0.016	n.d.	99.59
	97	TM 449	As	99.4	n.d.	n.d.	<0.038	<0.013	<0.013	0.012	<0.023	<0.006	0.036	<0.005	0.011	0.105	<0.016	n.d.	99.59
	97	TM 450	As	99.3	<0.012	n.d.	<0.038	<0.013	<0.013	0.021	<0.023	0.006	0.030	<0.005	0.008	0.071	<0.016	n.d.	99.49
	97	TM 451	As	99.4	<0.012	n.d.	<0.038	<0.013	<0.013	0.021	<0.023	0.006	0.034	<0.005	0.008	0.034	<0.016	<0.052	99.55
	97	TM 452 (Imit.)	As	99.1	<0.012	n.d.	0.058	0.023	0.040	0.085	<0.023	<0.006	0.013	<0.005	0.006	0.124	<0.016	n.d.	99.43
	100	TM 437	As	99.5	<0.012	n.d.	<0.038	<0.013	<0.013	0.017	<0.023	<0.006	0.019	<0.005	0.009	0.154	<0.016	n.d.	99.72
	100	TM 438	As	99.5	<0.012	n.d.	<0.038	<0.013	<0.013	0.017	<0.023	<0.006	0.029	n.d.	0.009	0.090	<0.016	n.d.	99.72
	100	TM 439	As	99.4	<0.012	n.d.	<0.038	<0.013	<0.013	0.019	<0.023	<0.006	0.028	<0.005	0.010	0.066	<0.016	n.d.	99.54
	100	TM 440	As	99.5	<0.012	n.d.	<0.038	<0.013	<0.013	0.013	<0.023	0.006	0.031	n.d.	0.006	0.070	<0.016	n.d.	99.61
	100	TM 441	As	99.5	<0.012	n.d.	<0.038	<0.013	<0.013	0.019	<0.023	<0.006	0.029	<0.005	0.014	0.136	<0.016	n.d.	99.72
	100	TM 442 (Imit.)	As	99.3	<0.012	n.d.	<0.038	0.046	0.017	0.061	<0.023	<0.006	0.012	n.d.	0.007	0.029	<0.016	n.d.	99.49
	100	TM 443 (Imit.)	As	99.4	0.015	0.129	<0.038	0.026	0.022	0.055	<0.023	<0.006	0.015	<0.005	0.016	0.008	<0.016	n.d.	99.75
	100	TM 444 (Imit.)	As	98.9	<0.012	0.269	0.084	<0.013	0.014	0.033	<0.023	<0.006	0.015	n.d.	0.075	0.008	<0.016	n.d.	99.41
5	111	TM 498	As	99.3	<0.012	n.d.	0.115	<0.013	<0.013	0.017	<0.023	<0.006	0.016	<0.005	0.009	0.045	<0.016	n.d.	99.50
42	111	TM 499	As	98.8	0.055	0.027	0.180	<0.013	<0.013	0.019	<0.023	<0.006	0.021	<0.005	0.011	0.308	<0.016	n.d.	99.45
	111	TM 500	As	99.3	0.012	0.099	<0.038	0.031	0.081	0.083	<0.023	<0.006	0.015	<0.005	0.014	0.015	<0.016	n.d.	99.65
	113	TM 501	As	99.7	<0.012	n.d.	n.d.	<0.013	0.013	0.017	<0.023	0.006	0.036	n.d.	0.008	0.057	<0.016	n.d.	99.87
