Centre for Archaeology Report 64/2002

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ISSN 1473-9224

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Summary

Excavations in London along the Thames opposite the Tower of London recovered hundreds of fifteenth to seventeenth century artefacts. A selection of these (62 lead-tin alloy, 57 copper alloy, and 2 glass) have been analysed using SEM-EDS to determine their chemical composition. A limited range of artefact types were selected (e.g. buckles, spoons, and thimbles) to examine the chemical compositions in relation to the records of the various Guilds that tried to regulate their production. The lead-tin spoons, for example, fall into two groups: those that are stamped with a maker's mark and largely abide by Guild rules, and those that are not stamped and are composed of 'illegal' alloys.

Keywords

Lead-Tin Alloy
Copper Alloy
Glass

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Introduction

This report details the analysis of 15th to 17th century artefacts recovered during archaeological excavations in Southwark, London. A total of 122 artefacts (mostly copper and lead-tin alloys) were quantitatively analysed using an energy dispersive X-ray detector attached to a scanning electron microscope. The compositions of medieval and earlier alloys are reasonably well known but the alloys of the post-medieval period have received less study. The report contains a summary of the archaeological and historical background, and the method used to determine the chemical compositions. The results are reported in three main sections: a summary of all the lead-tin alloys, a summary of all the copper alloys, and a discussion of results organised by artefact type.

Background

The Museum of London carried out a series of excavations between 1986 and 1999 in an area on the south bank of the Thames opposite the Tower of London (centred on NGR TQ 333 802). The archaeological deposits were mainly dumps that filled in riverside docks and a maze of small waterways during the 16th and 17th centuries. A total of 122 artefacts (two glass, 62 lead-tin alloys, 57 copper alloys and one antimony ingot) were selected by Geoff Egan for scientific examination. The artefacts analysed were mainly buckles, hooked clasps, spoons, toys, thimbles and scrap (sheet and wire).

Non-ceramic material of this period is poorly known and has rarely been analysed to determine the sorts of alloys used. The previous analytical work that has addressed comparable metal artefacts from London and elsewhere is reviewed below.

Methods

Each artefact was sampled to obtain material that had not been altered by corrosion processes. In an alloy, one metal is usually more likely to corrode and a corroded surface will usually have a chemical composition different from that of the uncorroded metal. It is also possible for some metal to corrode, and then be re-deposited on the surface of other artefacts. It is for this last reason, that those carrying out qualitative analyses of lead-tin alloys have usually ignored the presence of copper (Bayley & Mortimer 1998).

Two sampling techniques were used: drilling and cutting. Where possible a small fragment of metal was cut from the object. In some cases, however, this was not possible and so a sample of metal was removed using a drill (1mm diameter). Care was taken to remove any traces of a corroded surface. The sampled metal was embedded in cold-setting acrylic resin and polished to a 1 micron finish.

The polished samples were all examined using a scanning electron microscope (Leo S440i) to determine their condition and homogeneity. The samples were analysed using the energy dispersive X-ray detector attached to the scanning electron microscope (germanium detector, 25kV accelerating voltage, 2nA current, and 100 seconds livetime) and the results calibrated using a range of standards. It was not always possible to obtain modern certified standards with compositions close to those of the archaeological samples, in particular, the available lead-tin standards did not contain any copper. The limits of detection and the analytical errors for each element are given in table 1; they are different for different types of samples (lead-tin alloys and copper alloys).

Table 1. Limits of detection and error (2 standard deviations), in weight percent

Lead-tin Alloys	S	Fe	Ni	Cu	Zn	As	Ag	Sn	Sb	Pb
Limit of Detection	0.5	0.1	0.1	0.2	0.2	1.0	0.5	0.5	0.5	0.3
Error	±0.2	±0.2	±0.2	±0.2	±0.2	±0.5	±0.5	±2.0	±0.5	±2.0
Copper Alloys										
Limit of Detection	0.1	0.02	0.03		0.05	0.1	0.2	0.2	0.2	0.2
Error	±0.05	±0.02	±0.02	±0.8	±0.2	±0.1	±0.4	±0.4	±0.2	±0.4

The results are listed in appendix 1 with the description used in the catalogue prepared by Geoff Egan. The results, divided into lead-tin alloys and copper alloys, are summarised and discussed below.

