Traces of Copper
The origin of copper and the approximate chemical compositions of some 1,500 Dutch coins and medals

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Samenvatting – *Van bijna 10.000 munten en penningen in de collectie van Teylers Museum is de samenstelling bepaald. In dit artikel worden 1.080 exemplaren met meer dan 95% koper en 355 stuks met een lagere kopersamenstelling uit de periode 1460-1800 bestudeerd en gecombineerd met historische gegevens rond de winning van koper. Doel van het onderzoek is zowel om de mogelijkheden en beperkingen van niet-destructief onderzoek naar elementaire samenstelling te verkennen als om meer grip te krijgen op de herkomst van het muntmetaal. Er zijn ruwweg drie aanvoergebieden onderscheiden. Rond 1630 wordt de centraal-Europese koperwinning overvleugeld door Zweden, waarna Engeland het stokje rond 1750 overneemt. Eerste winpunt van het onderzoek is de veel nauwkeurigere vaststelling van de elementaire samenstelling. Zo blijken veel als 'brons' beschreven voorwerpen van messing te zijn. De spoorelementen blijken soms indicaties te geven van de herkomst van het metaal, wat een aanmoediging is voor toekomstig onderzoek, bijvoorbeeld naar loodisotopen. Ook blijken er verschillen te bestaan tussen de spoorelementen bij munten en penningen.*

Summary – *The elemental composition of almost 10,000 coins and medals in the collection of Teylers Museum has been determined. This article studies the 1,080 specimens with more than 95% copper and 355 specimens with a lower copper composition from the 1460-1800 period and combines them with historical data on copper mining. The aim of the research is to explore the possibilities and limitations of non-destructive metal composition measurements as well as to gain a better understanding of the origin of the mint metal. Roughly three supply areas have been distinguished. Around 1630, central European copper mining was eclipsed by Sweden, after which England took over around 1750. The first benefit of the research is the much more accurate determination of the metal composition. For example, many objects described as 'bronze' appear to be made of brass. The trace elements sometimes appear to provide indications of the origin of the metal, which encourages future research, for example into lead isotopes. There also appear to be differences between the trace elements in coins and medals.*

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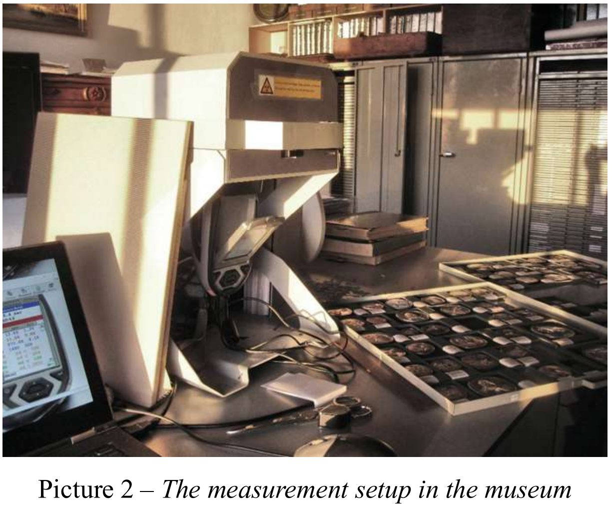
Picture 1 – R.M.D., *Various horizontal and vertical mine shafts in the Ore Mountains around Schemnitz*. 1621, woodprint (source: Agricolae, inv. 139i 1).[1]

If one looks superficially at coins and medals, the main focus lies on the obverse and reverse. These objects are therefore regularly referred to as 'flat' or two-dimensional. The rim is often overlooked, certainly by the uninitiated. Still, a rim can provide interesting information – such as counter marks – and its presence proves the third dimension, or the thickness of an object. However, that is not the end of the matter. Just think of what is hidden within the visible space: the 'fourth dimension'. Although there is no real fourth dimension here – the existence of which can only be argued and not proven – the interior of coins and medals is surrounded by many question marks.

1 Agricolae, 1621: 72.

This research takes the reader into the hidden depths, through research of the elemental composition of the copper coins and medals (including counter tokens) in the collection of Teylers Museum, Haarlem, the Netherlands. Unless otherwise indicated, the images are also provided by this museum. The research focuses in particular on the period 1460-1800 and on specimens produced in the Northern Netherlands, sometimes referred to as the Republic of the Seven United Netherlands or simply the Dutch Republic. What is the origin of the used copper and what kind of new information does a mutual comparison of the elemental composition provide on their production? This article highlights the potential and limitations of using XRF analysis on coins and medals to research the possibility of enhancing historical knowledge.

This essay is divided in four parts. First is in section 1 focused on the outlines of the research and the used measuring technique (including its advantages and disadvantages). Also an explanation is given of the selection of objects in groups of copper, bronze and brass coins and medals. In separate sub-sections also plated, polluted and alloyed objects are researched, as well as some foreign coins and medals. In section 2 this extended introduction is followed by the results of the collected data. Third, the historical background of copper, including ore veins, transportation and copper mills is given in section 3. In the fourth part of the essay, section 4, the data of the measurements is interpreted with a focus on changes over time and the differences in recorded metals. Coins and medals are compared to each other and to the historical data, after which conclusions are drawn. Finally, in a conclusion in section 5, the usefulness of the research is discussed. The conclusion is followed by a series of appendices that provide the (rounded) measurement data of the coins and medals in order to make them accessible for future research. The measurement data is also stored permanently in the object records in the collection database.



Picture 2 – *The measurement setup in the museum*

1 APPROACH

1.1 Outlines

The measurements were performed on the Teylers Museum collection (Picture 2). Together with the medals, the sub-collections of coins from West Friesland and Guelders (Gelderland) are exceptional in the degree of completeness. These objects are representing medal and coin production in the Dutch Republic very well. The size of the production could relate to the amount of copper that was transported to the Dutch Republic, but since the numbers per annum are not always known and this subject is less relevant for this study, this topic is not researched. Teylers Museum was founded in 1778 and is the oldest museum in the Netherlands. It has a broad collection of instruments, fossils, minerals, paintings, drawings and numismatics. Some 2,000 of the almost 18,000 coins and medals were collected by the museum's founder, Pieter Teyler van der Hulst (1702-1778). All objects are registered in the museum's collection database. This database is intended to record the elementary data of the objects. It appeared that some of this data was outdated (many descriptions were made in the nineteenth century) and subject to advancing insight. In this section, groups of objects have been formed, divided into coins and medals, and into sub-divisions of plated, polluted, hardened and foreign production. But first and for all, the used measuring technique is explained in detail.

This research examines, among other things, whether the trace elements measured with X-ray fluorescence (XRF) spectrometer (see further explanation below under the heading *Method*) are sufficient to designate different mining areas and thus to trace where the metal of the coins and medals comes from.[2] It is known that XRF-measurements are better suited for determining the proportions between gold, silver and copper in an object than for identifying ore veins.[3] The validity of a single measurement at one object is of course limited; it is well possible that it is not revealing enough. It should maybe not even be taken into account, because of the slightly different metal compositions on several locations on the surface of an object (not to talk about different chemical compositions hidden under the exterior), but in this case the power of a mass of measurement data has to be taken into account as well. So, an attempt is made, because never before has such a large number of coins and medals – almost 10,000 pieces – been subjected to a non-destructive research on elemental composition.

A better way to determine the origin of ore is with the help of lead isotopes.[4] In that case, surface XRF analysis is useful for the selection of good candidates for sampling, along with other considerations. A better understanding of the com-

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2 Shugar, 2013: 176; Shackley, 2011: 8-10.

3 Blet-Lemarquand, Gratuze & Barrandon, 2014: 128 & 142.

4 Van Os *et al.*, 2020: 206; Oxalid-database https://oxalid.arch.ox.ac.uk/ (consultation 22 July 2021); Skowronek *et al.*, 2021: 6; Pernicka, 2014: 248; Stos-Gale & Gale, 2009.

position of objects is very valuable, but at the same time this type of research changes the objects (for example, it leaves a tiny hole) and should therefore not be carried out without reservations on objects which are part of a museum collection.[5] In addition, research into the provenance of copper based on lead isotopes is made more difficult because during the refining processes of the past, lead (from other mines) was added to extract silver.[6] Because lead is insoluble in copper, it can vary slightly throughout the object and more than one measurement per object would be preferable.

1.2 XRF

The historical background of copper mining, outlined in section 3, can be related to the collection-wide study of the elemental composition of copper coins and medals, which was carried out for the Teylers Museum objects. All objects were measured with a portable X-ray fluorescence (XRF) spectrometer of the Niton XL3t GOLDD+ type, owned by the Cultural Heritage Agency of The Netherlands. The measurements were performed under the same conditions in the same location, on objects of excellent quality (which means without a layer of corrosion visible to the naked eye). But even in this case, the elemental composition of the surface does not necessarily reflect the composition of the core.[7] Other research has shown that data collected by XRF can be misleading, especially with corroded or treated surfaces.[8] On the other hand, if research would only focus on the chemical composition of the core, the – also interesting – composition of the surface would be neglected; both measurements have additional value.[9] In how far can the museum's collection, with pristine objects, be regarded as 'without corrosion'? After all, the surface of objects can be influenced by – for instance – handling, they can have a natural layer of patination or they were cleaned in the past, using chemicals.[10]

Using the XRF spectrometer, a large amount of data could be collected quickly (30 seconds per measurement) without damaging the objects. Thanks to the measurements performed, the elemental composition was determined more accurately than with 'on sight' registration. The measurements created a means of control with which the required production levels – insofar as they exist – can be checked. The XRF measurements offer the possibility to find anomalous objects, such as counterfeits or coins with other impurities from mint masters who were cheating the system. The measurements were executed in the measu-

5 Orfanou & Rehren, 2015: 387; Pernicka, 2014: 245.

6 Skowronek *et al.*, 2021: 11; Pernicka, 2014: 255-256, 259; Warnke, 1980: 433; Craddock, 1995: 232.

7 Cohen *et al.*, 2022: 3628-2629; Van Ham-Meert *et al.*, 2020: 5; Shugar, 2013: 182-183.

8 Orfanou & Rehren, 2015: 391, 395-396; Pernicka, 2014: 245; Fernandes *et al.*, 2013: 5.

9 Bolewski *et al.*, 2020: 6.

10 Gore & Davies, 2016: 840-841, 847-848.

rement mode for electronics and metals and have an error of 0.05%. The XRF is calibrated for metals by the manufacturer with over 200 metal standards, which are included in the measurement library. This calibration has been veri-fied with the CHARM archaeological metal dataset.[11] As described above surface effects can influence the measuring results; detection limits are likely to be higher for the objects, and accuracy lower than for the CHARM set. At the same time, the CHARM dataset shows that Sb has been measured on the K-line, with 50 kV: there is no overlap with other elements. During the system check, the efficiency and status of the pipe and detector are checked. On this basis, a correction of the calibration lines is made by the machine itself (in particular related to the adjustment of 'detector dead time'). During the measurement itself, the detector temperature is continuously corrected.

There are limitations to the XRF analyses.[12] In the 1960s, the elemental composition of approximately 20,000 prehistoric objects was determined in the Württembergisches Landesmuseum.[13] The objects were classified depending on the metal composition. According to Pernicka, the research was based on a publication by Otto & Witter from 1952, in which it is assumed that mining regions can be distinguished using a combination of the elements silver, nickel, bismuth, arsenic and antimony.[14] XRF is only a method for elemental analysis; since the emergence of the measurement of lead isotopes in the 1980s, this first view of the determination of origin has faded into the background, although XRF analysis has remained complementary to lead isotope analysis in determining 'metal provenance'.[15] Nevertheless, this method of measurement by XRF is useful to a certain extent. Sometimes trace elements even prove to be a better indicator than lead isotopes, which means that a combination of both methods can give the best results.[16] There are of course limitations to the XRF analysis method used in the current study, such as a detection limit that is higher than – for example – a µ-XRF (micro-XRF) that covers a smaller surface of an object and analyses more powerfully and precisely.[17]

Due to its non-destructive nature, the deeper core of the objects is not measured.[18] Measurements are only partly penetrating the surface, an area of the object possibly affected by irregular effects; a surface can be enriched or depleted

11 Thanks to Bertil van Os for his support with the technical aspects of the measurements; Roxburgh *et al.*, 2014: 120, 122; Heginbotham *et al.*, 2015, figure 2-4.

12 Blet-Lemarquand *et al.*, 2014: 133 and 138.

13 Pernicka, 1999: 163.

14 Otto & Witter, 1952.

15 Pernicka, 1999: 163 and 169.

16 Pernicka, 1999: 163; Hauptmann *et al.* 1992: 27-28.

17 Killick, 2012: 27.

18 Das *et al.*, 1966: 837.

depending on intentional treatments as well as various environmental processes. The precious elemental composition on the surface regularly appears to be slightly higher.[19] For example, an object may be gilded and coins of precious metal were usually coloured or blanched on the outside, to suggest that they have a better quality. Furthermore, the metal alloys are not completely homogeneous because in the past there was often poor mixing or because the applied enrichment of the surface has partly worn off.[20]

The instrument calibration of the used XRF is – like most portable XRF-instruments with built-in calibrations – programmed always to give a number, regardless of whether it is realistic. Therefore, the measured data in the appendices is rounded to two decimals and the data with values below the detection limits is removed and replaced with the abbreviation 'bql' (below quantification limit). Even after these interventions, the data – especially with values below 0.1% – should in general be handled with care.[21] Since the surfaces of the objects are non-abraded, the question remains how likely it is that trace element data can be found and if it is realistic to use measurement data of concentrations below 0.1%. Hopefully, additional research can be done in the future, using different techniques, so that the data found can be verified.

This means that the data collected by an XRF will not answer all questions and that measurements on several parts of the same object may produce slightly different results. The best measurement would be a destructive one, where the whole object is 'sacrificed'.[22] It has to be said that a new and accurate type of measurement is developed, where lead isotope ratio analysis can be conducted from for instance a surface swab with dilute acid.[23] This interesting technique is promising for researching museum collections, where sacrificing objects is not an option. With the XRF-research, only one measurement was performed per object. This was done because the time available for the research was limited, while bringing together and averaging two or more measurement results per object for all measured (trace) elements is rather complicated. Although some research has shown that there is no absolute reason to measure one object on multiple spots, I know from my own experience that two measurements on different locations on the same object give slightly different results.[24] The validity of this research has to come from 'the power of the mass'.

19 Pelsdonk *et al.*, 2021: 126-130; Shugar, 2013: 183.

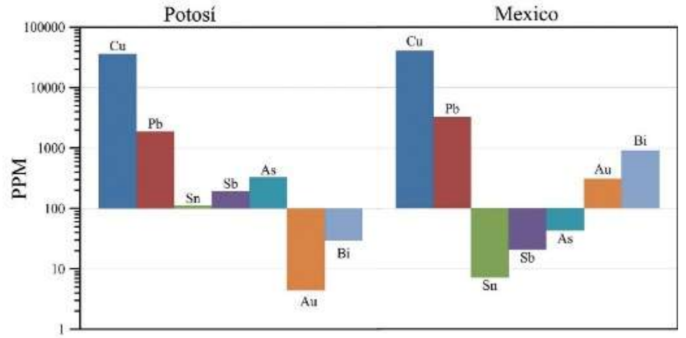
20 Pelsdonk *et al.*, 2021: 128; Van Ham-Meert *et al.*, 2020: 10.

21 Van Ham-Meert *et al.*, 2020: 6, 8; Orfanou & Rehren, 2015: 389, 395-396; Pernicka, 2014: 245; Shackley, 2011: 10.

22 Nissen, Lennaerts & Van der Hofstad, 2017.

23 Van Ham-Meert *et al.*, 2019: 3379, 3388.

24 Van Ham-Meert *et al.*, 2020: 5.



Graph 1 – *Average values of 49 silver coins analyzed with* ICPMS *(an inductively coupled plasma-mass-spectrometer), produced in Potosí (Bolivia) and Mexico* (image: Bertil van Os, Cultural Heritage Agency of The Netherlands, from: Van Os, Suvorova, Pelsdonk *et al.*, p. 202). Abbreviations: Cu = copper, Pb = lead, Sn = tin, Sb = antimony, As = arsenic, Au = gold and Bi = bismuth.

Despite the lack of measurement data for lead isotopes, statements can sometimes be made about the place of production and the ore used.[25] For example, with the aid of easily identifiable silver coins, the distinction between the ore areas in Potosí and Mexico has been demonstrated (Graph 1). So if it is possible to detect some different 'fingerprints' of ores, there is every reason to take a good look at the possibilities of non-destructive XRF testing. A new problem immediately arises with the copper coins and medals in the collection of Teylers Museum. The copper ore was mined abroad and the objects were made in the Dutch Republic. In general, the origin of the copper used is no longer known. It is likely that in the Mints, also recycled copper was used. It is therefore questionable to what extent the origin of the metal can be determined on the basis of the XRF research.

1.3 Copper coins

In the Northern Netherlands, after the dissolving of the Roman Empire, the pure copper coins have not been produced for centuries. Copper was seen as inferior and coins were made from silver or gold. This statement can be toned down a bit, because, especially from the end of the fourteenth century, so much copper was added to silver coins that they could hardly be called 'silver' anymore. Often this metal is called billon. The silver content was usually only a few percent. Nevertheless, the silver content still determined a large part of the value of these coins, which are not included in the study. The first pure copper coins were produced in the Northern Netherlands in the course of the sixteenth century. Utrecht kicked off in 1523 with a completely copper *duit* (Picture 3). The value of these coins is therefore no longer based on the amount of precious metal in the coin,

25 Van Os *et al.*, 2020: 202; Gorghinian *et al.*, 2013: 268-271.

but on the confidence that everyone will receive it for a fixed value; fiduciary money. A series of *kortes* (Picture 4) followed in the 1540s.

It was not until the middle of the sixteenth century that the use of copper money became widespread. The end year of the current copper research has been set at 1800. In the nineteenth century the majority of the old coins from the Dutch Republic were melted down, coined into new copper coins and put into circulation. In addition, from the 1880s tin and zinc were added to the new copper coins. Coinage of the nineteenth and twentieth centuries are a subject for future research.

Picture 3 – Utrecht, *duit*. 1523, copper, 18 mm, 1.0006 g (inv. TMNK 15953). The first pure copper coins in the Northern Netherlands for centuries.