	113	TM 502	As	99.1	<0.012	n.d.	<0.038	<0.013	<0.013	0.022	<0.023	<0.006	0.017	n.d.	0.011	0.205	<0.016	n.d.	99.40
	113	TM 503	As	99.5	<0.012	n.d.	<0.038	<0.013	<0.013	0.017	<0.023	0.006	0.018	<0.005	0.037	0.037	<0.016	n.d.	99.68
	113	TM 504	As	99.2	<0.012	n.d.	<0.038	<0.013	<0.013	0.013	<0.023	<0.006	0.021	<0.005	0.015	0.140	<0.016	n.d.	99.43
	113	TM 505	As	99.3	<0.012	n.d.	<0.038	<0.013	<0.013	0.016	<0.023	<0.006	0.015	<0.005	0.009	0.133	<0.016	n.d.	99.53
	113	TM 506	As	99.1	n.d.	n.d.	n.d.	<0.013	<0.013	0.022	<0.023	<0.006	0.019	<0.005	0.006	0.279	<0.016	n.d.	99.50
	116	TM 493	As	99.5	<0.012	n.d.	<0.038	<0.013	<0.013	0.014	<0.023	<0.006	0.029	<0.005	0.013	0.030	<0.016	n.d.	99.62
	116	TM 494	As	99.4	<0.012	n.d.	<0.038	<0.013	<0.013	0.018	<0.023	<0.006	0.020	<0.005	0.010	0.030	<0.016	n.d.	99.52
	116	TM 495	As	99.3	<0.012	n.d.	<0.038	<0.013	<0.013	0.017	<0.023	<0.006	0.022	<0.005	0.011	0.140	<0.016	n.d.	99.60
	116	TM 496	As	99.4	<0.012	n.d.	0.121	<0.013	<0.013	0.015	<0.023	<0.006	0.026	n.d.	0.010	0.091	<0.016	n.d.	99.71
	116	TM 497	As	98.9	0.016	0.124	0.142	0.026	0.085	0.077	<0.023	<0.006	0.017	<0.005	0.015	0.005	<0.016	n.d.	99.44
6	106	TM 507	As	99.1	<0.012	n.d.	<0.038	<0.013	<0.013	0.030	<0.023	<0.006	0.020	<0.005	0.008	0.089	<0.016	n.d.	99.33
42	106	TM 508	As	99.1	<0.012	n.d.	<0.038	<0.013	<0.013	0.032	<0.023	0.006	0.019	<0.005	0.013	0.086	<0.016	n.d.	99.28
	106	TM 509	As	99.2	<0.012	n.d.	<0.038	<0.013	<0.013	0.022	<0.023	0.008	0.019	<0.005	0.011	0.087	<0.016	n.d.	99.33
	106	TM 510	As	99.1	<0.012	n.d.	<0.038	<0.013	<0.013	0.023	<0.023	<0.006	0.023	<0.005	0.007	0.067	<0.016	n.d.	99.27
	106	TM 511	As	99.0	<0.012	n.d.	<0.038	<0.013	<0.013	0.024	<0.023	<0.006	0.014	n.d.	0.023	0.098	<0.016	n.d.	99.18
	106	TM 512	As	99.2	<0.012	<0.015	<0.038	0.045	0.016	0.066	<0.023	<0.006	0.015	<0.005	0.008	0.037	<0.016	n.d.	99.40