Alloy names

It is helpful, in discussing the results, to use alloy names, e.g. brass and pewter. The use of the term lead-tin here reflects it use in the catalogue; it is used to indicate metal items which were made from lead, tin or alloys of one or both of these two metals. Prior to the Industrial Revolution tin was commonly alloyed with lead and may have been alloyed with copper, zinc, antimony, mercury and bismuth. Most of these alloys have at one time or another also been referred to as pewters. The situation with copper alloys is rather more complicated. Different researchers have on occasion used the same names to refer to alloys of quite different compositions, and have used different names to refer to alloys of very similar compositions. Bayley (1991) argues for the use of neutral modern metallurgical names (copper, brass, gunmetal and bronze) that will then be universally applicable. The reasons include the uncertainties over what is meant by contemporary terms (such as latten), whether contemporary metal workers would have been able to maintain restricted composition for particular alloys, and the extensive (and perhaps uncritical) use of recycled scrap metal. Bayley (1991: 15) defines as copper all samples with less than 8% zinc and less than 3% tin. All other samples are classed as brass, gunmetal or bronze depending on the ratio of zinc to tin (where zinc > 4 x tin the alloy is brass, where tin > 3 x zinc the alloy is bronze, and alloys with intermediate levels of zinc and tin are gunmetals). This classification, which was originally developed to describe Roman copper alloys, has the benefit of being easy to use and unambiguous and can be used to compare assemblages of different date. The limitation of this approach is that it fails to uncover subtle variations in alloy composition. For example, both Caple (1986) and Blades (1995) detected two sorts of early post-medieval brass: one that typically contained 15% zinc and another that contained around 25% zinc.

Lead-tin alloys

Historical background

The manufacture of lead-tin artefacts was sufficiently important in medieval and post-medieval London to have led to the issuing of ordinances (1348) and charters (1473/4) to regulate the industry, and the establishment of a Guild of Pewterers (Welch 1902; Hatcher & Barker 1974; Homer 1985). Many of these records have survived and provide a wealth of information on how the industry was regulated. The regulations governing the compositions of the alloys used are of particular relevance to this present study.

The 1348 ordinances of the Guild of Pewterers of London distinguish two different alloys: Fine metal and Lay metal. Fine metal was composed of tin with added copper and was used for the manufacture of flatwares (plates, saucers, etc). The exact amount of copper added is uncertain; the 1348 ordinances are (perhaps deliberately) vague and simply refer to 'the proportion of copper to the tin is as much as, of its own nature it will take'. Lay metal was composed of tin with added lead for the manufacture of hollowares (flagons, cruets, etc). The exact limit for lead in Lay metal is also unclear; the original ordinances indicate 21%, but a later transcript gives 18%. The 1350 records of the fining of John de Hilton for producing sub-standard wares gives a limit of 12.5%. Whatever the exact limit for the lead content, the guild was clearly concerned to restrict this (Hornsby *et al*. 1989). From the sixteenth century, the Guild authorised three grades of pewter:

- Fine, for eating ware, tin with 4% copper
- Trifle, also for eating and drinking utensils but duller in appearance, tin with 4% copper, and up to 4% lead
- Lay, not for eating or drinking utensils, tin with up to 15% lead.

Lead was often more readily available and cheaper than tin and the unscrupulous may have been tempted to adulterate pewters with as much lead as possible. From the early 16th century pewterers were required to stamp their products so the makers of sub-standard items could be easily recognised (Welch 1902: 94–7). The Guild's control of the pewter industry outside London is likely to have been limited in its early years but by the 17th century the Guild was making inspections in the Midlands and further afield (Hornsby *et al*. 1989: 13).