Picture 4 – Gelre, Karel V (1543-1555), Arnhem or Nijmegen, *korte*. N.d. (1546-1550), copper, 19 mm, 1.7419 g (inv. TMNK 06630)

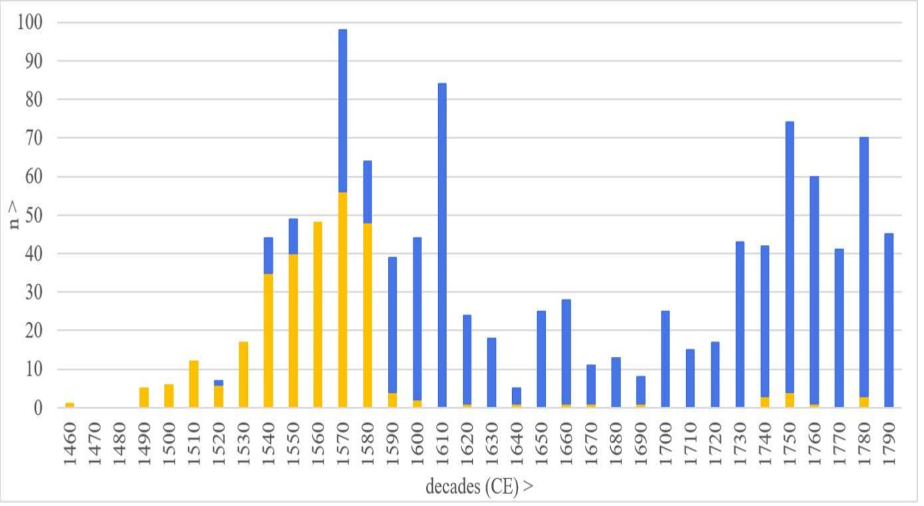
Graph 2 shows the numbers of measured coins and medals per decade. Since the museum's collection mainly contains different types per annum, the graph does not reflect the size of production (as for instance is given in Graph 3). First the 786 coins are discussed, the research into the medals will follow below.

The production of copper coins differed by region and by year. The descriptions of the coins are not part of this research. That information can be found in recent catalogues.[26] Those catalogues describe coin types and years; the production and origin of the metal used is barely or not explained. In his dissertation, Scheffers does go into more detail about the backgrounds of the sources of the metal used for coin production (more about this in section 2.9).[27] Beside this, the catalogues do not mention how much of the coin production was destined for use by the Dutch East India Company and therefore in principle did not come into circulation in the Dutch Republic (see Graph 3).[28] Due to the fluctuating production, Graph 2 shows gaps for the years in which little copper money was produced (or of which there are no coins in the museum collection). However, in the period from about 1570-1800 an almost incessant stream of copper coins was produced.

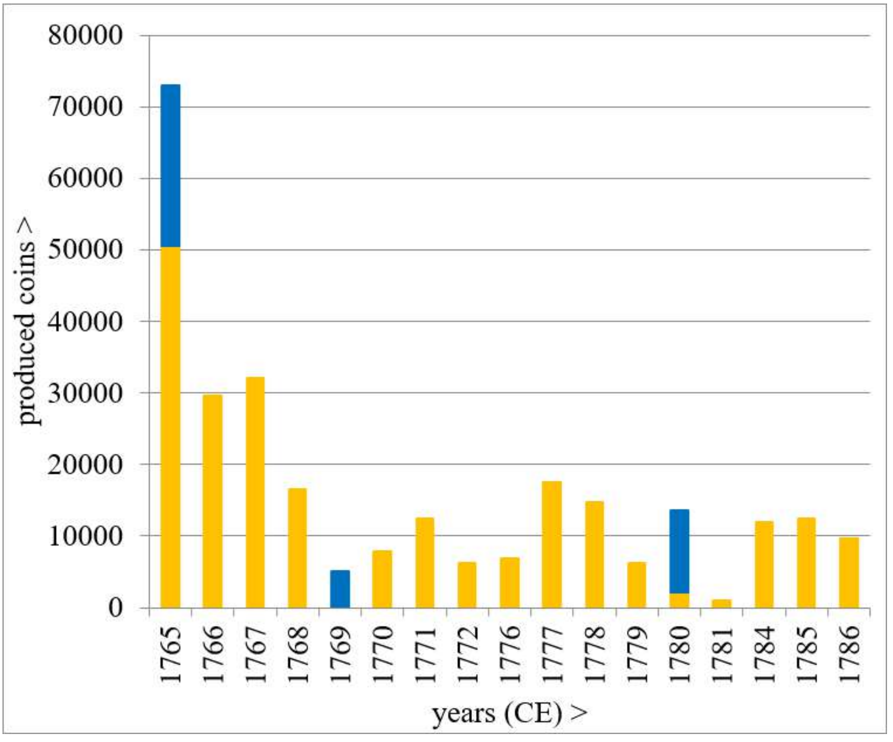
[26] Van der Wis & Passon, 2009; Purmer & Van der Wiel, 1996; Bos, 1995.

[27] Scheffers, 2013.

[28] Pelsdonk, 2015: 201-208.



Graph 2 – *Items measured per decade: 294 medals (yellow) and 786 coins (blue).*



Graph 3 – *The total production of copper money in West Friesland in the period 1765-1786, in guilders. The yellow bars show the production on behalf of the VOC*

1.4 Copper medals

Picture 5 – Holland, Dordrecht, *Counter token in commemoration of the execution of the counts of Egmond and Horne in 1568*. 1579, copper, 30 mm, 6.0191 g (inv. TMNK 16335).

The problem with medals (including counter tokens, Picture 5) is that it is more difficult to determine the year of production than with coins. Even if a year is mentioned on a medal, it normally relates to the depicted event or person rather than the year of production. A medal could easily have been made many decades later. Moreover, the dies may have been preserved and used again at a later time to produce additional medals. This is a big difference with coins, where the year on the object indicates the year of production much more precisely, although a *caveat* should be made here too for coins where the year indicates only the first year of emission (minted for several consecutive years, according to the specifications of the stated year). During coin production, a mint master may have 'cheated' and still used good dies in the following year or, for example, had coins made with the date of the – not yet arrived – new year as a New Year's gift. However, dating problems with coins are much smaller than with medals. After selection, a group of 294 analysed copper medals from the period 1450-1800 – with the above-described degree of uncertainty for dating – have been studied.

1.5 Plated objects

Following the research into nearly pure copper coins and medals, the objects are examined in which less copper has been recorded, but where copper is still the main component. In these specific cases, elevated precious metal values have been measured on the surface. Usually, the elemental composition of the copper is less than 95%. The measurement data are included in Appendix 5.

Objects that were produced outside the Republic were also included in this study. Gold- and silver plated objects are normally also recognisable with the naked eye. Gold finishing is a regular feature in the museum collection (Picture 6). These are usually special specimens, for example manufactured at the time for the collector's market or to be given away as gifts. Silver-plated copper (Picture 7) objects also occur, but are hardly represented in the museum collection.

Picture 6 – Zeeland, Middelburg, *duit*. 1777, gold-plated copper, 24 mm, 1.9239 g (inv. TMNK 14750). Before gilding, this coin has been sawn out.

Picture 7 – City of Utrecht, *duit*. 1739, silver-plated copper, 22 mm, 3.6686 g (inv. TMNK 05771) and the accompanying index card with information, where the coin is listed as 'silver'.

1.6 Pollution

Pollution – small amounts of other elements that in many cases are not intentionally added to the copper – occurs in all objects. Normally, these concentrations of trace elements are very small. The pollution can have a natural cause, for instance if the other material was already in the ore. It can also be a residue from recycled material, deliberately added to the copper to remove other elements (for instance: sometimes lead was added to remove silver) or to create a high finishing layer.[29]

1.7 Hardening: objects of bronze and brass

Copper is by nature a soft metal. It can be hardened by quickly cooling after heating in a furnace or by adding specific other elements to it. It is likely that in many cases, reducing costs and ease of casting were more important than hardening the objects. Bronze (copper with tin, Pictures 8 and 9) and brass (copper with zinc, Pictures 10 and 11) are often used. In the researched period, tin is added as a second element in 43 coins and medals. Zinc and lead are also regularly present.

Picture 8 – Maastricht, *emergency coin of forty stuiver*. 1579, bronze, 40 mm, 19.1828 g (inv. TMNK 11326).

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29 Cohen *et al.*, 2022: 3644.

Picture 9 – After Wouter Muller, *Decease of Alida Oortman (1687-1690)*. 1690, bronze, 68 × 74 mm, 58.0096 g (inv. TMNK 01163) *(scale 80%)*.

Picture 10 – Ireland, Dublin or Limerick, James II (1685-1688), *Crown, 'gun money'*. 1690, brass, 33 mm, 14.9071 g (inv. TMNK 05210).

Picture 11 – Blacksmiths' Guild Utrecht, *medal of member Everd Vos Kuyl*. 1749, brass, 57 mm, 63.122 g (inv. TMNK 05573).

Two pieces of Irish gun money, a *shilling* and a *crown* (Picture 10), have a lower composition of tin and zinc as the second largest element, while a third piece (Picture 38) is composed of more tin.[30] This shows that the distinction based on the second metal is practical, but at the same time arbitrary. In addition to tin, zinc was measured as the second metal in 156 cases, excluding a small number of imitations and counterfeits. Usually a small amount of lead and tin appears to be added to brass products, these metals could also be residual contaminants from the production chain.

1.8 Foreign coins and medals

A small amount of copper coins and medals from Germany, Sweden and the United Kingdom were examined as well. It could be expected that the objects from the United Kingdom and Sweden in particular are made of locally sourced copper. Tracing the origins is more difficult in Germany, because most of the pieces examined were not produced in the mining areas, but in Kleef and Anholt. Moreover, this happened at a time when a lot of copper came from Sweden. It is unknown to what extent the foreign copper penetrated the German production centres.

Picture 12 – Anholt, Dirk III of Bronckhorst (1586-1649), *duit*. N.d. (1616-1622), copper, 21 mm, 1.2321 g (inv. TMNK 07372).

Picture 13 – Great Britain, London (Tower, Royal Mint), John and Norbert Roettiers, *Medal on the death of Queen Mary*. 1695, copper, 50 mm, 51.8176 g (inv. TMNK 01281).

30 TMNK 05208 and TMNK 05210 *versus* TMNK 05209.

Picture 14 – Sweden, Christina (1632-1654), Avesta, *öre*. 1650, copper, 47 mm, 50.4867 g (inv. TMNK 15974). The reverse inscription, MONETA NOVA CVPREA DALARENSIS MDCL (New Dalarna Copper Coin 1650) refers to the area that also contains the Falun copper mine.

Picture 15 – Anonymous, *Medal on Queen Christina of Sweden*. N.d. (circa 1650-1725), copper, 64 mm, 64.128 g (inv. TMNK 08418) *(scale 80%)*. Because of the much higher antimony and zinc values, this medal is probably not produced in Sweden, but more likely in southern regions.

Unfortunately, only a small number of coins and medals could be measured: nine from Germany (three medals and six coins, Picture 12), seven from Great Britain (all medals, Picture 13), and ten from Sweden (five medals and as many coins, Pictures 14 and 15). The basic details of these objects are included in Appendix 2. More material was not available in Teylers Museum.

1.9 Selection and deselection

The researched coins and medals were divided in several groups. During this process, some objects had to be excluded from the research. The reasons to select or deselect objects is described in more detail in this sub-section.

1.9.1 Selection

The collection of Teylers Museum contains a large number of copper coins and medals, of which 1,413 objects were selected for study. The coins mainly consist of *half-duiten* (Picture 16), *duiten* (Pictures 17-20) and *oorden* (Picture 21), in addition to a few *kortes* (Picture 4). First, a selection was made of the objects to be included in the study (the dates were also checked, which led to small shifts, especially with the medals). First, the objects with a high elemental composition of copper were selected. This was done because it can be expected that the possibility to trace back the origins of the copper will be biased by the addition of metals from other mine regions during the production process.

Picture 16 – Holland, Philip II, Dordrecht, *half duit*. 1573, copper, 23 mm, 2.2986 g (inv. TMNK 12154).

Picture 17 – Holland, Dordrecht, *duit*. 1769, copper, 21 mm, 2.5889 g (inv. TMNK 05694).

Picture 18 – West Friesland, Medemblik, *duit*. 1658, copper, 22 mm, 1.8139 g (inv. TMNK 05706).

Picture 19 – Roermond, *duit*. 1678, cop-per, 19 mm, 1.1781 g (inv. TMNK 08120).

Picture 20 – Gelderland, Harderwijk, *duit*. 1703, copper, 23 mm, 3.5981 g (inv. TMNK 07126).

Picture 21 – Zeeland, Middelburg, *oord with the head of Prince Maurice of Orange*. 1669, copper, 26 mm, 4.0712 g (inv. TMNK 15933).

Because the addition of other metals, such as tin and zinc, could influence the presence of trace elements, coins containing less than 95% copper were examined in more detail in a separate part of the research, from section 2.3 onwards. At first, forgeries and special specimens (silver-plated, gold-plated) were deselected (see section 1.9.2). Emergency coins (Picture 8) were researched as well, but those are not discussed in detail since they are already the subject of a recent series of articles in *De Beeldenaar*.[31] In total, 786 coins and 294 medals with a high elemental composition of copper and 355 objects with a lower measured copper alloy were determined as suitable for the research, from the period circa 1460-1800. The basic details of these objects are included in Appendix 1.

1.9.2 Deselection

Due to the research of the elemental composition, there was sometimes a reason to change an attribution. A couple of examples are given to clarify. For instance, a *duit* from the province of Gelderland stands out, with a low composition of copper of 73.93% (Picture 22). This coin also contains a significant amount of tin (5.79%), lead (9.27%) and zinc (9.65%) and is – partly because of the uneven surface – apparently a cast forgery. The coin comes from the collection of Theodorus Roest (1832-1898), which was bequeathed to the museum in 1898. It is unknown where he obtained this piece. Also forged are an *oord* from the Catharinagasthuis in Leiden and a *penning (half duit)* from the duchy of Gelre (soon afterwards becoming the province of Gelderland, Guelders) during the reign of Philip II.[32] The Leiden piece was recently studied in *De Beeldenaar*.[33] Two coins from Rekem (Reckheim) have also been removed from the list of objects to be investigated.[34] Based on a relatively high composition of zinc, another three deviant coins were found. The first – with 5.25% zinc – is a coin from Nijmegen from the period 1618-1620 (Picture 23). This coin appears to have been struck over an older coin, possibly from the German Empire or France. The second coin is a Gelderland *oord* from 1589 (4.97% zinc), which may be a cast forgery given the pits in the surface.[35] A *duit* from Roermond also shows this deficiency and has an elemental composition of zinc of 4.84%.[36] A relatively high iron composition (3.33%) was found in a *half duit*, minted in West Friesland in 1769 (Picture 24) on behalf of the Dutch East India Company (VOC). The coin – from the Woestenburg collection, which the museum acquired in 2014 – shows

[31] Pelsdonk, 2020: 314-319; *Id.*, 2021a: 19-22; *Id.*, 2021b: 181-188; *Id.*, 2021c: 337-346; *Id.*, 2022a: 123-126; *Id.*, 2022b: 207-213; *Id.*, 2022c: 290-294.

[32] TMNK 06653; TMNK 11356.

[33] Pelsdonk, 2021b: 186.

[34] TMNK 10833; TMNK 12381.

[35] TMNK 06864.

[36] TMNK 08114.

a slightly irregular surface and light brown traces that may indicate rust. This may be an imitation; it is from the Roodenburg collection (acquired in 2009) and contains 3.40% iron.[37] This heavily worn coin is clearly an archaeological find. More research is needed to determine whether some trace elements can be related to the soil conditions of the site or whether they are actually part of the original elemental composition of the coins. Metallurgical research has shown that in some cases it is possible to distinguish between burial environments.[38] A recent example shows that coins from two shipwrecks off the coast of Australia – the Portuguese *Correio da Asia* (wrecked in 1816 on the Ningaloo Reef near Point Cloates) and the *Batavia* (a ship of the VOC, which sank some 600 km more south, in 1629, off the Abrolhos Islands near Geraldton) – can be distinguished on the basis of the trace elements strontium and magnesium.[39] These elements have ended up in the coins due to the local conditions of the environment (water and soil).

Picture 22 – Gelderland, *duit* (forgery). 1755, brass, 22 mm, 2.7497 g (inv. TMNK 07198).

Picture 23 – Nijmegen, *duit* (over older coin). N.d. (1618-1620), copper, 26 mm, 3.5829 g (inv. TMNK 07959).

Picture 24 – VOC, West Friesland, *half duit* (imitation). 1769, copper, 18 mm, 1.3259 gram (inv. TMNK 13936).

The effect of gilding and silvering on the measurement results (see also section 1.5), is illustrated by means of two objects. First the gilded piece. In 1900 the Haarlem landscape gardener Louis Paul Zocher (1820-1915), who was also one of the directors of the Teylers Foundation in the period 1872-1915, donated a series of gilded coins to the collection of the foundation. The example of Picture 6 measures 12.48% copper, 73.04% gold and 0.89% silver. Given the high composition of mercury of 12.31%, this coin is fire-gilt, just like the rest of this

[37] TMNK 12124.

[38] Huisman *et al.*, 2023: 4, 17-20.

[39] Van Os *et al.*, 2020: 204-205.

series. During the gilding process, the object was covered with gold dissolved in mercury, after which the mercury evaporated by heating and the gold adhered to the object. Around 1830, this gilding method was banned because evaporating the highly toxic mercury was life-endangering. Based on this, it can be stated that the series of coins was not edited in Zocher's time, but rather in the early nineteenth century, possibly in the early years of the kingdom of The Netherlands, after the fall of Napoleon.

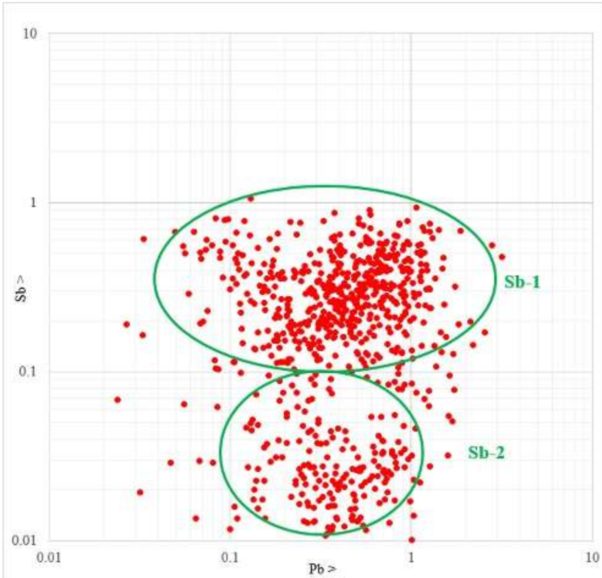
The second coin (Picture 7) is according to the description made by curator Theodorus Roest of silver, but on the reverse the copper colour clearly shows through the silver. The measurement for this coin shows an elemental composition of 40.52% copper and 58.27% silver, in addition to 1.20% contamination. This coin is clearly silver plated.