Quadrantes (41) are characterised by EGP IV. One coin (TM 455) contains lead above the detection limit.

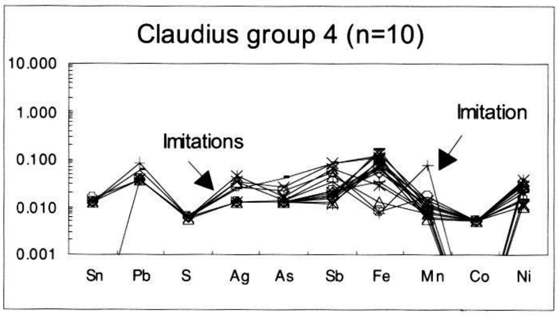


Quadrantes (January 42) are homogeneous and characterised by EGP IV.

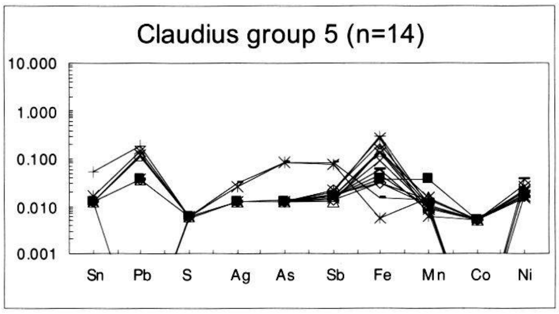


Quadrantes (struck after 25 January 42) are characterised by EGP IV. One coin (TM 516) is remarkable for having more manganese than iron.

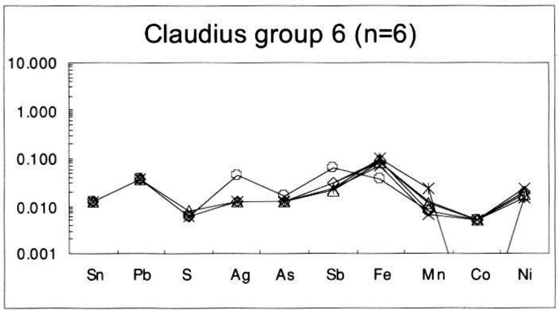
Each data point represents the mean value of six analysis repetitions, aquired from six different locations of the sample. The Y-axis of diagrams is weight percent. Note the detection limits of the elements displayed in the figures of the EGP's and the data tables.



Asses (41/42). The regular pieces are characterised by EGP IV. The imitations differ in chemical composition: four of the six imitations analysed (TM 442; 447; 448; 452) correspond best in chemical composition to late Tiberian coins of 34/37 (element pattern and increased silver:nickel ratios; 1.7-4.0 Ag:Ni). The composition of the two other imitation coins (TM 443; 444) are different, with significant levels of zinc (0.13, 0.27 wt.% Zn). In addition, the Mn:Fe ratio is high (Mn:Fe = 2.0, 10.0; usually Mn:Fe = <1).



Asses (42) are chemically heterogeneous. Most of the coins are characterised by EGP IV, some having increased lead contents. Three coins differ from the others in having detectable amounts of zinc (TM 497; 499; 500).



Asses, Germanicus (42) are a quite homogeneous group characterised by EGP IV. One exception is coin TM 512, which has a similar quantitative composition (silver:nickel ratio: 3.0) to late Tiberian *asses* of 34/37 (silver:nickel ratio: 2.0-6.5).

Each data point represents the mean value of six analysis repetitions, aquired from six different locations of the sample. The Y-axis of diagrams is weight percent. Note the detection limits of the elements displayed in the figures of the EGP's and the data tables.