Theophilus, writing in the 12th century, appears to recommend the use of a pewter formed by adding small amounts of mercury to tin (Hawthorne & Smith 1979: 181) and a single medieval spoon with 5.8% mercury has been analysed by Brownsword and Pitt (1983a).

Documentary evidence (Hatcher & Barker 1974: 225) suggests that by the later 16th century small amounts of bismuth were added to fine pewter (3–4 parts bismuth to 1000 parts tin and 30 parts copper). By the later 17th century the bismuth levels may have been increased to 1% (Hatcher & Baker 1974: 227). The analytical technique used for the analyses reported here could not detect less than 0.5% bismuth.

Pewters formed by adding antimony to tin (Britannia metal) were established by the later 18th century but the use of antimony in type metal was known on the continent from the early 16th century (Smith & Gnudi 1990: 374).

Previous analytical research

Pewter composed of lead and tin originated in the Roman period and continued to be used through the medieval period. Beagrie (1989) summarises the results from a number of researchers and shows that Roman pewter had a variable lead content (up to 60%).

Brownsword & Pitt (1984; 1985) showed that medieval pewter flatwares contained low levels of lead (only four out of 36 contained more than 5% lead) but these had a small but deliberate addition of copper (average = 1.7±1.0%). The flatware with lead contents over 1% was all found outside London, and there were no significant differences between the composition of those found in the city of London and those found in Southwark.

Qualitative EDXRF analysis (i.e. analysis of the corroded surfaces) of 140 lead-tin objects by Heyworth (1991) showed the use of pewters (lead-tin alloys) and pure tin. As noted above, the qualitative analytical methodology did not enable the reliable detection or quantification of copper. Heyworth's data shows a decrease in the use of lead in lead-tin alloys from the 12th to the 15th centuries. There were also some links between alloy use and typology: tin was used for buckles, mounts and bells, while pewter was used for brooches and finger rings.

Qualitative EDXRF analysis of 45 medieval lead-tin objects by Bayley & Mortimer (1998) showed that most were low-lead pewters (again the methodology did not enable the reliable detection of copper). The flatware tended to have very low levels of lead, while holloware, lids and candleholders contained more lead. Spoons had variable lead levels (judged to be up to 50%) although the early spoons tended to have more lead than the later examples. Quantitative analysis of five items from the same assemblage by Mortimer (Bayley & Mortimer 1998) confirmed that one example of a lid and one of holloware contained substantial added lead (20–30%) while an example of flatware contained no detectable lead. Significantly, three of the five items analysed quantitatively proved to contain added copper (1–4%).

Summary of Results for Lead-Tin Alloys

The 62 lead-tin artefacts contained detectable levels of lead, tin, copper and antimony. None of the samples contained detectable amounts of bismuth, mercury or zinc (limits of detection were 0.5%, 0.4% and 0.2%, respectively).

Eighteen of the samples analysed quantitatively had previously been analysed qualitatively (Dungworth 2000). The lead:tin ratios for quantitative and qualitative analyses for these samples showed a reasonable correlation ($r^2 = 0.87$). However, comparison of the copper:tin ratios showed no correlation ($r^2 = 0.05$) and confirms earlier suspicions that the levels of copper detected on the surface of lead-tin artefacts may be affected by complex corrosion and re-deposition processes (Bayley & Mortimer 1998: 180).

Figure 1 shows that most of the samples lie close to the line, tin + lead = 100% (i.e. they were composed almost entirely of tin and lead). Those that fall slightly below this line usually contain copper (see below). Most of the lead-tin alloys are rich in tin (80% tin or more) although there are several samples which are rich in lead (90% or more) and a dozen or so examples with around 50–60% tin.