Indeed, as described earlier, the XRF measurement in both cases does not only detect the outer layer of the coins, but also penetrates the objects a bit deeper. The result is always a mixture of the elemental composition of the surface and that of the original coin. As a result, both the measured elemental composition of the surface enrichment and that of the underlying coin are incorrect. In both cases, the copper composition of the coins can be expected to be close to 100%, as seen in measurements on other *duit*-coins. However divergent the outcome may be; these measurements of elemental composition prove particularly useful, because objects that seem to be of pure gold or silver prove to be plated. (It is possible that the thickness of the plating could block the underlying substrate, but I have not found any suspicious object in the museum's collection where I would expect this to be.) For example, not every silver-plated medal had the word 'BRONZE' stamped in the rim. Later in the text, copper coins and medals are discussed in more detail, with gold or silver being the second largest metal measured.

2 RESULTS OF THE ANALYSES

2.1 Copper coins

In the analysis of the museum collection, it is striking that the amount of antimony in copper coins is about three times that of antimony in silver coins. In addition, it shows about the same rate over time. However, this is not a real surprise, since antimony occurs naturally in copper ore as a trace element. In Graph 4, the trace elements of antimony (Sb) and lead (Pb) are compared. It is noticeable that the amount of lead is relatively constant and that two groups of antimony seem to form. These groups are circled in green in the scatter chart (Graph 4). The top group (Sb-1) consists of coins with an elemental composition of antimony of roughly 0.1-1%. The lower group (Sb-2), with 0.01-0.1% antimony, is significantly smaller and with 258 coins, almost half of the first group (528 coins). Pictures 25 and 26 show coins from both groups.



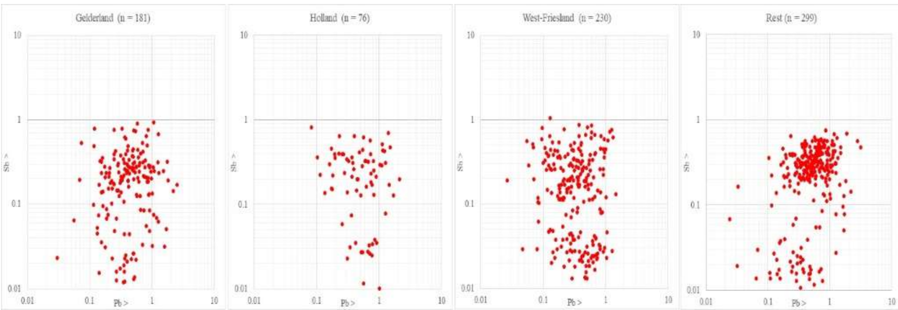
Graph 4 – *Scatter chart showing the ratio of antimony to lead in the 786 coins.*

Picture 25 – Gelderland, Harderwijk, *duit*. 1634, copper, 20 mm, 1.7498 g (inv. TMNK 06962). This coin fits into the antimony group Sb-1.

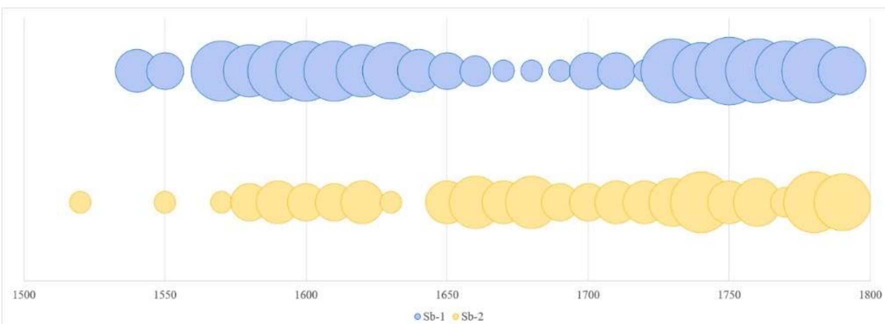
Picture 26 – Gelderland, Harderwijk, *duit*. 1678, copper, 22 mm, 1.7219 g (inv. TMNK 07074). This coin fits into the antimony group Sb-2.

In an attempt to explain the existence of the two groups, the coins were divided into four sets: Gelderland, Holland, West Friesland and Other. Graphs were made of these groups to see whether the deviating antimony values are related to the coin production (Graph 5). This does not appear to be the case. In the Mints connected to these groups both antimony clusters Sb-1 and Sb-2 occur in more or less the same proportions. Apparently, the amount of antimony appears not to be directly dependent on the place of coin production.

Subsequently, the 786 coins were studied to see if the differences between the antimony clusters Sb-1 and Sb-2 can be related to the time of their striking. For this purpose, the coins were sorted by decade according to the year of production in Graph 6. For the small number of coins for which this year is unknown, the first possible year of production was used. For each of the two groups of antimony, the number is always set to '1' if a year was represented by several coins. After all, the question is not how many coins of a certain year are in the museum. Per decade, the bubble chart of Graph 6 shows whether – and how often – antimony is present. Each circle therefore encompasses ten years, with the surface of the circle varying from 1 (the smallest circles) to 10 years represented in the given decade. The outcome is shown in the bubble chart.

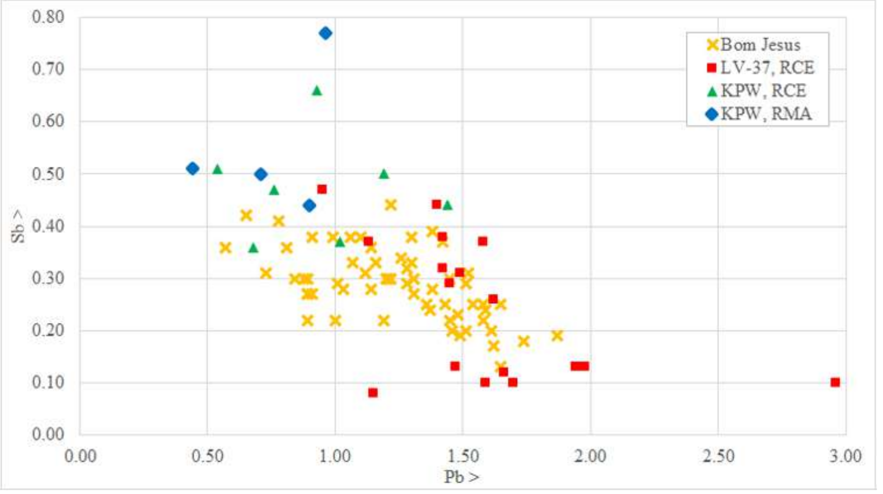


Graph 5a/b/c/d – *Scatter chart with the ratio between antimony and lead in the coins of Gelderland, Holland, West Friesland and the remaining coins.*



Graph 6 – *Bubble chart of the antimony groups Sb-1 and Sb-2 per decade.*

The first pure copper coinage is represented by an Utrecht *duit* produced in 1523 (Picture 3 and the isolated dot on the far left of antimony group Sb-2 in Graph 6), followed in 1540 with a series of *kortes* (Picture 4). It is striking that group Sb-2 is fairly constant, but shows a sharp decline in the 1630s and 1640s. This can partly be explained by the smaller number of measurements that could be performed during this period. In group Sb-2, however, this smaller amount of measurement data did not demonstrably lead to differences. Group Sb-1 is more prominent than Sb-2 in the period 1570-1630 and shows a decline from the 1640s, with the years 1670-1690 as the low point. It is not until the 1730s that the size has returned to its former level, after which it is quite constant in the following decades. The scatter charts of Graph 5 show that cluster Sb-2 has a smaller size than Sb-1. This is also apparent from the numbers processed in the bubble chart. Sb-1 yields 134 coins with different years, compared to 94 for cluster Sb-2.



Graph 7 – *Finds of the Bom Jesus, the* LV*-37 and the Koperplatenwrak (*KPW*). The* LV*-37 measurements were performed by the Cultural Heritage Agency of The Netherlands (*RCE*), those of the Koperplatenwrak by the Rijksmuseum Amsterdam (*RMA*) and the* RCE*.*

In another research, the copper sheets from two wrecks off the Dutch coast (the *Koperplatenwrak* and the LV-37/*Terschellinger Gronden* 2), were examined with p-XRF and are of Hungarian origin. The results appear similar to the tested copper from the 1533 wreck of the *Bom Jesus* off the coast of Namibia. All plates have a high composition of antimony that matches cluster Sb-1 (Graph 7).[40]

2.2 Copper medals

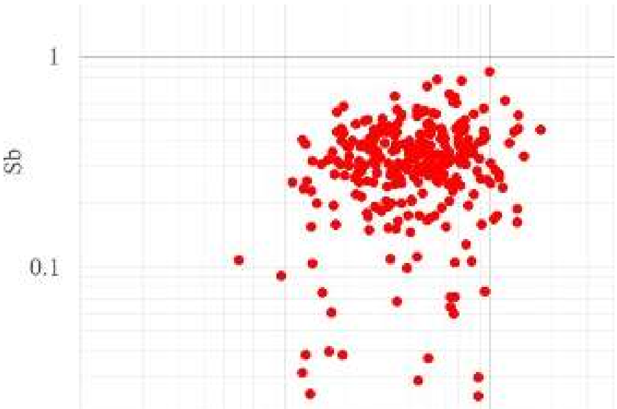
After researching the coins, a start was made with the medals and counter tokens, from the oldest specimen onwards. Because of the limited amount of time available to perform the measurements, not all medals could be measured, which is why a gap appears in the data from the mid-1580s onwards.

Unlike with coins, there are fewer or no requirements for the use of materials during the production of medals. In copper specimens this is reflected in a wide spread in admixture. Especially tin and zinc are often added, to create bronze and brass respectively. As with coins, the addition of other metals can influence the presence of trace elements. To be able to compare the medals with the coins,

[40] Van den Brenk *et al.*, 2019: 28; Van Os, 2019: 65-67; Hauptmann *et al.*, 2016: 195.

medals with more than 2% tin or zinc have been omitted, as well as the other medals where the elemental composition of copper is less than 95%. Also a specimen with no traces of gilding but with 5.25% mercury ('no problem as long as you don't lick it' a colleague used to say) was removed from the study.[41] Ultimately, of a possible 362 medals, a group of 294 copper medals from the period 1450-1800 – with the above-described degree of uncertainty for dating – have been studied.

First, it was studied whether the difference found in the coins can also be detected in copper medals. The scatter chart (Graph 8) shows a strikingly different picture. The elemental composition of lead is almost the same, but where the coins show a clear cluster with antimony values between 0.01 and 0.1% (Sb-2), the medals only show a few scattered dots in this range. The measured values clearly often end up in the middle of the range 0.1-1%. Pictures 27 and 28 show medals from both groups Sb-1 and Sb-2.

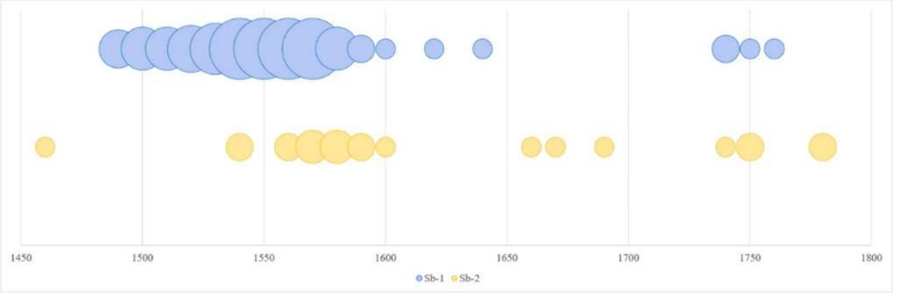


Graph 8 – *Scatter chart showing the antimony to lead ratio, at the 294 medals.*

Picture 27 – Flanders, Bruges, *Counter token of the mint masters of the city of Bruges*. 1468, copper, 28 mm, 3.1454 g (inv. TMNK 04096). This counter token fits into the antimony group Sb-1.

Picture 28 – Gelderland, Nijmegen, *Counter token of Gelderland*. 1561, copper, 31 mm, 4.3467 g (inv. TMNK 04246). This counter token fits into the antimony group Sb-2.

41 TMNK 04258.



Graph 9 – *Bubble chart of the antimony groups Sb-1 and Sb-2 for medals per decade.*

Converted to decades, the bubble chart for the medals (Graph 9) shows 81 values of 0.1-1% antimony (cluster Sb-1) and 22 values of 0.01-0.1% antimony (cluster Sb-2). The lack of measurement data from the mid-1580s onwards is well visible.

2.3 Plated objects

Objects with less than 95% copper are kept separate, because it is likely that the metals added to the copper come from other mines. Even with coins and medals made of almost pure copper, it appears that it is extremely difficult to find enough differences in trace elements using XRF analysis. In addition, in total there are 355 objects researched with less than 95% copper (see Appendix 5). They can be divided into plating, pollution and hardening.

First the plated coins and medals. As described earlier, the measured elemental composition in these types of objects is a difficult to interpret mixture of the wafer-thin refined top layer and the copper that is located underneath it. Due to the layer of gilding, the actual copper composition is equally difficult to determine. In thirteen cases – all medals – the copper core is likely to form the main element and the gold top layer the second highest element in the measurements. In general, it appears that the used measuring technique is penetrating somewhat through the enriched top layer; it would be interesting for future research with other techniques, to look deeper into this subject. The elemental composition of gold varies between 1.57% and 44.08%. The presence of mercury (with 4.84% as the highest value recorded) shows that the medals are fire-gilt, as described earlier (see also Picture 29).

The opposite, with gold as the main element and copper as the second element, occurs more often. Mostly these are regular gold coins and medals of good quality, to which a fraction of copper has been added (to harden the object or to make the end result cheaper). When these are kept aside, five coins and fourteen medals or adapted coins are left. Here too, the fire-gilt specimens show a higher concentration of mercury, as recorded in Appendix 5. The low concentration of mercury in a *gold guilder* from Desana (Picture 30), four *gold guilders* from Stevensweert and a *medal for a PhD promotion* (TMNK 02316) shows that it is unlikely that they are gilded (although ideally, all mercury will be dissolved during the gilding process). Usually, gold coins were coloured on the surface (impurities were etched away with chemicals) to suggest that they had a higher gold content. The copper must already have been added deliberately during the melting process to debase the gold. However only measured on the surface, the low elemental composition of gold (in combination with a lot more copper than regular) in the coins from Desana and Stevensweert shows clearly why these mints had a dubious reputation.

Picture 29 – Christiaan Wermuth, *Mocking medal about the Treaty of Utrecht*. 1714, fire-gilt copper, 44 mm, 35.1221 g (inv. TMNK 01648). Note the mirrored legends.

Picture 30 – Desana, Antonio Maria Tizzone (1598-1641), *gold guilder*. N.d. (1598-1641), gold, 22 mm, 2.8674 g (inv. TMNK 07731). With an elemental composition of copper of 26.86%.

Picture 31 – West Friesland, Hoorn, *stuiver*. 1599, silver, 24 mm, 1.4905 g (inv. TMNK 16839). With an elemental composition of silver of only 25.43%.

Picture 32 – Overijssel, Kampen, *duit*. 1767, silver-plated copper, 22 mm, 3.2098 g (inv. TMNK 11741).

Just like gilding, finishing with silver occurs regularly. In the copper objects where silver is the second highest metal, the billon coins have been kept aside, as are the other regular coins with a low elemental composition of silver. After all, most silver coins contain some copper and it often happens that the composition of silver is low. For example, the West Frisian *stuiver* (Picture 31) from 1599 shows an elemental composition of only about 25-30% silver according to the measurements. After ignoring the coins with a high copper composition already included in the first part of this study, only two silver-plated copper coins remain: an *oord* from Gelderland (dated 1589) and a *duit* from Overijssel (dated 1767, Picture 32).[42]

2.4 Objects with pollution

In the examined group of coins and medals, the variation in the second element is limited. In addition to trace elements, 'pollution' consists of consciously or unconsciously added metals. Found are mercury (4×), iron (9×), bismuth (3×), nickel (5×), antimony (11×) and lead (90×).

The presence of the element mercury in four specimens (Picture 33) – which, as indicated earlier, was used in fire gilding – is most striking. In these four cases however, the copper is not coated with gold. The reason for the presence of mercury has not yet been determined, probably the mercury was used to remove an old layer of gilt. The objects come from different production centres and periods.

Picture 33 – Antwerp, *Guild's medal of the archers 'De Oude Voetboog', with the name of Joos van Asse*. N.d. (circa 1600), copper, 35 mm, 10.8917 g (inv. TMNK 12022). A medal for daily use as a silent killer, with 6.35% mercury.

Picture 34 – Dutch United East India Company, Enkhuizen, *half duit*. 1769, copper, 18 mm, 1.3259 g (inv. TMNK 13936). Possibly an imitation, the elemental composition contains 3.33% iron.

[42] TMNK 06867; TMNK 11741.

In the period under research, iron as the second element is sparsely present. It only occurs in two coins (Picture 34) and seven medals. This is different in – for instance – the composition of ancient bronze, where often iron was added.[43] The low number can also be explained by more advanced smelting techniques. The elemental composition of the copper under research is usually high and the iron can be regarded as pollution. The two coins are the most interesting: both have a worn appearance and an irregular surface, which makes it likely that they are counterfeit coins or imitations.[44]

Picture 35 – Barend van Calker, *Prize medal of the Zeeuwsch Genootschap der Wetenschappen.* N.d. (1769), copper, 60 mm, 71.112 g (inv. TMNK 02139). With 0.10% bismut.

The lead-like element bismuth occurs three times (Picture 35) and can also be interpreted as pollution. In all three cases it concerns only a very small amount.

Picture 36 – Venice (Dalmatia and Albania), *two soldi*. N.d. (1684-1691), copper, 27 mm, 4.7561 g (inv. TMNK 09035). With 0.62% nickel.

Picture 37 – Nijmegen, *grootken*. N.d. (1499?), copper,

[43] Craddock & Meeks, 1987: 189.

[44] TMNK 12124; TMNK 13936.

13 mm, 0.1719 g (inv. TMNK 07817). With 9.38% lead.