Augustus
TM 31 (24726/97);
TM 32 (24726/98);
TM 33 (24727/101);
TM 34 (24727/109);
TM 35 (24727/114);
TM 36 (24728/118);
TM 37 (24728/122);
TM 38 (24728/157);
TM 39 (24728/159);
TM 40 (24754/915);
TM 41 (24754/917);
TM 42 (24755/918);
TM 43 (24755/921);
TM 55 (24764/961);
TM 56 (24764/962);
TM 57 (24764/964);
TM 58 (24764/970);
TM 59 (24765/985);
TM 60 (24766/987);
TM 61 (24767/988);
TM 69 (24772/1010);
TM 70 (24773/1023);
TM 71 (24773/1025);
TM 72 (24773/1027);
TM 74 (24774/1033);
TM 75 (24775/1035);
TM 76 (24776/1037);
TM 84 (24781/1062);
TM 85 (24782/1063);
TM 86 (24782/1065);
TM 89 (24783/1084);
TM 90 (24784/1089);
TM 91 (24784/1091);
TM 92 (24785/1096);
TM 105 (24793/1152);
TM 106 (24794/1158);
TM 107 (24794/1160);
TM 108 (24795/1201);
TM 109 (24796/1205);
TM 110 (24796/1212);
TM 114 (24800/1219);
TM 115 (24801/1220);
TM 119 (24804/1237);
TM 120 (24804/1241);
TM 121 (24804/1252);
TM 122 (24804/1255);
TM 123 (24805/1271);
TM 124 (24806/1272);
TM 125 (24806/1276);
TM 126 (24806/1277);
TM 133 (24810/1313);
TM 134 (24810/1330);
TM 135 (24810/1331);
TM 136 (24810/1340);
TM 144 (24820/1368);
TM 145 (24821/1380);
TM 146 (24821/1384);
TM 147 (24821/1388);
TM 148 (24823/1419);
TM 149 (24823/1428);
TM 151 (24825/1436);
TM 156 (24833/1450);
TM 157 (24834/1455);
TM 158 (24837/1459);
TM 159 (24838/1463);
TM 160 (24839/1466);
TM 166 (24856/1499);
TM 167 (24856/1505);
TM 168 (24857/1528);
TM 169 (24857/1530);
TM 170 (24857/1550);
TM 173 (24860/1564);
TM 174 (24861/1565);
TM 177 (24864/1576);
TM 180 (24950/2182);
TM 181 (24950/2186);
TM 182 (24950/2187);
TM 183 (24950/2189);
TM 184 (24952/2220);
TM 185 (24952/2223).

Tiberius
TM 226 (24929/2010);
TM 227 (24930/2011);
TM 228 (24933/2029);
TM 229 (24933/2028);
TM 230 (24932/2024);
TM 231 (24930/2013);
TM 232 (24986/2261);
TM 233 (24932/2025);
TM 234 (24983/2258);
TM 235 (24946/2196);
TM 236 (24946/2135);
TM 237 (24946/2130);
TM 238 (24945/2112);
TM 239 (24948/2175);
TM 240 (25011/2299);
TM 241 (25013/2326);
TM 242 (25023/2330);
TM 243 (25012/2312);
TM 244 (25013/2333);
TM 245 (24936/2049);
TM 246 (24923/1953);
TM 247 (24924/1955);
TM 248 (24924/1957);
TM 249 (24936/2046);
TM 250 (24939/2063);
TM 252 (24939/2062);
TM 253 (24934/2036);
TM 254 (24928/2000);
TM 255 (24928/2007);
TM 256 (24979/2254);
TM 257 (25004/2284);
TM 258 (s.n./2237);
TM 259 (24943/2091);
TM 260 (24941/2070);
TM 261 (24991/2266);
TM 262 (24943/2094);
TM 263 (24998/2274);
TM 264 (24735/616);
TM 265 (24735/611);
TM 266 (24735/613);
TM 267 (24736/642);
TM 268 (24736/673);
TM 269 (24730/200);
TM 270 (24730/205);
TM 271 (24729/171);
TM 272 (24730/294);
TM 273 (24730/262);
TM 274 (24730/277);
TM 275 (24730/282);
TM 276 (24729/183);
TM 277 (24729/164);
TM 278 (24731/412);
TM 279 (24731/428);
TM 280 (24731/587);
TM 281 (24731/569);
TM 282 (24731/507);
TM 283 (24737/682);
TM 284 (24738/706);
TM 285 (24738/708);
TM 286 (24737/687);
TM 287 (24738/695);
TM 288 (24739/724);
TM 289 (24739/774);
TM 290 (24737/688);
TM 291 (24740/783);
TM 292 (24742/834);
TM 293 (24741/799);
TM 294 (24741/805);
TM 295 (24740/786);
TM 296 (24740/787);
TM 297 (24742/839);
TM 298 (24740/784);