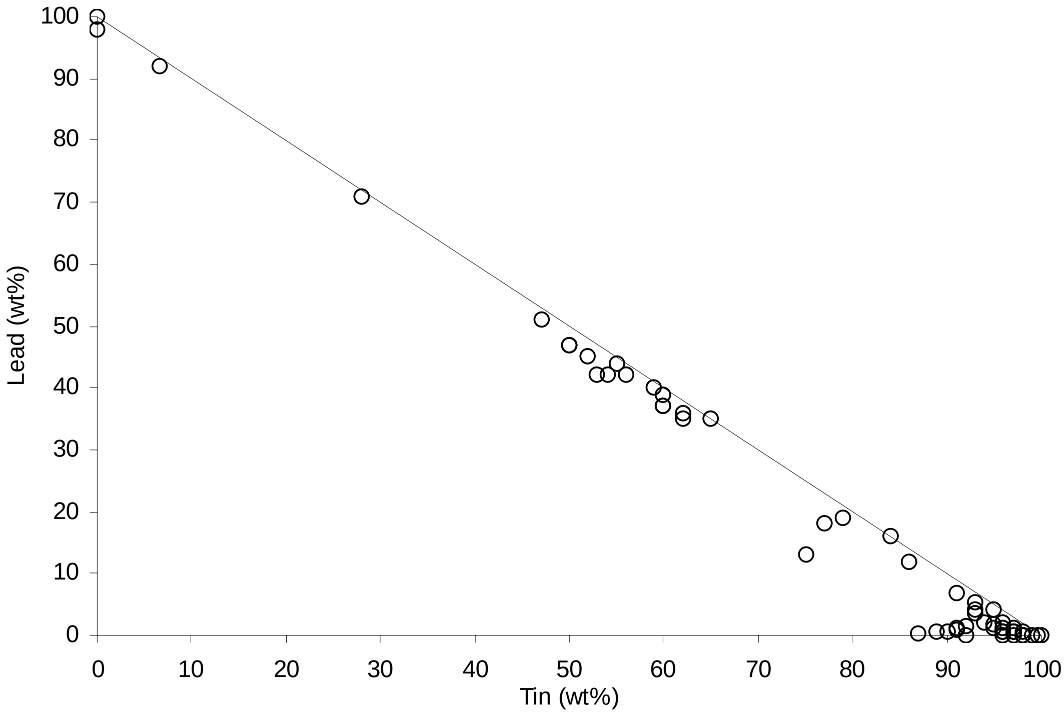

Figure 1. Tin and lead compositions of the lead-tin samples.

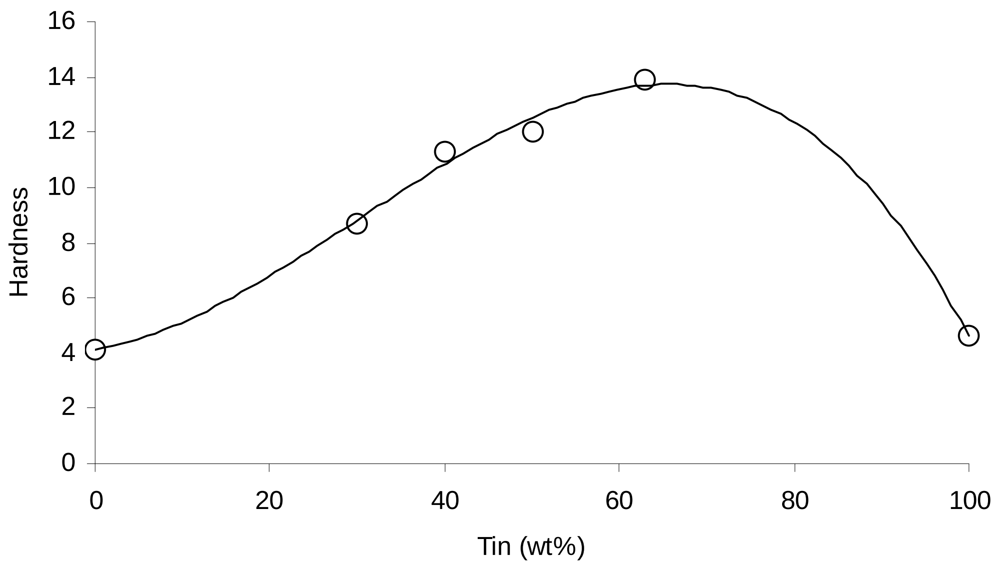

Figure 2. Hardness of lead-tin alloys (Source: Hedges 1960)