Nickel as a second metal occurs in five objects – excluding the previously examined objects – and varies between 0.11% and 0.62% (Picture 36). That nickel can be classified as pollution is apparent from the low concentrations found; all items contain a minimum of 98.84% copper. Copper-nickel (sometimes called cupronickel) coins were not produced until about the mid-1800s and are beyond the scope of this study.

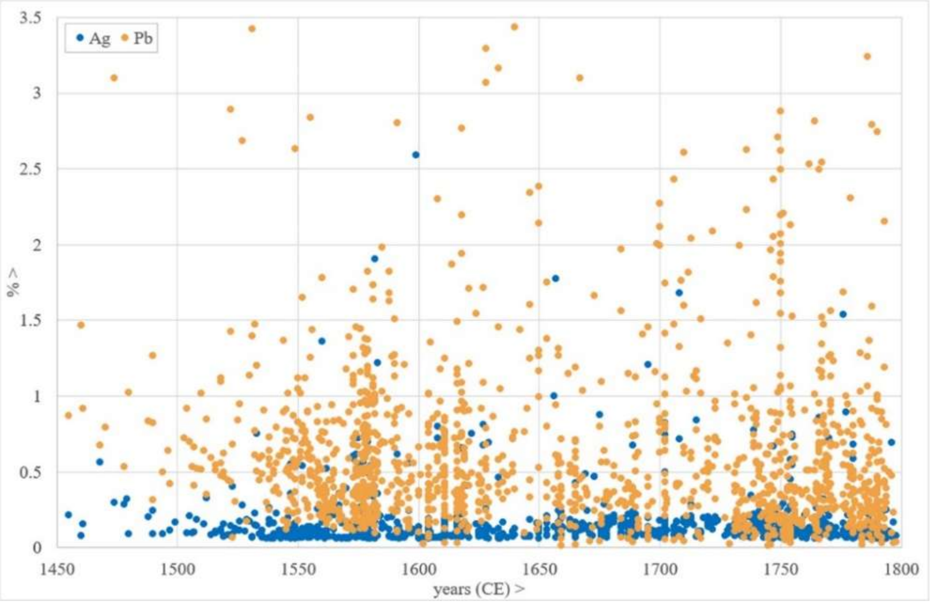
As previously described, antimony occurs naturally in copper ore as a trace element. Only eleven objects with antimony as the second element have not been mentioned before, they are also included in Appendix 5.

Objects are most often polluted with lead, which has been found 90 times as the second major element. The group of forgeries and imitations has been omitted from this selection. Copper-lead alloys are not used to improve the resistance to wear of the object. However, lead is found in many copper coins and medals (Graph 10). If the previously studied coins and medals are also included, then there are 823 pieces with lead as the second metal. This may be because lead was a trace element in the copper ore, or because it was added during the refining process to extract other metals, mainly silver, which eventually left some traces of lead in the copper objects (and traces of silver, since during the refining process it was too laborious to remove silver completely).

Lead was also used to improve the casting properties of copper, but since the coins in this research have been struck, this will more likely only be the case if second-hand copper was used. In the vast majority of cases (727 out of 823) the elemental composition of lead is less than 1%. Of the 90 previously not researched specimens (see Appendix 5), 62 are composed of less than 1% lead. It is possible that in these cases, the amounts of lead measured on the surface are not reflecting the core of the objects.[45]

In the remaining 28 pieces, the lead composition ranges from 1.03% to 13.47%. In the group of 19 coins and medals containing more than 2% lead, one copy has, in addition to some trace elements, only lead as an admixture. It is a *grootken* from Nijmegen, minted around 1499 (Picture 37). The remaining 17 medals and 1 (emergency) coin show next to lead a significant increase in the elemental composition of tin (0.84% - 10.92%) and zinc (0.31% - 7.45%). Possibly the copper of these pieces is less refined. Cost savings (which is certainly conceivable with lead as an addition) or attempts to harden the end product could play a role.

45 Epstein *et al.*, 2010: 387, 389.



Graph 10 – *All objects researched in this text, with an elemental composition of silver (blue) or lead (orange) up to 3.5%.*

2.5 Bronze objects

The elemental composition of tin fluctuates between 0.18% and 15.29% and only 32 of the 43 specimens in Graph 11 have a tin composition of 5% or more. Bronze is mainly spoken of if between approximately 5% and 20% of tin was added to the copper.[46] For comparison, the other measured objects in Teylers Museum were also looked at. Tin was detected in a measurable amount in 4,112 objects (Graph 12).

Here too, the group that can be classified as 'bronze' is remarkably small. Even if the definition of bronze is stretched a few percent, to 35%, only 138 specimens fall within this range (Graph 13). It appears that in the literature, especially with medals, bronze might be mentioned more often than the measurements indicate, which shows the added value of research of elemental composition.[47]

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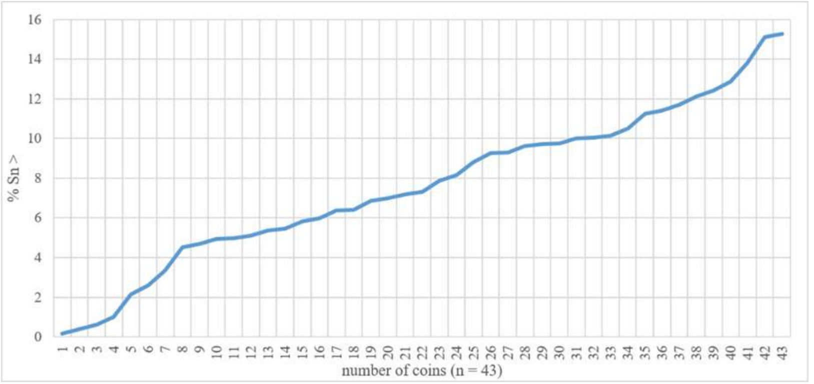
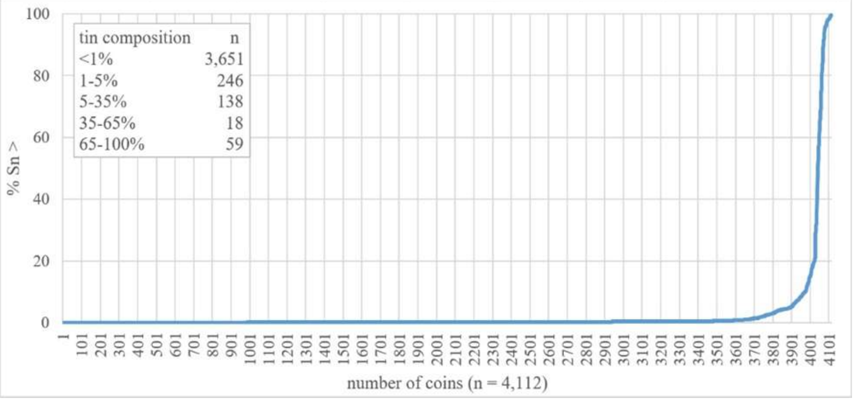
46 Van Beek, 1986-2002: K-55.

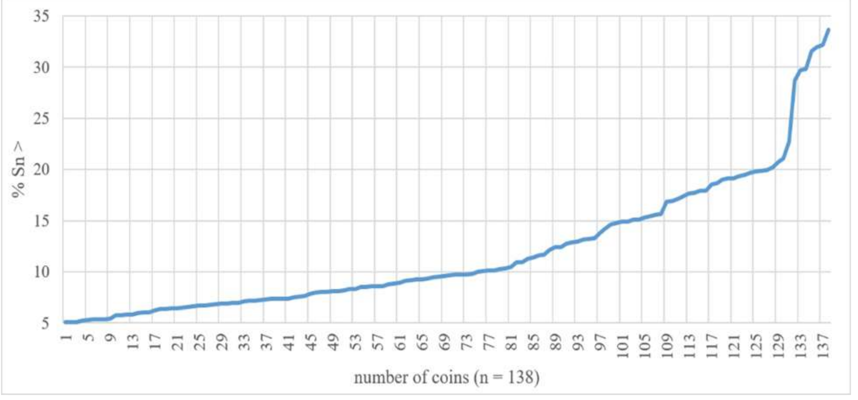
47 Pernicka, 2014: 262.



Graph 11 – *The 43 coins and medals with an elemental composition of tin between 0.18% and 15.29%.*

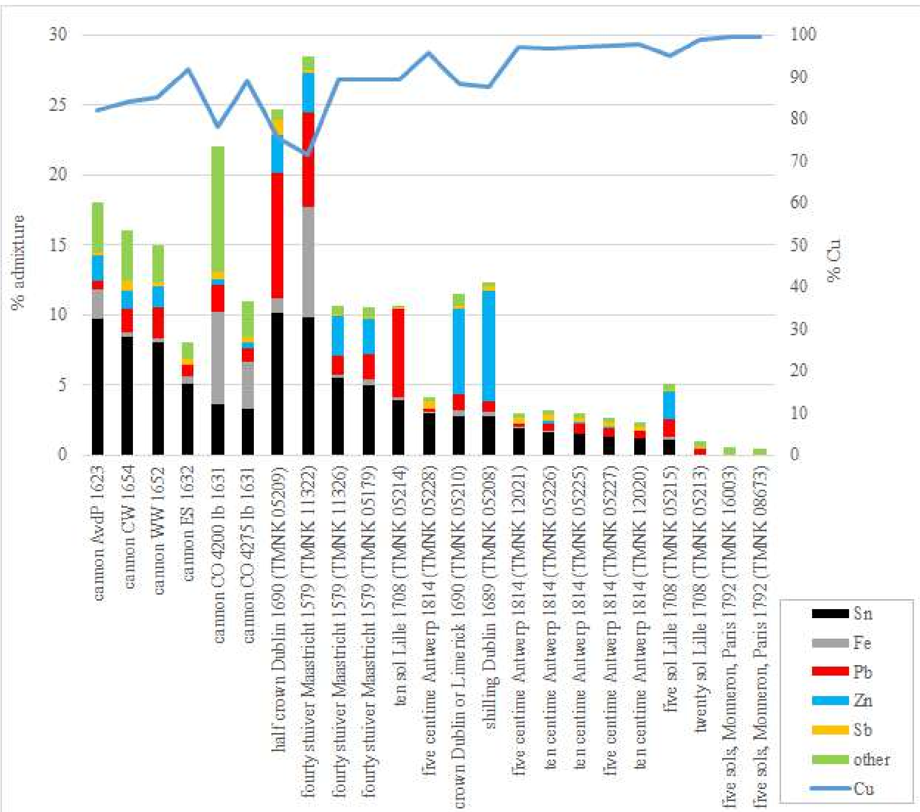


Graph 12 – *Measured elemental composition of tin of 4,112 coins and medals in the museum collection.*



Graph 13 – *The 138 coins and medals in the museum collection with an elemental composition of tin between 5% and 35%.*

Picture 38 – Ireland, Dublin, James II (1685-1688), *Thirty pence (half-crown), 'gun money'*. 1690, bronze, 29 mm, 11.3960 g (inv. TMNK 05209).



Graph 14 – *Comparison between the elemental composition of six cannons and coins, according to lore and the measurements made from melted-down cannons.*[48]

[48] Van Os *et al.*, 2012: 136.

Picture 39 – *Cross-section of the mouth of a cannon from the shipwreck of the* Batavia*, sunk in 1629 off the coast of Western Australia.*

A notable piece in this group is a 1690 Irish *half-crown* (Picture 38). After King James II (1685-1688) was expelled from England, he went to Ireland. In Dublin he had a number of cannons, clocks and old objects melted down to make coins to pay his soldiers. After the Battle of the Boyne against William III in 1690, this production of so called *gun money* moved to Limerick. In Graph 14 and Appendix 6, this *half-crown* has been compared with two other Irish coins (Picture 10), six cannons and other coins, according to lore (or research) believed to have been made from artillery.[49] It is striking that the elemental composition of the Irish gun money differs only in details from the examined cannons. It should be noted that the composition of guns could differ depending on the manu-facturer. An extreme example was found in the wreck of the VOC ship *Batavia*, which sank off the west coast of Australia in 1629 (Picture 39).[50] The sawn-open cannon shows a combination of bronze and iron, making it both lighter and cheaper than a massive bronze one. The disadvantage was that this type of cannon was weaker and could only fire scrap, no cannonballs. Other sources seem to have been used for the metal of the two Paris payment tokens and the six emergency coins from Antwerp. The Paris tokens appear not to have been minted in Paris at all, but in Birmingham, of almost pure copper, that was probably mined in England because of the peaking English copper production in that period. The copper of the emergency coins of Antwerp could come from recycled cladding from ship hulls.[51] Interesting are three emergency coins from Maastricht (1579) and at least one of the three measured emergency coins from Lille (1708). These also seem to have had old cannons as copper source.[52] Measurements on the other coins in the museum's collection show that tin is virtually absent in most of the regular coins during this period.

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49 Van Os *et al.*, 2012: 136.

50 Collection Western Australian Museum, Shipwreck Galleries, Fremantle, Australia.

51 Verbist, 2001: 210.

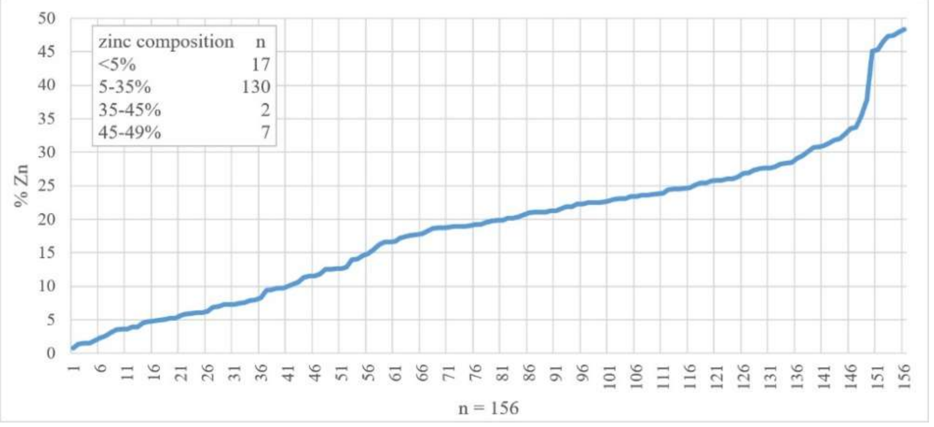
52 Pelsdonk, 2022c: 290-294; Pelsdonk, 2023.

2.6 Brass objects

The measurements show that the elemental composition of zinc in the selected 156 objects varies from 0.74% to 48.29% (Graph 15). According to Morton, brass objects are composed of at least 8% zinc and according to Pohl between 30% and 50%.[53] As with tin, the practice is therefore fickle, in the current research the focus is on copper with a zinc composition between 5% and 45%. In seventeen measured coins and medals, an elemental composition of zinc of less than 5% was recorded and in seven medals more than 45%. The rare occurrence of the latter group should not come as a surprise, because such a high zinc composition makes the material brittle. Zinc also occurs as a trace element.

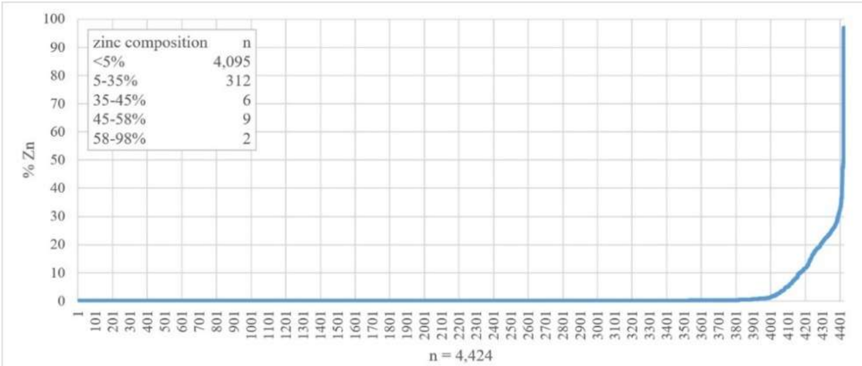
For comparison, the selection was compared with the entire group of measured objects in the museum collection. A detectable amount of zinc was found in 4,424 of the total number of objects measured (Graph 16), the majority of which contain less than 5% zinc. 318 of the 4,424 specimens can be classified as 'brass' (Graph 17), with an elemental composition between 5% and 45%.

Graph 15 and Graph 17 show a fairly even distribution, showing that there was no preference for a specific composition of zinc.

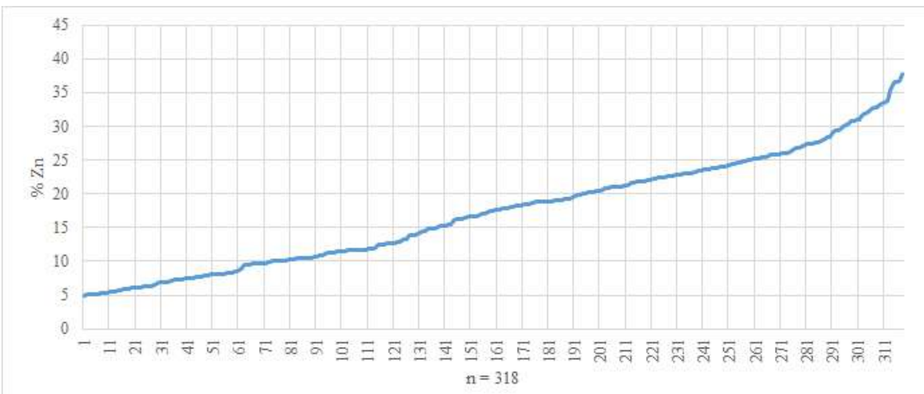


Graph 15 – *The 156 coins and medals with an elemental composition of zinc between 0.7% and 49%.*

[53] Morton, 2019: 4; Pohl, 1977: 225.