Caligula
TM 307 (K 76; 25029/2419);
TM 308 (K 79; 25029/2422);
TM 309 (K 84; 25030/2427);
TM 310 (K 104; 25031/2447);
TM 312 (K 16; 25078/2647);
TM 313 (K 18; 25079/2649);
TM 314 (K 22; 25079/2653);
TM 315 (K 31; 25080/2662);
TM 316 (K 65; 25080/2696);
TM 317 (K 71; 25081/2702);
TM 318 (K 133; 25065/2605);
TM 321 (K123; 25034/2452);
TM 322 (K 127; 25038/2478);
TM 323 (K 129; 25038/2480);
TM 329 (K136; 25066/2608);
TM 330 (K 138; 25066/2611);
TM 334 (K 116; 25082/2708);
TM 335 (K120; 25082/2712);
TM 336 (K 122; 25084/2724);
TM 340 (K 159; 25033/2449);
TM 341 (K 165; 25034/2457);
TM 342 (K 172; 25035/2465);
TM 343 (K 178; 25036/2474);
TM 346 (K181; 25068/2615);
TM 347 (K 185; 25068/2619);
TM 348 (K 191; 25069/2625);
TM 350 (K156; 25084/2722);
TM 351 (K 158; 25085/2726);
TM 367 (K 197; 25068/2622);
TM 368 (K 251; 24915/1656);
TM 369 (K 252; 24915/1657);
TM 370 (K 253; 24915/1658);
TM 371 (K 257; 24915/1662);
TM 372 (K 269; 24916/1674);
TM 373 (K 335; 24916/1735);
TM 374 (K 337; 24917/1742);
TM 375 (K 356; 24917/1761);
TM 376 (K 385; 24918/1790);
TM 377 (K 388; 24918/1793);
TM 378 (K 413; 24918/1818);
TM 379 (K 435; 24918/1840);
TM 380 (K 518; 24918/1923).

Claudius
TM 437 (vk 106; 25130/3200);
TM 438 (vk 107; 25131/3201);
TM 439 (vk 117; 25129/3188);
TM 440 (vk 126; 25129/3185);
TM 441 (vk 151; 25131/3220);
TM 442 (vk 189; 25135/3310);
TM 443 (vk 191; 25134/3288);
TM 444 (vk 193; 25138/3385);
TM 445 (vk 203; 25094/2762);
TM 446 (vk 226; 25096/2797);
TM 447 (vk 230; 25096/2790);
TM 448 (vk 232; 25096/2800);
TM 449 (vk 247; 25108/2970);
TM 450 (vk 251; 25108/2984);
TM 451 (vk 280; 25105/2912);
TM 452 (vk 307; 25114/3096);
TM 453 (vK 310; 25121/3116);
TM 454 (vK 325; 25122/3132);
TM 455 (vK 331; 25123/3137);
TM 456 (vK 334; 25124/3142);
TM 457 (vK 344; 25126/3162);
TM 458 (vK 345; 25128/3182);
TM 493 (vk 431; 25129/3187);
TM 494 (vk 438; 25130/3197);
TM 495 (vk 508; 25131/3219);
TM 496 (vk 518; 25135/3303);
TM 497 (vk 560; 25136/3336);
TM 498 (vk 573; 25095/2772);
TM 499 (vk 594; 25094/2758);
TM 500 (vk 628; 25096/2814);
TM 501 (vk 648; 25108/2988);
TM 502 (vk 652; 25105/2917);
TM 503 (vk 717; 25205/2920);
TM 504 (vk 751; 25103; 2881);
TM 505 (vk 762; 25109/2998);
TM 506 (vk 806; 25114/3101);
TM 507 (vk 817; 25042/2494);
TM 508 (vk 819; 25042/2489);
TM 509 (vk 841; 25044/2528);
TM 510 (vk 852; 25044/2525);
TM 511 (vk 861; 25044/2529);
TM 512 (vk 872; 25044/2551);
TM 513 (vK 884; 25125/3149);
TM 514 (vK 885; 25125/3150);
TM 515 (vK 892; 25125/3160);
TM 516 (vK 912; 25127/3178);
TM 517 (vK 913; 25128/3179).