Both lead and tin are soft and weak metals, but the intermediate alloys have higher hardnesses and tensile strengths (figure 2, the tensile strength is proportional to the hardness). Both lead and tin have low melting points (327°C and 232°C, respectively) and intermediate alloys can have even lower melting temperatures (see figure 3). The lead-tin alloy with the lowest melting point (184°C) occurs with an alloy containing 61.9% tin and 38.9% lead (the eutectic composition).

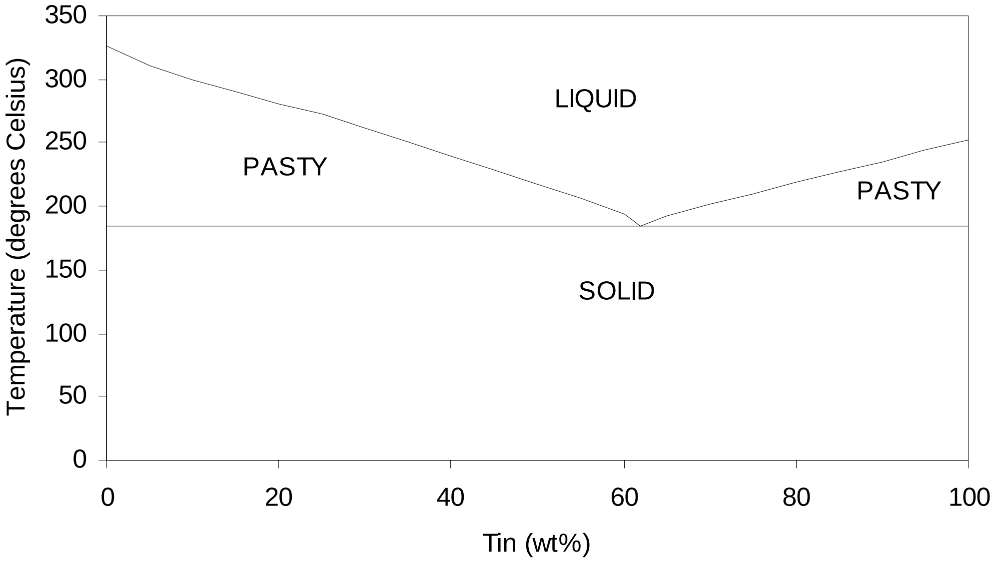

Figure 3. Melting temperatures for lead tin alloys

The cluster of analysed lead-tin alloys around 60% (figure 1), which would have melted at less than 200°C and would have been relatively strong, were probably deliberately produced with this composition.