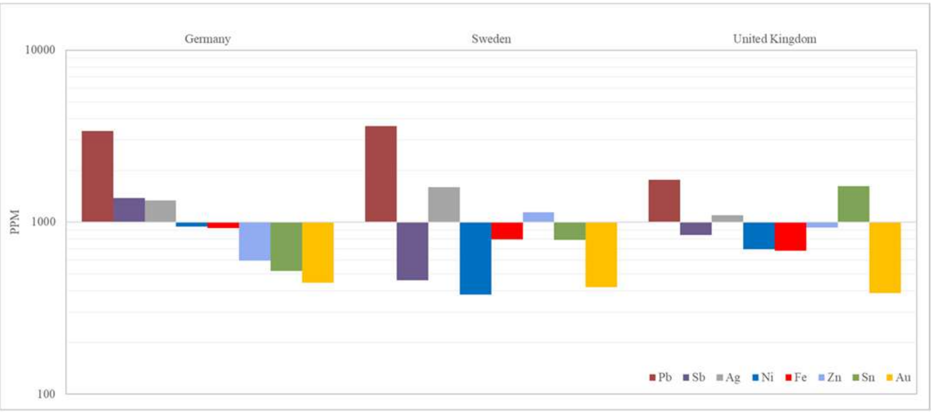
Graph 16 – *Measured elemental composition of zinc of 4,424 coins and medals in the museum collection.*



Graph 17 – *318 coins and medals in the museum collection, with a measured elemental composition of zinc between 5% and 39%.*

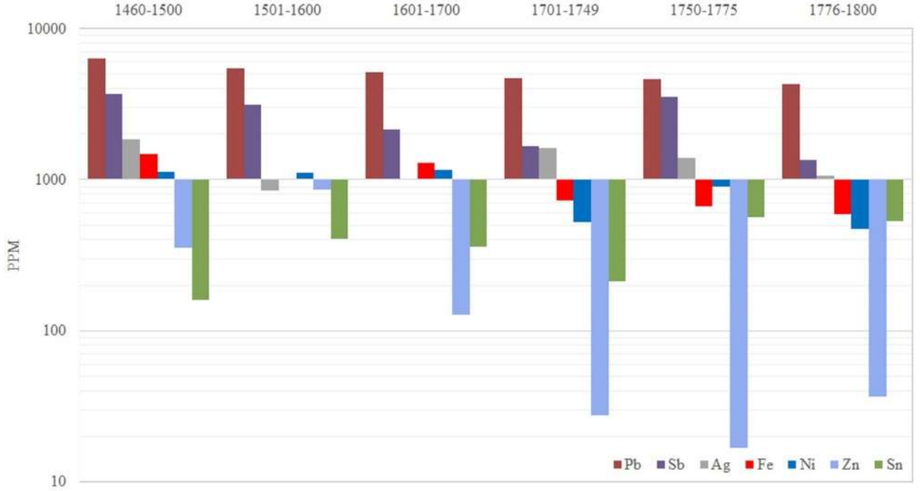
2.7 Foreign production

In analogy to the research into the silver mines in Mexico and Bolivia (Graph 1), Graph 18 examines some coins and medals from the United Kingdom, Sweden and Germany. The English pieces were minted into coins and medals in London and Birmingham, the Swedish ones in Stockholm and Avesta, and the German ones in Anholt, Augsburg, Kleve and Nuremberg. Although the selection is too small to indicate the differences with certainty, the outcome is an interesting starting point for further research into the local ores and the refining methods used. For example, the German objects seem to contain more antimony, the Swedish pieces less antimony and slightly more zinc and those from the United Kingdom include more tin. Appendix 2 shows that the recorded data of zinc are unreliable because these are below detection limits except for three objects. For nickel this is the case of half of the objects.



Graph 18 – *Average values of trace elements, in the XRF-analysed copper coins and medals, produced in Germany (9 pieces, period 1582-1710), Sweden (10 pieces, period 1650-1735) and the United Kingdom (7 pieces, period 1649-1797).*

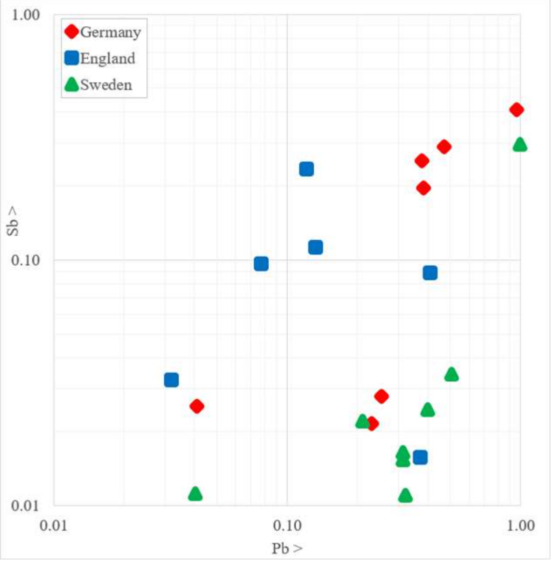
Graph19 shows the average trace elements of all coins and medals by period. The eloquence of this graph is low, because the averages have been determined with many objects of which the origin of the metals is unknown. Therefore, the graph should be viewed with the utmost caution.



Graph 19 – *Average values of trace elements, in the XRF analysed copper coins (786 pieces) and medals (294 pieces), produced in the Netherlands, by period.*

The 786 coins and 294 medals in Graph 19 can be compared to the insights from Graph 18. Unfortunately, the overviews of bismuth do not allow comparison: the measured values in the three reference countries are too low. Because gold and lead don't differ enough in the three countries, those metals are also difficult to compare. In Graph 19 gold could not even be taken into account, since a measurable amount was recorded on only a few objects.

The most interesting element is antimony (see also section 2.8). Antimony shows much lower values in Graph 18 than in Graph 19. In general, the comparison of Graph 18 and Graph 19 provides no clear indications for the origin of the copper processed in the Northern Netherlands. However, when the presence of antimony in the foreign coins and medals (Graph 20) is compared with Graph 4, it is noticeable that all but one of the Swedish specimens fall into group Sb-2. The deviating piece is a medal about Queen Christina from circa 1650.[54] It seems very likely that this medal has not been produced in Sweden.



Graph 20 – *Scatter chart showing the ratio of antimony to lead in the foreign coins from Germany (red), Sweden (green) and the United Kingdom (blue).*

In Graph 20, the German and English groups cluster together less strongly. The number of measured objects is too small for firm statements, but there seems to be a connection between the origin of the material and the antimony groups Sb-1 and Sb-2 of Graph 4. This difference is studied in more detail in the next section, for coins from the Dutch Republic of which the origin of the copper is apparent from archival records.

[54] TMNK 08418.

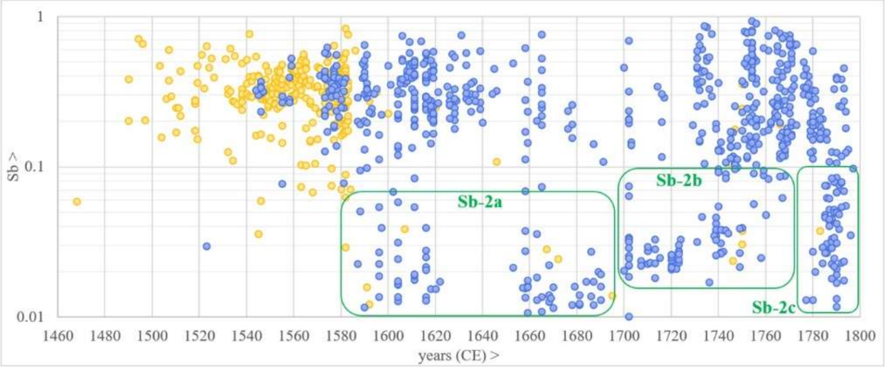
2.8 The factor of time

A comparison of the medals and coins of the previous sections show, that the scatter charts of both groups clearly differ. Antimony seems the best trace element to study the differences further, since it is apparent in all researched objects, in different amounts. To study whether the antimony difference can be related to time, all measured coins and medals have been brought together in one scatter chart (Graph 21). Clearly visible are the abrupt end of the measurements on the medals in the 1580s and the beginning of the more extensive production of copper coinage from about 1570.

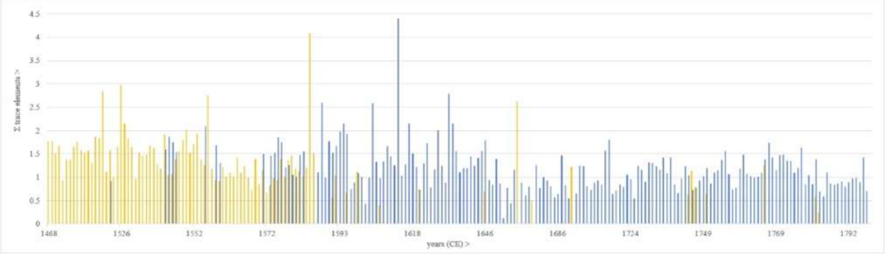
It is well possible, that the difference between high and low antimony values (previously shown in Graphs 4, 5 and 8) is an indication of the origin of the copper. Graph 7 and Graph 21 also hint in this direction. In the sixteenth century the medals show virtually no low values, while a *lacuna* is clearly visible for the coins in cluster Sb-1 in the second half of the seventeenth century. It seems possible to refine the image of Sb-2 for the coins in three groups: a first (Sb-2a) from about 1590-1700, a second (Sb-2b) from 1710-1760 and a third (Sb-2c) from 1780-1800. The trace elements show that the differences are probably time-related. This division could be helpful for future research with other techniques. For now, the differences are too small to be useful; already in the beginning of this article is stressed, that the validity of the research is supported mainly by the vast amount of measured objects.

Graph 22 shows a summation of all elements (except copper) per object. Apparently, copper coins and medals have both approximately the same amount of trace elements. Copper coins appear to have no better quality than medals, where the purity was expected to be of less importance. Other trace elements have been studied as well. During the measurements, many of these elements mainly remained below the detection limit. With regard to the sparsely present silver, tin, lead and iron, no clear differences between coins and medals are apparent in the period 1450-1800. As shown in Graph 10, silver as a trace element occurs often. The amount of detected silver lies in average around 0.1%. Since silver has a higher market value than copper, it is not deliberately added (unless an object is silver plated, see section 2.3). Silver as a trace element in copper coins and medals is clearly a residue from the refining process (of ore as well as re-melted old silver coins).

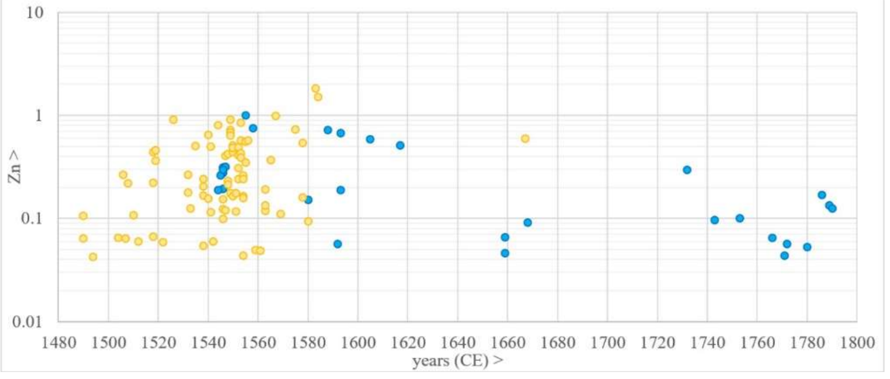
A clear deviation has been found for zinc (Graph 23), where the values between 0.1-1% appear to occur disproportionately often with medals, in the period up to 1620. Unfortunately, in the following period 1620-1700 fewer objects could be measured (as is clearly visible in Graph 2) but even so, the amount of zinc in coins is remarkable low compared to medals.



Graph 21 – *Scatter chart of antimony in all measured copper coins (blue) and medals (yellow), period 1460-1800.*



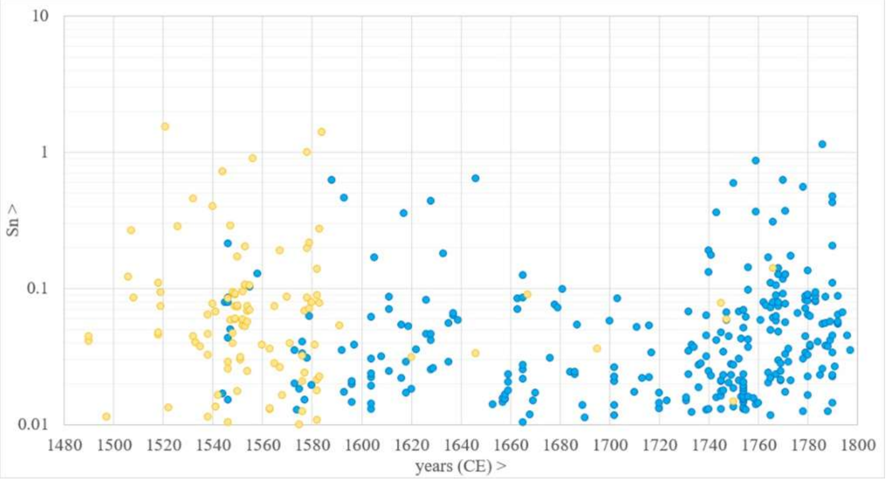
Graph 22 – *Bar chart with the sum of all trace elements in the measured copper coins (blue) and medals (yellow).*



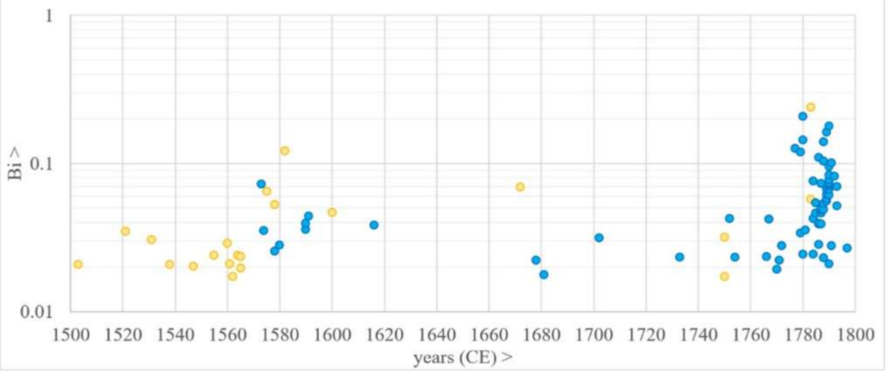
Graph 23 – *Scatter chart of zinc in all measured coins and medals, period 1480-1800* (yellow = medals, blue = coins).

Furthermore, a void is noticeable in the scatter chart of tin (Graph 24). In the seventeenth and early eighteenth centuries the tin values of 0.1-1% are almost completely absent for the coins. Unfortunately, the medals of this period were not analysed.

A special phenomenon occurs with bismuth. This material is naturally found as a by-product of silver mining and at first glance studying this metal in copper coins seems less relevant. However, the scatter chart (Graph 25) shows two notable peaks, the first around 1580 and the second in the 1780-1800 period.

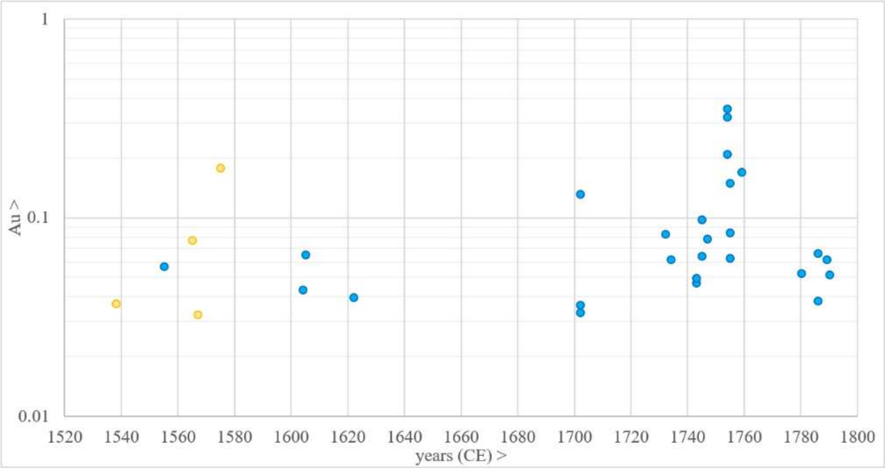


Graph 24 – *Scatter chart of tin in all measured coins and medals, period 1480-1800* (yellow = medals, blue = coins).



Graph 25 – *Scatter chart of bismuth in all measured coins and medals, period 1500-1800* (yellow = medals, blue = coins).

Finally, there is a noticeable peak in the trace element gold around 1750 (Graph 26, appendix 4). This concerns eight *duit*-coins from Holland (1754, Picture 40), Zeeland (1754), West Friesland (1745, 1754 and 1755, the first and last minted for the Dutch East India Company), Utrecht (1748) and Gelderland (1755 and 1759).



Graph 26 – *Scatter chart of gold in all measured coins and medals, period 1520-1800* (yellow = medals, blue = coins).

Picture 40 – Holland, Dordrecht, *duit*. 1754, copper, 21 mm, 3.2778 g (inv. TMNK 15930). 'Polluted' with 0.35% gold.

2.9 Eighteenth Century

According to his doctoral research, Scheffers found in archival records the provenance of the material used for the eighteenth-century copper money from Holland and West Friesland over several years.[55] In 1702 the mint materials is supplied from both Sweden and Hamburg, in 1710-1715 from Sweden, in 1716 from Hungary (present day Slovakia, Picture 41), in 1717-1723 and 1738 from Sweden (Picture 42), in 1739 both from Sweden and from copper mills in the Veluwe, in 1741-1742 from Sweden (Picture 43) and in the period 1753-1780 again from the Veluwe copper mills (Picture 44). Of course, these recorded

55 Scheffers, 2013-2: 362-363.

provenances should be studied with reservations. Perhaps sometimes an old leftover batch from another origin has been processed. Moreover, the source of the copper that was converted into coin flans in the Veluwe copper mills is unknown.

Picture 41 – West Friesland, Medemblik, *duit*. 1716, copper, 23 mm, 3.2322 g (inv. TMNK 10274). Probably from Hungarian copper.

Picture 42 – West Friesland, Medemblik, *duit*. 1717, copper, 22 mm, 3.3982 g (inv. TMNK 13556). The only coin of presumed Swedish copper with an abnormally high elemental composition of antimony. About a third of this year's production or 759,600 coins, were destined for Groningen and Ommelanden despite the legend 'WEST FRISIAE'.[56]

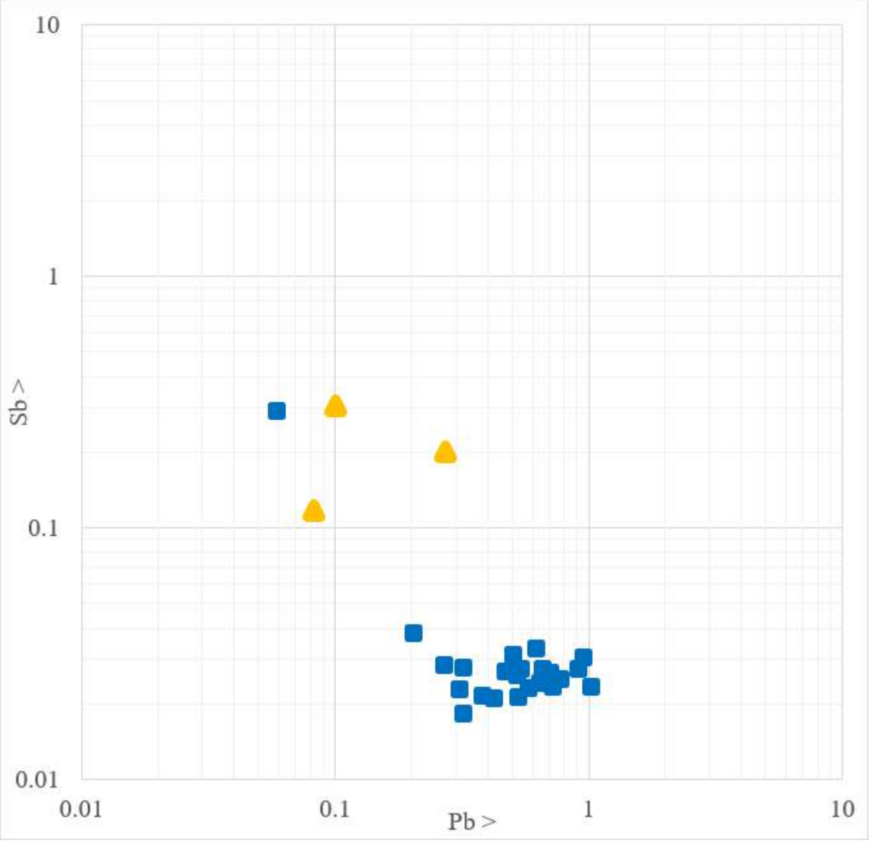
Picture 43 – Holland, Dordrecht, *duit*. 1741, copper, 22 mm, 3.2164 g (inv. TMNK 10591). Probably from Swedish copper.

Picture 44 – West Friesland, Enkhuizen, *duit*. 1765, copper, 22 mm, 3.2003 g (inv. TMNK 10379). Probably from Veluws copper.

The collection of Teylers Museum contains 128 coins bearing one of the above dates, according to Scheffers to be divided in: 3 from Hungary, 81 from the Veluwe, 25 from Sweden, 11 from Sweden or Hamburg and 8 from Sweden or from the Veluwe. It follows that only two groups of coins (the 3 Hungarian and 25 Swedish) have a traceable provenance. These are shown in Graph 27. Unfortunately, the number of coins that could be measured is very low, so that

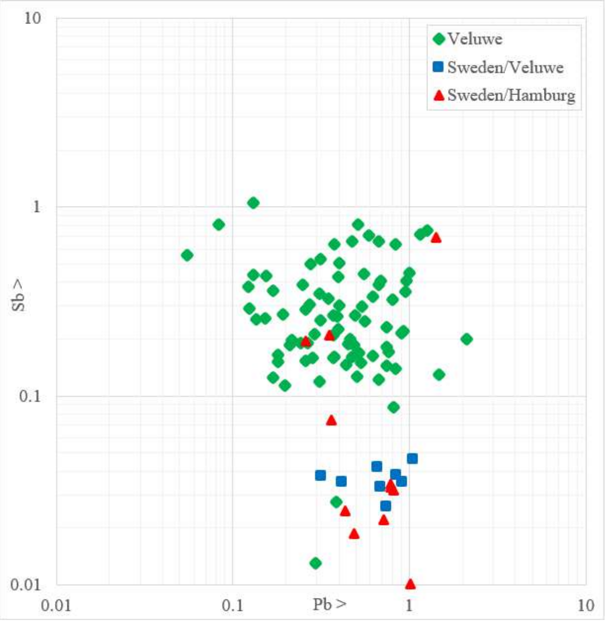
56 Scheffers, 2013-1: 243-244.

the demonstrated differences cannot be interpreted with certainty. The graph shows that the Hungarian copper has a higher antimony value and a slightly lower amount of lead, while the Swedish coins show a remarkably strong cluster with lower antimony values except for one specimen. The deviating coin is a West Frisian *duit* from 1717 (Picture 42).[57] In the museum collection this is the only copper coin from 1717 from the Dutch Republic, which means that it cannot be compared with other coins from the same year; Graph 27 makes it plausible that this coin is not made of Swedish copper, but of Central European copper. Graph 28 includes coins with an assumed Sweden-Hamburg, Sweden-Veluwe or Veluwe origin.

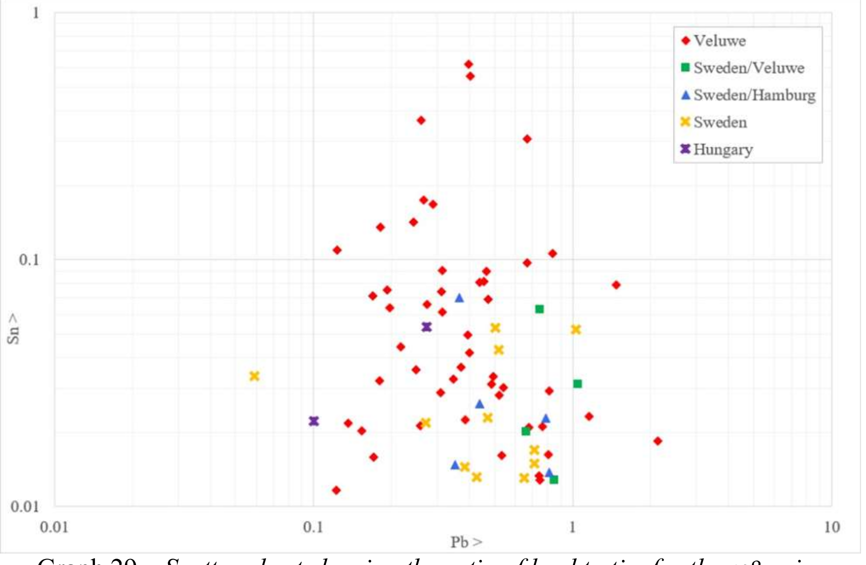


Graph 27 – *Scatter chart showing the ratio of antimony to lead, with metal of presumed known provenance; 25 from Sweden (blue) and 3 from Hungary (yellow).*

[57] TMNK 13556.



Graph 28 – *Scatter chart showing the ratio of antimony to lead, with metal of presumed known provenance; 81 from the Veluwe (green), 11 from Sweden or Hamburg (red) and 8 from Sweden or from the Veluwe (blue).*



Graph 29 – *Scatter chart showing the ratio of lead to tin, for the 128 coins of the Veluwe (red), Sweden-Veluwe (green), Sweden-Hamburg (blue), Sweden (yellow) and Hungary (purple).*

Graph 29 shows the trace element tin of the 128 coins. Although the scatter chart shows higher values than for the elements bismuth and gold – which remain just above the detection limits, those graphs are not shown – there is no clear difference between the groups. Tin could be a residual contaminant from the production chain, where metals – mainly lead – were added to extract other metals, mostly silver.[58] The lack of difference could be caused by the relatively small amount of objects as well as the limited period in time (1702-1780).

3 HISTORICAL BACKGROUND

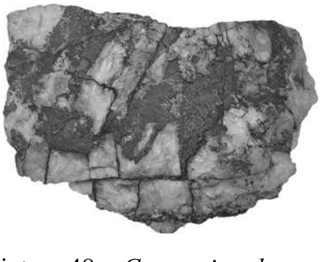
3.1 Copper

The name copper is derived from the Latin word *cuprum*, which in turn is derived from *aes cyprium* (Cyprian ore). Copper ore (examples: see Pictures 45-48) has been mined all over the world. It was already mined in pre-historic times, as evidenced by the ore mining in Tyrol, which started about 5,000 years ago.[59]

Picture 45 – *Amorphous copper sulphide from Dalarna (Sweden)* (inv. M 05824). Falun, with the Stora Kopparberget, is also located in this region.

Picture 46 – *A lump of chalcopyrite (copper-iron disulphide, $CuFeS_2$) from Plymouth, Cornwall* (United Kingdom) (inv. M 05490).

Picture 47 – *Nugget of copper from Rheinbreitbach (south of Bonn, Germany)* (inv. M 05423).



Picture 48 – *Copper in a lump of pegmatite, from Rheinbreitbach (south of Bonn, Germany)* (inv. M 05421).

[58] Skowronek *et al.*, 2021: 11; Pernicka, 2014: 255-256, 259; Warnke, 1980: 433.

[59] Breitenlechner *et al.*, 2012: 7.

Native copper is *sometimes* found when the rock around it has eroded (forming nuggets) or without other minerals attached to it (a pure form). It often takes more effort to extract copper; refining is needed. Copper ore is complex in nature because it contains many other elements. For instance, one of the ore samples found near Banská Bystrica (Slovakia, German: Neusohl) – one of the active mining areas in the researched period – contained between 8% and 15% copper and a second sample was between 1.5% and 4% copper.[60]

After *ore* beneficiation, ore was crushed and roasted in smelting furnaces.[61] Sometimes other metals are added to the copper to be able to extract metals.[62] For example, lead is added to extract silver via liquation (where metals are separated from each other on the basis of their different melting points), after which a higher elemental composition of lead remains in the copper.[63] In Europe in the researched period 1500-1800, much lead was used in the refining of copper from the mines in Upper Silesia (southeast Poland), the Harz Mountains, the Eifel and the Rhineland.[64] The Swedish copper contained no silver, so no lead had to be added to that copper.[65]

The source for the copper in the individual objects studied is difficult to determine, for the raw material purchase documents were not preserved. At some point, copper from various areas came together and, moreover, 'second-hand' copper may have been mixed in. Furthermore, only research of elemental *compositions* might be able to provide a definitive answer. Time seems to be an important factor for the source of copper, as it could indicate copper coming from different sources or ore veins.

3.2 Mining: ore veins

Historically, there have been shifts in the supply of copper in the Northern Netherlands, as mining areas became exhausted or new mines opened (Graph 30). During the period under study, the centre of copper production in Europe shifted several times. In the period circa 1500-1700, there were only a couple of main mining areas where copper was extracted in Europe.[66] There were three main regions: Thuringia, Tyrol and the Slovak Ore Mountains.[67]

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60 Westermann, 1986: 191.

61 Craddock, 1995: 168.

62 *Ibid.*: 232.

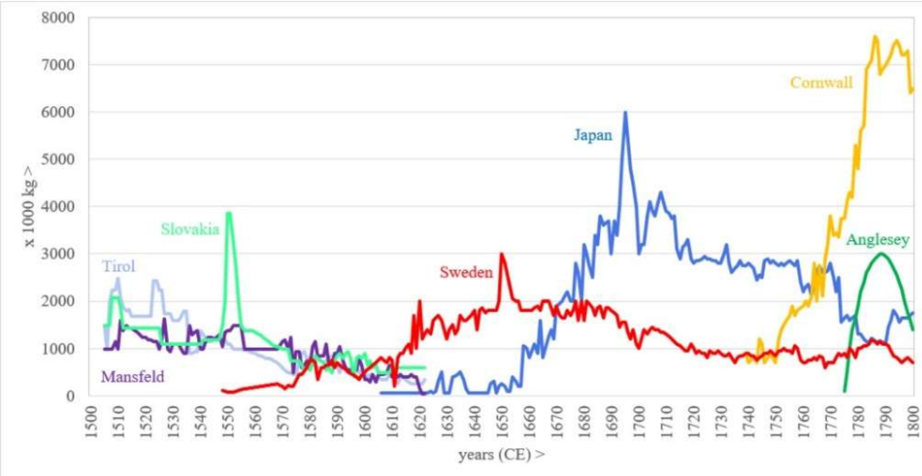
63 Skowronek *et al.*, 2021: 2; Hauptmann *et al.*, 2016: 181 and 197; Héritier & Téreygeol, 2010: 136-152; Westermann, 1986: 188.

64 Skowronek *et al.*, 2021: 2; Westermann, 1986: 193.

65 Van Os, 2019: 68; Hansson & Rootzén, 2002: 130.

66 Hauptmann *et al.*, 2016: 191; Kellenbenz, 1977: 292.

67 Paehr, 2018: 16; Hauptmann *et al.*, 2016: 191-193; Westermann, 1986: 187, 196-197.



Graph 30 – *Global copper production in tons, for Mansfeld (purple), Slovakia (light green), Tyrol (light blue), Sweden (red), Japan (blue), Anglesey (green) and Cornwall (yellow).* Sources: Modified combination of the data from Eiji (Japan and Sweden 1620-1800, Cornwall to 1760), Forshell (Sweden 1548-1620), Hauptmann *et al.* (from Westermann, covering Tyrol, Slovakia and Mansfeld 1505-1622), Symons (Cornwall and Anglesey 1760-1800) and Hansson & Rootzén (Falun 1580).[68]

The copper ore in these three regions contained traces of silver as this metal was also mined in these areas.[69] In the fifteenth century, much copper came from the region around the Harz (on the north side of Thuringia, from towns such as Mansfeld and Goslar, Picture 49) and the Ore Mountains (Krušné hory, Pictures 1 and 50) south of Schemnitz, on the border of Germany and the Czech Republic.[70] In the sixteenth century this was supplemented with ore from the Inn Valley in Tyrol and from Slovakia. The copper mines in the Slovak Ore Mountains (in those days called 'Hungarian Ore Mountains', because the region was part of Hungary), were mainly located in the vicinity of Banská Bystrica (German: Neusohl, Picture 51). Over 50% of the copper extracted there was transported to the Netherlands.[71]

This was also the time when, under the influence of the large influx of precious metals from Spanish America, the old, medieval coins – made of metal of European origin such as Saxony and Bohemia – were withdrawn from circulation. After re-melting and adjusting the metal to the demanded silver content, new coins were produced from the old metal.

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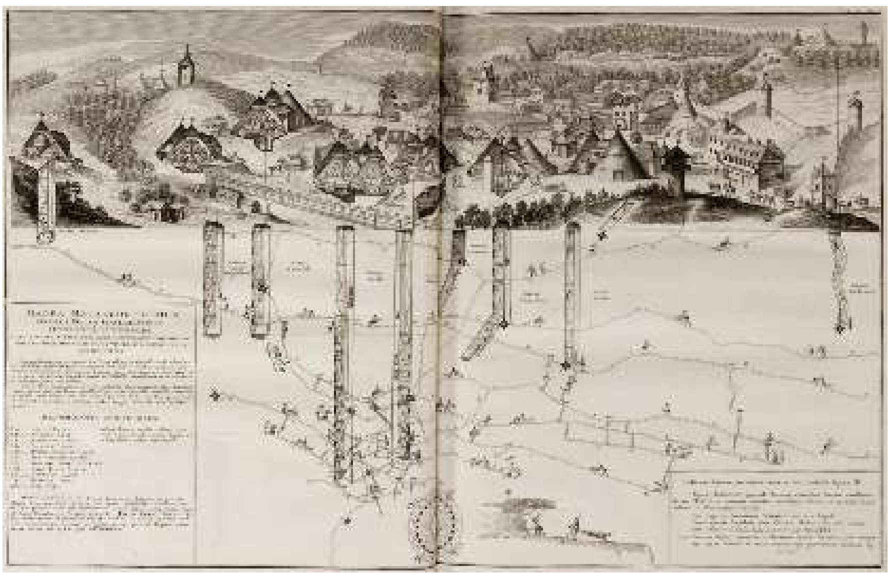
[68] Eiji, 2013: 16, figure 1.2; Forshell, 1992: 46 figure 2; Hauptmann *et al.*, 2016: 192, figure 7, from Westermann, 1986: 196-197; Symons, 2003: 79; Hansson & Rootzén, 2002: 129.

[69] Hauptmann *et al.*, 2016: 193; Westermann, 1986: 187.

[70] Skowronek *et al.*, 2021: 2; Martinón-Torres *et al.* 2018: 43-44.

[71] Westermann, 1986: 201.

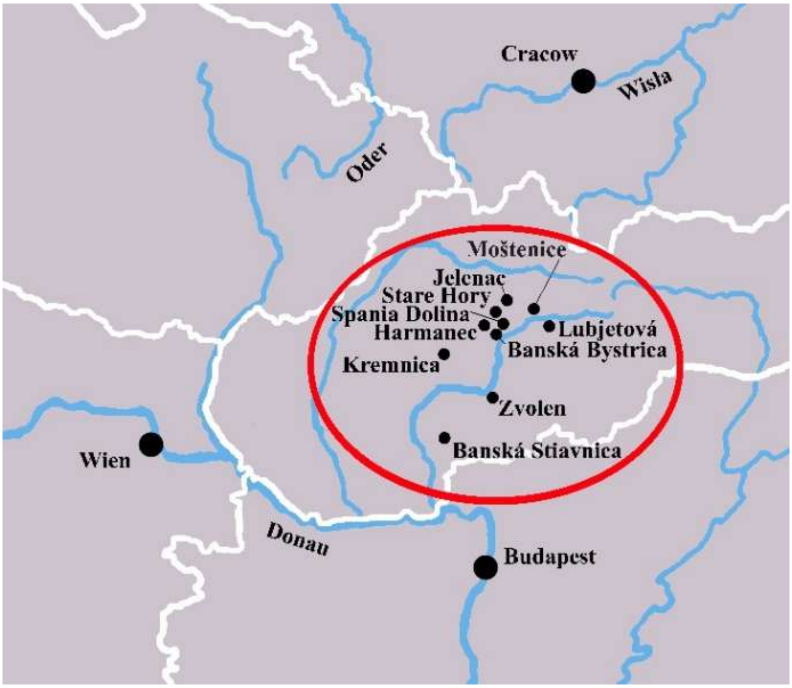
Picture 49 – Matz Sincken, *Goslar with the Rammelsberg in the background*. 1574, watercolor 36 × 20 cm (collection: unknown, public domain).[72]



Picture 50 – Luigi Marsigli, *Mines at Banská Štiavnica (German: Schemnitz) in Slovakia*. 1726, etching on paper (inv. 138a 106).[73]

72 https://commons.wikimedia.org/wiki/File:Rammelsberg_Goslar_Bildkarte_1574_Matz_Sincken.jpg (consultation 24 January 2022).

73 Marsili, 1726: 21-23, picture 52.



Picture 51 – *Copper mines in the Slovak Ore Mountains* (map: author). The Baltic Sea could be reached via the Vistula (Wisła) and the Oder.