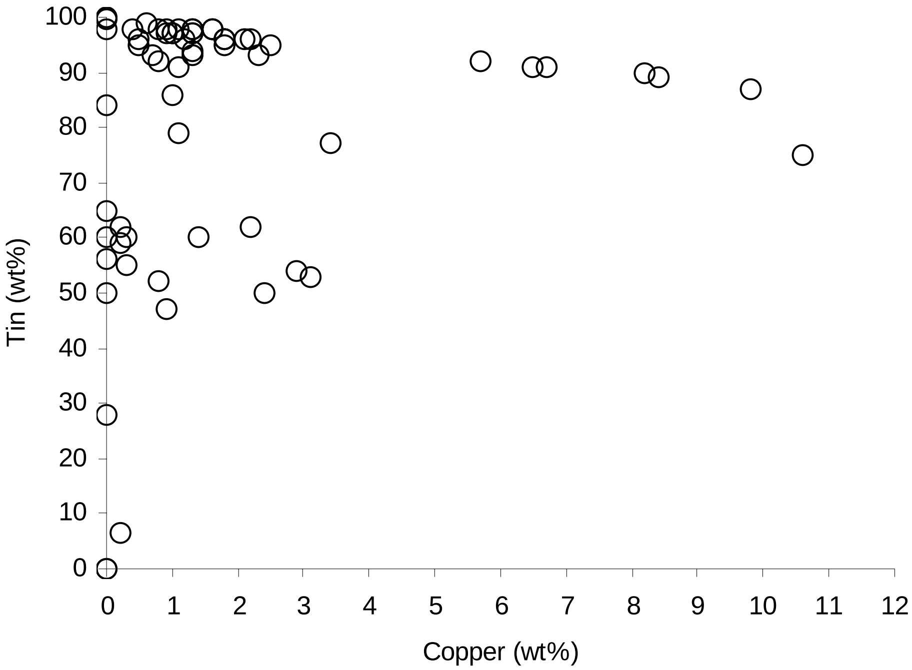

Figure 4. Tin and copper content of lead-tin alloys

Copper was detected in most (51 out of 62) of the lead-tin samples and varied from 0.2% to 11%. The detection limit for copper was 0.2% and those samples in which none was detected may still have contained small amounts of copper. Figure 4 shows the tin content plotted against the copper content for all lead-tin samples. Copper was rarely present at more than 4%, and then only in the spoons. The addition of copper to tin produces a harder more durable metal but increases the temperature required to fully melt it. The changes in these phenomena are most noticeable for small additions of copper (table 2), especially compared to the amounts of lead required to achieve comparable improved hardness. There does not seem to have been any serious attempt to achieve the recommended 4% copper content of the lead-tin alloys.

Table 2. Physical properties of tin rich, tin-copper alloys (source: Hedges 1960)

Copper (wt%)	Hardness (Vickers)	Melting Temperature (°C)	Ultimate Tensile Strength (MPa)
0	5.0	232	9.6
1	8.8	245	27.6
2	10.3	295	33.1
3	11.1	335	34.5
4	11.5	360	35.8
5	11.8	385	37.9

The documentary evidence reviewed above, indicates that by the later 17th century pewterers were experimenting with the addition of other elements (bismuth, antimony, etc) to tin. The analytical results, however, show that bismuth was never present above the detection limit (0.5%) and in only one case (a shoe buckle, Cat. 120) was antimony detected in sufficient quantities (6.6%) to indicate a deliberate addition. This indicates that, in practice, pewterers were rather conservative.

Copper alloys

The copper smiths and founders did not have a single guild comparable to the Guild of Pewterers. Many guilds were organised by the form and use of their product rather than the type of metal used, and many objects could be made from more than one metal (iron, lead-tin alloys and/or copper alloys). The Girdlers' Guild, for example, exercised control over the manufacture of some dress fittings (such as buckles) and attempted to control the use of certain alloys (Egan & Pritchard 1991: 18–19).

Previous research

Research into late medieval copper alloys is now reasonably well-established. In Britain, Cameron has examined monumental brasses (1946; 1974) while Brownsword and co-workers have examined a range of (mostly cast) artefacts (Brownsword 1981; Brownsword & Ciuffini 1988; Brownsword & Pitt 1983b). Werner (1977; 1982) has examined a large number of (again mostly cast) artefacts from Germany. Caple (1986) examined one type of wrought artefact (pins) from 400–1600 AD. More diverse (and perhaps more representative) assemblages of everyday artefacts have been qualitatively analysed by Heyworth (1991) and quantitatively by Blades (1995). Analyses of post-medieval copper artefacts are a good deal rarer but some results can be found in Blades (1995), Cameron (1974), and Caple (1986). Pollard & Heron (1996: 205–226) provide a discussion of late medieval and early post-medieval brass production in the light of analyses of jettons and scientific instruments. The analyses of 12th to the 16th century copper alloys has identified a steady increase in the use of brass and a decline in the use of bronze. Pollard & Heron (1996: 218) also identify changes in the impurities in copper alloys, which they link to the changing fortunes of those controlling the major copper ore sources in Europe.