Picture 52 – Erik Dahlberg, *The Falun Copper Mine*. 1705, etching on paper, approx. 39 × 28 cm (private collection).

Picture 53 – *Copper bars from Japan*. 18th century (photo: website Huygens ING).[74]

Picture 54 – John Warwick Smith, *The Copper Mine of Parys*. Circa 1800, watercolor and pencil on paper, 27 × 32 cm (collection: © Amgueddfa Cymru, National Museum Wales, inv. NMW A 3198).

74 https://voc-kenniscentrum.nl/prod-koper.html, consultation 23 January 2022: collection Rijksmuseum Het Koninklijk Penningkabinet, but not found in the spring of 2021 by employees of De Nederlandsche Bank, where the National Numismatic Collection is stored.

From the end of the seventeenth century copper came mainly from the Swedish area of Falun (with the Stora Kopparberget, Picture 52) – with a peak in the period circa 1600-1690 and the most productive period around 1650 – which at the beginning of that century had met about 90% of the European demand.[75] Until the early 1620s, this was black copper, containing about 90% copper in addition to elements such as iron, zinc, lead and sulphur.[76] Under the influence of the coppersmith and arms dealer Louis de Geer (1587-1652) – who had been given a monopoly on the copper and iron trade by the Swedish king in the 1620s – Swedish production grew and professionalised. From that time on, the copper was better refined. In the seven-teenth century, copper from Norway in addition to the Swedish copper was traded in the Dutch Republic. This Norwegian copper arrived in Amsterdam in large quantities around 1650.[77] Moreover, around 1630 Japan became a major supplier.[78] The supply of Japanese copper (Picture 53) continued in fits and starts into the eighteenth century, with the four main mines being Ashio, Ani, Besshi, and Osarizawa.[79] Much of that Japanese copper – often exported in bars – remained in Asia, where it was resold at a profit.[80] Japan struggled with copper exports as copper became scarce domestically and the mines yielded less and less. As a result, at one point, iron was used for coinage instead in Japan; *kan'ei tsūhō*.[81] In the second half of the eighteenth century, a large amount of Norwegian copper arrived in the Republic of the Seven United Netherlands.[82] From 1740, copper production in China (Yunnan) rose sharply, but that production was probably destined for the Asian market.[83] In the eighteenth and nineteenth centuries, much copper came from Cornwall (where mining was already taking place in the sixteenth century). In the third quarter of the eighteenth century, a new influx of copper was added from Mount Parys on the Isle of Anglesey (Ynys Môn) in Wales (Picture 54).[84] Anglesey and Cornwall were the most productive areas, but that does not mean that all the copper used in the Dutch Republic came from there. For instance, on 18 April 1770 the Brussels mint master Thomas Vander Motten ordered copper coin flans in Cologne.[85] In England there was the smaller but equally

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75 Van Os *et al.*, 2014: 135-138; Forshell, 1992: 45-46.

76 Van Os *et al.*, 2014: 137; Hansson & Rootzén, 2002: 130.

77 Forshell, 1992: 40.

78 Glamann, 1958: 172-173.

79 Eiji, 2013: 21; Shimada, 2006: 187; Pol, 1989: 44; Scholten, 1951: 44.

80 Website Huygens ING: https://voc-kenniscentrum.nl/prod-koper.html (consultation 23 January 2022); Shimada, 2006: 187; Warnke, 1980: 436.

81 Munro, 1904: 112, 135.

82 Ranestad, 2019: 201 note 19.

83 Eiji, 2013: 16.

84 Symons, 2003: 8, 79 figure 3.13; Hamilton, 1967: 13.

85 Kind notice of Lei Lennaerts, source: State Archive Brussels, Jointe-de-Monnaies, inv. 294.

active Ecton mine in Staffordshire and also other regions – such as on the Iberian Peninsula and the Balkans – produced copper that may have ended up in the Dutch Republic.[86] Around 1800, production in Anglesey declined while that in Cornwall grew, thanks in part to the use of the first steam engines to pump water from the mines.[87] In the French period (1795-1815), the supply of English copper in the Dutch Republic came to a halt.[88]

3.3 Transportation

During the centuries, the source of the copper shifts a couple of times. Prior to 1546, the Fugger banking family had a big finger in every pie in Central European mining (including a widespread organisation focusing on transport and selling copper).[89] Rivers such as the Elbe and the Oder played an important role in the transport of Central European copper via the Baltic Sea to the Netherlands (Picture 55).[90]

Picture 55 – *Overview of the most important copper mining areas in the researched period (red), important waterways, the Sound Toll at Kronborg (yellow) and the ports mentioned by Scheffers and in the Sound Toll Register from where copper was transported to the Netherlands (green)* (map: author).

86 Ranestad, 2019: 190-209, 204 figure 2; Hauptmann *et al.*, 2016: 194; Symons, 2003: 50.

87 Symons, 2003: 8-9, 159; Hamilton, 1967: 17.

88 Symons, 2003: 114-115; Hamilton, 1967: 343.

89 Van den Brenk *et al.*, 2019: 3; Warnke, 1980: 443; Jansma, 1976: 22.

90 Hauptmann *et al.*, 2016: 193; Pohl, 1977: 237.

The copper was often transported from Mansfeld (Saxony-Anhalt, on the edge of the Harz Mountains) and Thuringia to Aachen, Nuremberg and Frankfurt am Main.[91] In addition, Mansfeld had access to the Elbe via the nearby Saale River. It is also known that Nuremberg merchants transported copper from Mansfeld and Schwaz (Tyrol) to Dordrecht.[92] Copper from Tyrol was also traded through Venice.[93] Much of the Hungarian copper reached Danzig (Gdańsk) and the Baltic Sea via Kraków and the Wisła (Vistula), from where it was transported – among other places – to Antwerp and Amsterdam.[94] Some copper even went around the world in trade via Portuguese merchants to India, as shown by the cargo of various shipwrecks.[95] The route via Gdansk was lucrative, because from 1524 onwards, the Fuggers did not have to pay a toll at the Sound at Kronborg (Picture 56, the strait between Sweden and Denmark that connects the Baltic Sea to the North Sea).[96]

Picture 56 – Georg Braun & Frans Hogenberg, *The Sound at Kronborg – Freti Danici or Sundt Accuratiss Delineatio*. 1620, hand-coloured etching on paper, 34 × 47 cm (private collection).

91 Westermann, 1986: 189.

92 Jansma, 1976: 7.

93 *Ibid.*: 8.

94 *Ibid.*: 6 & 12-13.

95 Van den Brenk *et al.*, 2019: 33; Hauptmann *et al.*, 2016.

96 Coenen *et al.*, 2021: 15.

That the transport routes of the copper were diffuse is apparent from the mention of Hungarian copper that was transported to Denmark via Sweden.[97] This would involve 'old' – so to be recycled – copper. This was probably done to circumvent import restrictions or because Swedish production was lagging behind demand.

Recently – in 2019 – archaeological evidence of the widespread copper trade was found off the coast of the Dutch isle of Terschelling. It concerned a sunken ship, the so called '*Koperplatenwrak*' (*Copper Sheets Wreck*) that sailed from the Baltic towards the Netherlands between 1538 and circa 1550.[98] It transported 37 round and 433 rectangular Hungarian copper sheets from the period 1508-1540, bearing the Fugger mark (Pictures 57 and 58).[99] The sheets – packed in copper covers, of which 17 have been found – measure approximately 84 × 61 cm, with a thickness of 1-2 mm and a weight between 6-9 kilograms each. The discs have a diameter of about 104 cm, a thickness of 2-3 mm and weigh about 28 kilograms. The wood of the ship most likely comes from North-western Germany, which means that the ship was probably built in the Hamburg region or in the Northern Netherlands.[100]

Picture 57 – *Copper sheets from the ship that was found in 2019 off the coast of Terschelling* (photo: Periplus Archeomare).

Picture 58 – *Detail photo with the Fugger-mark on a copper sheet of the ship found in 2019* (photo: Periplus Archeomare).

97 Ranestad, 2019: 204-205.

98 Coenen *et al.*, 2021: 16; Van den Brenk *et al.*, 2019: 3.

99 Van den Brenk *et al.*, 2019: 27-29 & 57.

100 Van Daalen: 5.

Tyrol is known to have refined copper ore on site (leading to both pollution and deforestation).[101] In Great Britain, the ore was transported over a greater distance to South Wales and Bristol, due to the presence of fuel for the furnaces. The extraction again led to pollution, lawsuits have even been filed against the mining companies.[102] In the period 1785-1792 the Cornish Metal Company (CMCo) cooperative was a leader in the processing and trading of the ore, after which South Wales took over the leading role again.[103] Possibly, after refining, the copper was transported by land or sea towards London before being transported to the Dutch Republic although more direct transport routes from other English ports to the Dutch Republic are possible.

The diversity of origin of the copper transported to the Dutch Republic becomes clear when the Sound Toll Register is consulted.[104] In the period 1634-1857, copper for coins appears to have been transported to the Dutch Republic about 30 times, from different regions of origin (see Appendix 3 and Picture 55). Stockholm is often mentioned in the register as a departure point, other cities mentioned are Nyköping (Sweden), Reval (Tallinn, Estonia), Königsberg (Kaliningrad, Russia), Riga (Latvia) and Memel (Klaipėda, Lithuania). Although not recorded in the Sound Toll Register, but according to Scheffers, copper was also supplied from Hamburg.[105] Depending on the circumstances, this was partly done over land. Hamburg acted as a major transit port, with copper arriving from Central Europe via the Elbe.[106] The Sound Toll Register also shows that copper from Stockholm was traded there in the nineteenth century. It cannot be ruled out that copper from Sweden also arrived in Hamburg during the period of the current investigation, 1460-1800. This probably happened via a detour (such as via Danish copper mills) because Hamburg is not mentioned as a destination in the Sound Toll Register during this period.

It is difficult to link the transports mentioned in the Sound Toll Register to the suppliers and delivery periods mentioned by Scheffers.[107] Moreover, the contemporary descriptions in the register sometimes leave room for speculation about what exactly was transported. It is probable that copper transports for coin production occurred more frequently than the register shows, but sometimes the registration is too brief to determine what the copper was intended for, or the destination of the ship is not stated. In addition to spelling variations, the register also contains words such as '*myntekobber*' (coin copper), whereby the reader

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[101] Breitenlechner *et al.*, 2012: 17.

[102] Rees, 2000.

[103] Symons, 2003: 8, 109-110.

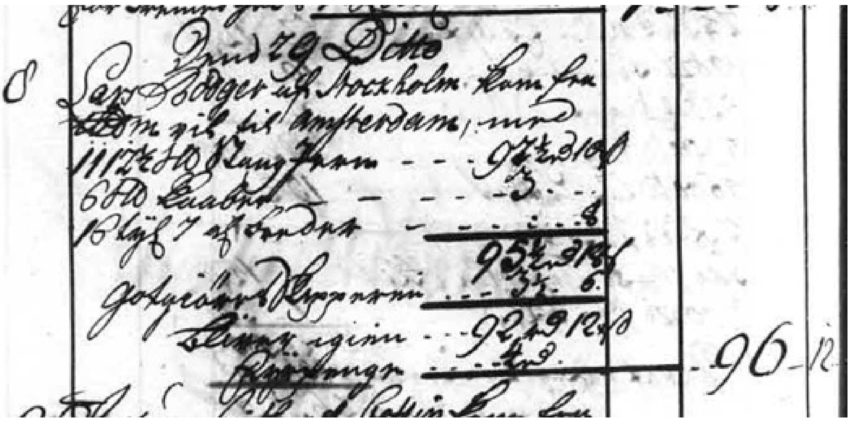
[104] www.soundtoll.nl.

[105] Scheffers, 2013-1: several entries, amidst other 188, 220, 229-231, 251, 261.

[106] Westermann, 2002: 87-88.

[107] Scheffers, 2013-2: 363.

may wonder whether it concerns coin flans or sheets of copper the thickness of coins. Scheffers' study shows that the former is as likely as the latter. A name such as '*penge*' also causes ambiguity. This could be read as medals (for example: counter tokens), coins (the Danish word *pengar* can be translated as money) or perhaps also coin flans. As an example: Scheffers reports that at the beginning of April 1739 six barrels with copper coin flans arrived from Sweden.[108] Only one transport movement can be linked to this in the Sound Toll Register (Picture 59). On March 29 of that year, Lars Bodger from Stockholm – en route from Stockholm to Amsterdam – passes the toll with a batch of 6 *skippund kaaber* (960 kilogram of copper).[109] So it is only registered here that he has copper as cargo; this record is far too meaningless because shiploads of copper were often delivered to Amsterdam for other purposes as well.



Picture 59 – *Entry in the Sound Toll Register of 29 March 1739.* On his way from Stockholm to Amsterdam, Lars Bodger passes Kronborg with, among other things, a cargo of (converted) 960 kg of copper in his hold (source: Sound Toll Registers).[110]

In the Dutch Republic it turned out that often intermediaries were involved before the copper arrived at a Mint. Scheffers, for example, relates that in 1701 the (Swedish-born) Amsterdam essayist Anthonij Grill (1664-1727) received an order, while the Amsterdam merchants Pieter and Jacob Vermaten and the Dordrecht merchant Salomon Levi Meijer overpriced their bid and missed the order.[111] So there were several merchants who were able to deliver flans for the production of copper coins. In the course of the eighteenth century, minting ma-

[108] Scheffers, 2013-1: 254.

[109] www.soundtoll.nl, record 514251, passage 8, picture: Sonttol film 207 image 157 folio 211.

[110] www.soundtoll.nl, record 514251, passage 8, picture: Sound Toll film 207 image 157 folio 211 (consultation 11 December 2021).

[111] Scheffers, 2013-1: 185-186.

terial was to be supplied for the Mints in Holland and West Friesland on behalf of the general masters of the Mint, by goldsmith and essayist Johannes Grill (1668-1734), the Amsterdam merchants Dirck Slicher, Willem van Elen, Jacob and Barent Bolck and Johannes Grill (1708-1754) and the Amsterdam copper trader Jacobus Vermaten.[112] Copper traders Daniël Mits and Jan Hessels (1729-1801), both owners of copper mills in the Veluwe (a forest-rich ridge of hills in the province of Gelderland in The Netherlands), also supplied coin flans.

3.4 Copper mills

In eighteenth-century Oldenburg, it was mainly raw copper that was brought in, which was processed into sheets in local copper mills, after which it was sold to coppersmiths to make objects.[113] This state of affairs can be explained, among other things, by the easier transport of copper ingots in combination with the multitude of products to be produced from the copper. In addition, the value of the copper after refining, re-smelting and hammering increased considerably; the trade price was more than ten times higher than for raw copper.[114] This also happened in the Northern Netherlands, where sometimes raw copper from other areas was transported via Denmark.[115] Dozens of copper mills were active in the Northern Netherlands – also outside the Veluwe, such as in the Zaan region – that were powered by water power (Picture 60).[116] It is known that a mill on the Klaarbeek in Zuuk (near Epe) not only hammered copper sheets, but also had a '*duitenknipperij*' (an installation to cut coin flans for small copper coins). Ready-made coin flans were therefore produced in the mill itself. Probably, this was not the only mill where coin flans were produced.

According to an instruction for the mint masters of Holland and West Friesland from 1702, it appears that the provincial government had to supply the coin flans, on a weight of '2 english and 11 5⁄17 aas' with a deviation of maximum 3 aas.[117] The troy pound of 494,094 gram, was subdivided into 320 english and 10,240 aas, so a coin flan weighed between 3.49 and 3.78 g, with the ideal of 3.63 g. Not all coin flans were produced by the copper mills in the Veluwe area. Coin flans were often brought in from abroad and, in the Dordrecht Mint in 1702, as a test coin flans were made from a batch of Hamburg copper sheets.[118] Scheffers mentions Sweden and Hamburg as the origin, whereby he suspects that the copper supplied via Hamburg originates from Hungary. Following the

[112] Scheffers, 2013-2: 363.

[113] Ranestad, 2019: 196.

[114] *Ibid.*: 202.

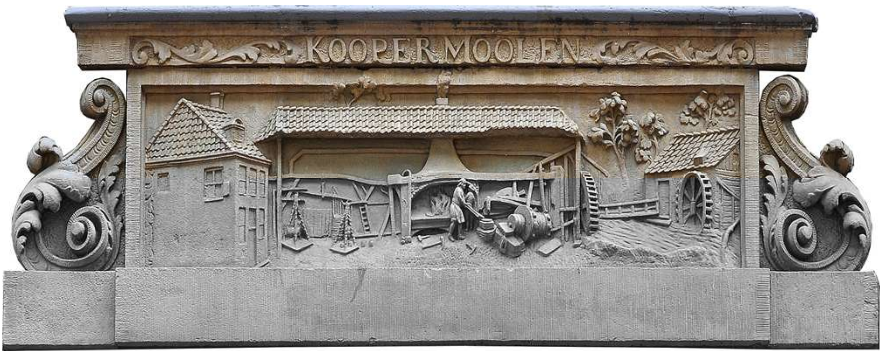
[115] Ranestad, 2019: 196 & 206-207.

[116] 58 registered in www.molendatabase.org.

[117] Scheffers, 2013-2: 328.

[118] Scheffers, 2013-2: 332-363; Scheffers, 2013-1: 186 and further.

course of the rivers, it would seem that the Hungarian copper was mainly transported to the Baltic Sea via the Wisła and Danzig, while the copper from Mansfeld was traded via Hamburg. A further investigation into the trans-port movements would be useful.



Picture 60 – Anonymous, *Gable stone from the house 'Warmoesstraat 5' in Amsterdam, with the interior of a copper mill*. Approx. 1725, approx. 120 × 70 cm (photo: author). Visible are scales, an oven with bellows and a crushing installation, driven by a water wheel. This copper mill was active from 1569 until shortly after 1753, on the Grift River near Vaassen (Gelderland). The resident of the Amsterdam building, Rudolphus Knuijse (1684-1747), owned several copper mills. His widow Eva Wateringe (1699-1770) sold the mills in 1753 for *f* 28,000 to Frederik Johan van Isendoorn à Blois (1699-1771), lord of the Cannenburgh (in Epe) from 1712-1771.[119]

Not all smelters mastered the copper refining process well.[120] Contemporary Danish research showed that the quality of copper varied from area to area, affecting the ability to process it into a finished product.[121] For example, the Hungarian copper turned out to be hard and uneven, causing it to break or crack quickly, while the sulphur-rich Norwegian and Swedish copper was much more usable after refining. In turn, the makers of brass objects in Aachen preferred the pure copper from Mansfeld.[122] As a result, copper could be ordered from different areas, depending on the processing it had to undergo and – of course – the price paid for it. For example, for the production of copper coins in the Dutch Republic in 1720, the '*veel cierlijker ende beter*' (much more elegant and better) coin flans from Sweden could not be purchased due to increased prices and they had to be satisfied with the less quality coin flans from Hamburg.[123]

[119] N.N., (n.d.): internet publication on www.vaassenhistorie.nl (consultation 18 July 2021).