Summary of Results for Copper Alloys

The 57 copper alloy artefacts analysed consisted of a variety of small everyday artefacts as well as waste from the manufacture of such items (buckles, hooked clasps, thimbles, sheet and wire). In addition to copper, the samples contained varying levels of zinc, tin, lead, iron, nickel, arsenic and antimony. The samples were assigned to the four main alloy types (brass, gunmetal, bronze and copper) according to the levels of zinc and tin present (Bayley 1991). Lead was not a significant component of these alloys; lead was below 1% in 44 out of 57 samples and the highest lead content was only 3.5%.

The average compositions for each alloy are shown in table 3. Arsenic and antimony are not included in table 3 as they were detected in only a small number of samples. Iron, nickel, arsenic and antimony are usually regarded as impurities accidentally included in the copper when it was smelted from ores containing these impurities.

Table 3. Composition of different alloys (wt%, average and standard deviations) (data from this project)

	Zn	Sn	Pb	Ni	Fe
Brass (42)	19.4±4.1	0.6±0.8	1.0±0.9	0.21±0.15	0.35±0.29
Gunmetal (10)	7.9±3.6	3.7±0.8	1.0±1.0	0.19±0.12	0.68±0.45
Copper (4)	3.9±2.7	0.9±1.4	0.5±0.2	0.18±0.18	0.18±0.10
Bronze (1)	1.0	4.1	0.5	0.22	0.13

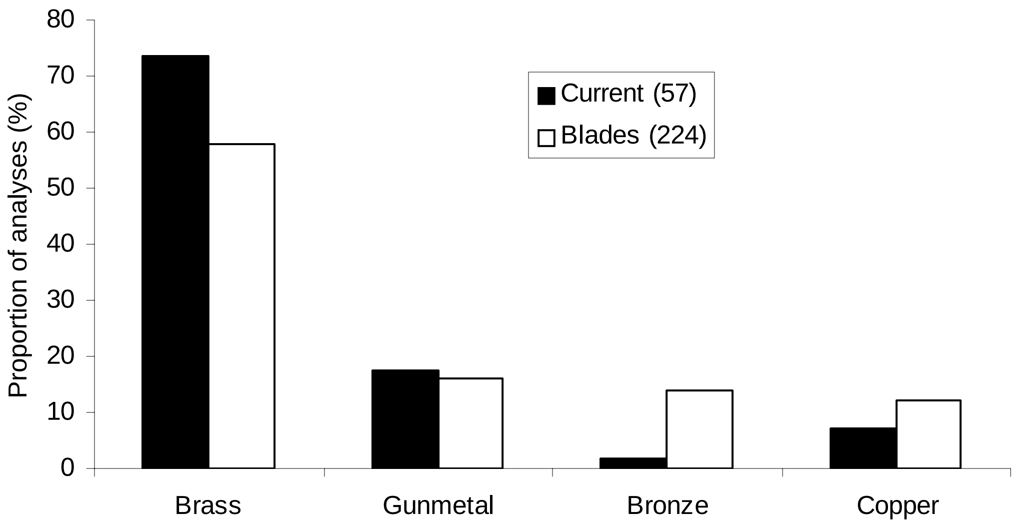

Figure 5. 16th and 17th century copper alloys. Proportions of the principal copper alloys (data from current project and Blades (1995)