[120] Skowronek, 2021: 6-7.

[121] Skowronek, 2021: 6; Ranestad, 2019: 202-203.

[122] Skowronek *et al.*, 2021: 2 and 9; Westermann, 1986: 188; Peltzer, 1908: 369.

[123] Scheffers, 2013: 234.

4 INTERPRETATION

In some 30 graphs, the possibilities of XRF-research on copper coins and medals has been explored. Also the historic background has been researched, from ore to object. In this section both researches will be combined, to investigate if the data gained by XRF-research provides new insights.

Even after refining, copper generally contains some degree of impurities, the trace elements. It is known that in each ore region, the trace elements differ slightly. For example, Cornish copper usually contains sulphur and sometimes iron.[124] In Anglesey, zinc is also found. In Cornwall, tin is often found near copper.[125] Copper also occurs naturally together with lead.[126] All these elements occur frequently in other ore regions as well; it would be important to research the composition of the raw copper from these regions for proper comparisons.[127]

The combination and size of trace elements are like a fingerprint; they might indicate specific mining regions. In addition, refining or processing of the copper can affect the presence of these trace elements.[128] For example, the amount of antimony (stibium), which is common in sulphur-containing (sulfidic and oxidic) copper ores, decreases when the ore is heated. Later, when copper is melted down for reuse, the amount of antimony decreases even further. Adding or subtracting metals – like the addition of lead to retrieve silver – diffuses the 'fingerprint'.

4.1 Ore regions

During the period under investigation, several ore regions peak in production (Graph 30). Around 1600, there is a shift from Central European to Swedish copper, around 1750 followed by a shift to copper from Great Britain. Although there must be overlap in the supply of copper from several sources, as well as the recycling of old copper, it is possible that the shifts from one region to another are visible in the trace elements.[129]

Graph 19 shows the average values of various elements over time. In the period of the first two groups, up to 1600, much copper was mined in Central Europe, after which Swedish copper becomes dominant (the two middle groups). The last two periods, 1750-1775 and 1775-1800, show copper which in many cases must have come from Great Britain. The graph shows only average values per

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124 Symons, 2003: 15.

125 *Ibid.*: 27.

126 *Ibid.*: 83.

127 Pernicka, 1999: 165-166, 169; Ixer, 1999.

128 Hauptmann *et al.*, 2016: 183; Pernicka, 2014: 253-255; Pernicka, 1999: 164-165; Ixer, 1999; Tylecote *et al.*, 1977: 320.

129 Pernicka, 2014: 250-259.

period; this makes it difficult to compare since it is very likely that not all used copper arrived from the same source.

The data on iron and nickel coins and medals are in line with each other and there are also no clear differences over time. That is why these two metals are not researched further. For the other metals, the recorded values per element over time are presented in more detail: Graph 23 for zinc, Graph 24 for tin, Graph 25 for bismuth, Graph 26 for gold, Graph 21 for antimony and Graph 10 for lead and silver. In addition to the origin of the copper, later refining – for example in the Veluwe copper mills – can play a role in the amount of trace elements present. Therefore, Graph 28 includes coins with an assumed Sweden-Hamburg, Sweden-Veluwe or Veluwe origin. The differences will be discussed in the sub-sections below.

4.2 Gold

Graph 26 shows the measured gold values. In most cases, the amounts of gold as trace element in copper remain below the detection limits. A significant peak around 1750 is probably related to the large gold discoveries in Brazil, where about 15,000 kilograms of gold was mined annually around the middle of the eighteenth century.[130] This caused the gold price in Europe to fall and in the Dutch Republic the production of coins from the cheaper gold was stimulated.[131] This may have briefly resulted in a reduced focus on refining minute quantities of gold from copper.

4.3 Silver and lead

Almost all copper objects contain a measurable amount of lead, which was partly already present in the ore. Lead was often added during the refining process to extract other metals, mainly silver. This process eventually left some traces of lead in the copper objects. Some silver remained as well, since it was too expensive to remove all of it during refining.

The Swedish copper probably originates from Falun, which supplied almost all copper for Swedish coin production in the period 1624-1831.[132] As is shown in Graph 10, even in the period where a Swedish source of the copper can be assumed, a lot of objects appear to contain lead and silver. This contradicts the vision that Swedish copper does not contain silver.[133] The presented data is insufficiently robust to make any broad statements on the composition of (exported) Swedish copper; additional research is needed to find out if this is a

[130] Machado & Figueirôa, 2001: 13.

[131] Van Gelder, 2002: 168-169.

[132] Hansson & Rootzén, 2002: 131.

[133] Van Os, 2019: 68; appendix 6.

result of – for instance – Swedish refining techniques or that non-Swedish copper is used more often than expected.

The Anglesey period, 1775-1800, is characterized by lower silver values.

4.4 Antimony

The trace element antimony shows interesting differences both over time (Graphs 19 and 21) and compared to lead (Graphs 4, 5 and 8). In these last three graphs, two clusters are visible. The top group (Sb-1) consists of coins with an elemental composition of antimony of roughly 0.1-1% and the lower group (Sb-2), with 0.01-0.1% antimony. The ratio of the number of measured objects in the groups Sb-1 and Sb-2 is approximately 2:1. Since there are no clear differences in antimony values between coins and medals or between several production locations, it is likely that the two groups are related to ore regions and new refining methods. For instance, in section 3.4 was stated that Central European copper was of slightly lower quality (and thus cheaper to obtain) than Scandinavian copper.

In Graphs 19 and 21, the ratio between antimony and time is studied in more detail. Intriguing is the slightly lower value of antimony in the periods of the Swedish copper (circa 1600-1750) and copper from Anglesey (circa 1775-1800). This is visible in both graphs. The Swedish-produced coins and medals in Graph 20 show a low antimony value that corresponds to group Sb-2. The higher antimony values (Sb-1) in the oldest period indicate the coins produced of Hungarian copper.

In Graph 21, an overview of antimony in all measured objects, it is shown that group Sb-2 especially occurs in coins from about 1580. This is also evident from the bubble chart of the medals (Graph 9); in the second half of the sixteenth century it broadly corresponds to that of the coins (Graph 6). The differences before and after that period are mainly due to the fact that far fewer copper coins were produced in the first half of that century and because fewer or no measurements were made on medals from the 1580s onwards.

In Graph 28, it is immediately noticeable that the copper from the Veluwe copper mills falls into the Sb-1 group, with higher antimony values. All coins from the Sweden-Veluwe group cluster together in the group Sb-2 with lower antimony values. This suggests that these coins are made of Swedish copper and in this case not refined in the Veluwe. Based on these data, the third group, with copper of Swedish or Hamburg origin, could be divided into Swedish copper (Sb-2) and Central European copper (Sb-1), from which it could be assumed that a large part of the copper processed in the Veluwe comes from Central Europe.

4.5 Tin

The tin-copper alloy called bronze is widely known. Because of this, it is sometimes too quickly assumed that an object is made of bronze; it seems that bronze is mentioned more often in the literature than the measurements indicate. It is therefore advisable that researchers and writers should not be too quick to regard objects as 'bronze'.

Tin is less common in the period circa 1600-1730 (Graph 24, the tin values of 0.1-1% are almost completely absent) but increases in later years. Graph 19 is clearly not refined enough to point out this difference. If Graphs 18, 19 and 24 are compared, the less common amounts of tin in the period circa 1600-1730 and the increases thereafter, seem to be in line with the periods of Swedish and English copper. It could also hint at an improved refining technique and likewise the lower number of measured objects from this period should be taken into account. According Graph 24, copper from the period before 1600 – where a Central European origin can be expected – contains more tin than Graph 18 would suggest.

4.6 Zinc

A deviation has been found for zinc in Graph 23, where the values between 0.1-1% appear to occur disproportionately often with medals, compared to coins. It may be related to a different origin of the copper. Graph 30 shows that copper mining in Sweden increases around the same time – around 1600 – that the measurements on copper medals had to be ceased. Future research is needed to learn if there is a change in zinc values in medals produced in the seventeenth century. The amount of zinc in coins is remarkably low.

Only two foreign specimens exceed the detection limit and show a value of more than 0.1% (Graph 23). The first is a medal from Great Britain (on the battle of Culloden in 1746).[134] The second is the in section 2.7 mentioned medal on Queen Christina from circa 1650. If the decreasing elemental composition of zinc is assumed to be related to a shift in copper supplies from Central Europe to Sweden, it seems very likely that this deviating Swedish medal was not produced in Sweden but elsewhere in Europe – from Central European copper. The medal is unsigned and the lettering and finish of the portrait indicate a production that was later in time, for example 1689 (the year of Christina's death) or the beginning of the eighteenth century. Further research reveals, that a copy in the National Museum of Finland shows the signature TRAVANVS, of the goldsmith and medallist Gioacchino Francesco Travani (circa 1634-1675), who worked in Rome. The medal in Teylers Museum is probably a contemporary copy, also produced in Italy. It most likely comes from the private collection of Pieter Teyler van der Hulst (1702-1778).

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[134] TMNK 01898.

4.7 Mercury

Mercury is only present in a small amount of objects. Therefore this trace element is not shown in a graph. Its presence can often be linked to fire gilding. In cases where there is no apparent link to fire gilding, it is still the most likely reason why mercury is detected.

4.8 Bismut

Graph 25 shows two peaks in bismuth, the first around 1580, the second around 1780-1800. This may be an indication of the origin of the copper: the first peak falls in the period of copper with Central European origin. Thereafter follows a period of Swedish copper and low bismuth values. In the time of the last peak a lot of copper originates from England.

5 CONCLUSIONS

In this study, the origin of the copper that was used for coins and medals in the Northern Netherlands was investigated. Also, the possibilities of non-destructive analysis were explored. This study was exploratory; it was not certain whether new insights would emerge. From the XRF-measured objects in the collection of Teylers Museum, 786 coins and 294 medals have been selected from the period circa 1460-1800 and with an elemental composition of copper of more than 95%. In addition, 355 objects with a copper alloy were also examined. The trace elements of these specimens have been studied and they have been embedded in the historical context of copper mining and coin production.

The historical context gives insight in the copper trade in the researched period, with a shift over time from central European copper via Swedish copper to English copper. The outcome of the metal analysis shows these shifts as well, although less clear. The outcome is too uncertain to make any statements about the origin of the metal based on the XRF analysis of a single coin. Only because of the possibility to compare a large number of examined objects with each other, the study is still useful. It appears that the measured trace elements sometimes give a hint of the used ore origin. At the same time, the differences are too small and there are too many uncertainties to pinpoint the origin of copper using only an XRF. Therefore, the interpretation of the analysed data should be regarded with caution.

Throughout the period studied, there almost always appears to be some lead in the copper objects. The expectation that the elemental composition of lead in Swedish copper is lower (because no lead had to be added during the refining process to extract silver) is not apparent from this study. Between coins and medals, the graphs indicate small differences in the detected amounts of antimony, zinc, tin, bismuth and gold.

The presence of low levels of antimony in coins – and not in medals – in Graph 21 could indicate that the metal was purified more for coins than for medals, which may be explained by the fact that the elemental composition of copper medals mattered less. By far most of the measured counter tokens were produced in the Mints; the different antimony levels seem to indicate a separate production of the metal for coins and medals. Graph 22, with a summation of all elements except copper per object, shows however that this marginal difference is not the ultimate key denominator. The amount of trace elements in copper coins appears to be comparable to that of the medals and usually totals to about 1%. The coins are therefore not of better copper than the medals and in both cases the elemental composition of copper is high. Moreover, Graph 7 shows that the distribution in antimony values for both coins and medals in the period up to about 1580 is comparable, while hardly any medals have been measured from a younger date. In other words; it seems that the copper used for medals was processed in another way, or other copper sources have been used. Even when the medals were produced in a Mint.

Several trace elements show changes over time, that can be related to the use of ore from different regions or to different refining techniques. According to Graph 23, zinc is more common in medals, at least up to circa 1620 (after which date hardly any medals have been measured due to a lack of time). Tin occurs almost exclusively in very low concentrations in the period 1600-1740, roughly covering the 'Swedish period'. Two striking peaks in the trace element bismuth were found in Graph 25, around 1580 and 1780-1800. These peaks coincide with the transitions outlined in the article from Central European copper (the first peak) via Swedish copper (the period between the peaks) to English copper (the second peak). Despite only occurring in eight coins, the peak in gold around 1750 in Graph 26 is remarkable, all the more so because gold and silver were normally extracted from copper as much as possible due to their high value. Since it occurs in five different Mints in a short period of time, there must be a particular reason. There may be a connection with the large gold finds in Brazil. In Europe, this caused a significant drop in the gold price for several years.

Furthermore, two clusters of antimony values have been found at the coins, with cluster Sb-2 appearing to subdivide into three parts over time. Graph 6 shows that there are some gaps in both clusters during the examined production period. For the medals, cluster Sb-1 in Graph 9 clearly forms the large group. In 128 coins with a supposedly known provenance from the eighteenth century, cluster Sb-1 appears to be linked to the Veluwe copper mills and cluster Sb-2 to copper of Swedish origin. The copper of Swedish coins in the museum collection also matches cluster Sb-2. The lower antimony values (Sb-2) in the period circa 1630-1750 can be related to Swedish copper production. A large part of the copper processed in the Veluwe seems to originate from Central Europe. At the same time, the graphs show that the amount of antimony is not always the decisive factor in determining the origin of the coin metal. Next to this, the production method between the various Mints in the Dutch Republic also differs too little from each other to be able to make a distinction.

355 of the coins and medals with a copper alloy were examined. Objects with a lower measured elemental composition of copper often turn out to be less refined, provided with a refined (gold-plated, silver-plated) top layer, or other metals (mainly lead, tin and zinc) have been added during the smelting process. Mercury often occurs in combination with gold; this points to fire gilding. In the rare occasions where the mercury is missing, the gold has already been added during the melting process. Tin is often added to coins and medals, but in general the elemental composition of tin is very low. Objects are less often made of bronze than is claimed in literature. More often, zinc is added to make brass.

Previously, the metal of an object was often determined on experience during registration in the collection database of Teylers Museum. Thanks to the XRF research, various uncertainties have been resolved. For example, a comparison of coins claimed to be made from melted-down cannons shows that these kinds of stories cannot simply be accepted as true. Measuring lead isotopes is more precise, but on the other hand, XRF testing is cheaper, less time consuming and non-destructive. The research shows that with the XRF equipment used, it looks as if the difference between copper from Sweden and from Central Europe is demonstrable. This is a motivation for future research. Bubble chart 4 also shows that this distinction cannot be made without more background knowledge, since cluster Sb-2 extends in periods in which it is not obvious that Swedish copper was used. In addition, the numbers of measured objects in some groups are quite low.

The comparison of measured trace elements leave too much space for speculation to allow the found differences to be presented as facts. An extra reason to be careful with the data is the fact that XRF measurements cover only a part of the object and penetrate just a fraction through the surface. Still, the results of this research provide a first impression of the sources and use of copper. Hopefully these first outcomes can be tested in the future with more research and measurement data. Particularly, the XRF analysis of small surface areas that have been abraded would be helpful to obtain more reliable data in a minimally invasive way. Furthermore, the XRF analysis can act as a guide to select a range of artefacts for sampling to conduct complete (trace) element and lead-isotope ratio analysis.

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Appendices

The six appendices may be found at https://jaarboekvoormuntenpenningkunde.nl/jaarboek/2023/2023e.pdf

- appendix 1: *Basic data of the researched 786 copper coins and 294 copper medals*
- appendix 2: *Basic data of the researched coins from Germany (9), the United Kingdom (7) and Sweden (10)*
- appendix 3: *Copper for coinage, transported via the Sound, destined for the Dutch Republic*
- appendix 4: *Copper coins with a remarkably high amount of gold as a trace element*
- appendix 5: *Basic data of the researched copper objects with admixture of other metals*
- appendix 6: *Elemental composition of six cannons and coins, which are said to have been made from melted down cannons.*

Traces of Copper

The origin of copper and the approximate chemical compositions of some 1,500 Dutch coins and medals

Jan Pelsdonk*

Samenvatting – *Van bijna 10.000 munten en penningen in de collectie van Teylers Museum is de samenstelling bepaald. In dit artikel worden 1.080 exemplaren met meer dan 95% koper en 355 stuks met een lagere kopersamenstelling uit de periode 1460-1800 bestudeerd en gecombineerd met historische gegevens rond de winning van koper. Doel van het onderzoek is zowel om de mogelijkheden en beperkingen van niet-destructief onderzoek naar elementaire samenstelling te verkennen als om meer grip te krijgen op de herkomst van het muntmetaal. Er zijn ruwweg drie aanvoergebieden onderscheiden. Rond 1630 wordt de centraal-Europese koperwinning overvleugeld door Zweden, waarna Engeland het stokje rond 1750 overneemt. Eerste winpunt van het onderzoek is de veel nauwkeurigere vaststelling van de elementaire samenstelling. Zo blijken veel als 'brons' beschreven voorwerpen van messing te zijn. De spoorelementen blijken soms indicaties te geven van de herkomst van het metaal, wat een aanmoediging is voor toekomstig onderzoek, bijvoorbeeld naar loodisotopen. Ook blijken er verschillen te bestaan tussen de spoorelementen bij munten en penningen.*

Summary – *The elemental composition of almost 10,000 coins and medals in the collection of Teylers Museum has been determined. This article studies the 1,080 specimens with more than 95% copper and 355 specimens with a lower copper composition from the 1460-1800 period and combines them with historical data on copper mining. The aim of the research is to explore the possibilities and limitations of non-destructive metal composition measurements as well as to gain a better understanding of the origin of the mint metal. Roughly three supply areas have been distinguished. Around 1630, central European copper mining was eclipsed by Sweden, after which England took over around 1750. The first benefit of the research is the much more accurate determination of the metal composition. For example, many objects described as 'bronze' appear to be made of brass. The trace elements sometimes appear to provide indications of the origin of the metal, which encourages future research, for example into lead isotopes. There also appear to be differences between the trace elements in coins and medals.*

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