The proportions of the different copper alloys are shown in figure 5 with post-medieval data from Blades (1995) for comparison. This shows that brass was by far the most common copper alloy at this period, while only one sample from the current project (a candlestick, Cat. No. 337) was composed of bronze. The incidence of bronze is significantly higher among the data collected by Blades (1995) which reflects the different sampling strategies employed. Blades (1995) selected samples from a wide range of sites and a wide range of artefact types. Blades (1995) concluded that in the 16th and 17th centuries bronze was primarily used for the manufacture of large castings (such as bells and cauldrons). These items are absent from the current assemblage, which is made up of small cast or wrought artefacts. Figure 6, which combines the qualitative analyses of Heyworth (1991) and the current data, illustrates that the increase in use of brass in the later medieval period (Blades 1995; Heyworth 1991) continues into the post-medieval period (cf. Cameron 1974: 3). In the light of the comparison of qualitative and quantitative analyses of the same artefacts discussed below, it is possible that the incidence of gunmetal has been underestimated in Heyworth's (1991) data.

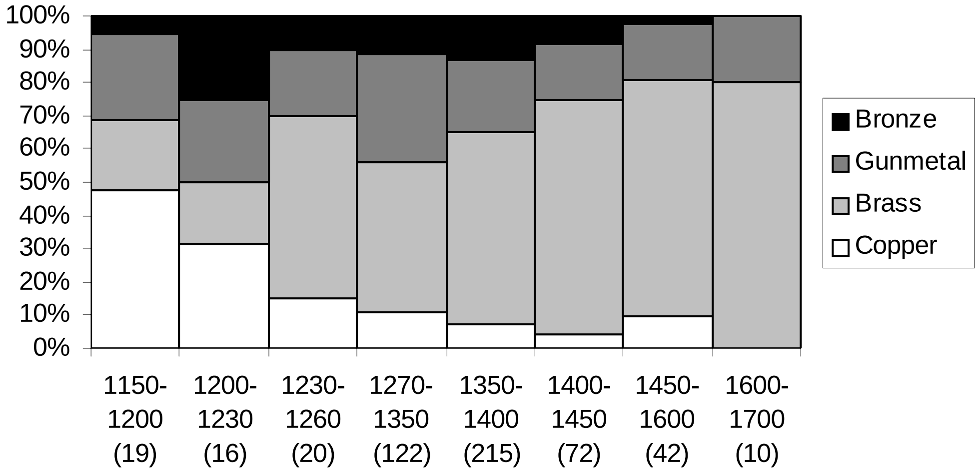

Figure 6. Changes in the use of copper alloys (1150–1700). Data from 1150–1450 taken from Heyworth (1991), data from 1450–1700 taken from current project.

Relatively little copper was produced in Britain during the later Middle Ages and the industry only became a significant supplier from the beginning of the 18th century (Crossley 1990: 197; Tylecote 1992). From the 15th century to the end of the 17th century much of the copper used in Britain was imported. One of the most significant was the Falun mine in Sweden (Tylecote 1976). Pollard & Heron (1996: 218) suggest that this source would produce copper with a low nickel content (cf. Tylecote 1992: 85). Other significant sources might include the *kupferschiefer* deposits in Germany (which would produce copper with minor amounts nickel, cf. Werner 1977: 146), Hungary and Tyrol, however, some contribution may have been made from sources as distant as Japan (Tylecote 1992: 109).

The impurities in the copper alloy samples were examined to determine if any distinctive patterns might indicate the source(s) of the copper used. Most impurities (e.g. silver, arsenic and antimony) were present at levels that were below the detection limits of the instrument used for this research. Nickel was detected in a majority of the samples and the distribution of nickel contents is shown in figure 7. This shows a bi-modal distribution with one group having low levels of nickel (<0.1%) and one group centred around 0.25% nickel. This pattern can also be seen in Blades' post-medieval data. This suggests that at least two separate copper sources were in use at this time. It is possible that the samples with low levels of nickel were made using copper from the Falun mine, while those with higher levels of nickel were made using copper from the *kupferschiefer* deposits in Germany. Nickel levels of various types of artefact were compared (in particular the thimbles, many of which are believed to have been manufactured in Germany) but there does not appear to be any correlation between nickel content and any typological criterion.

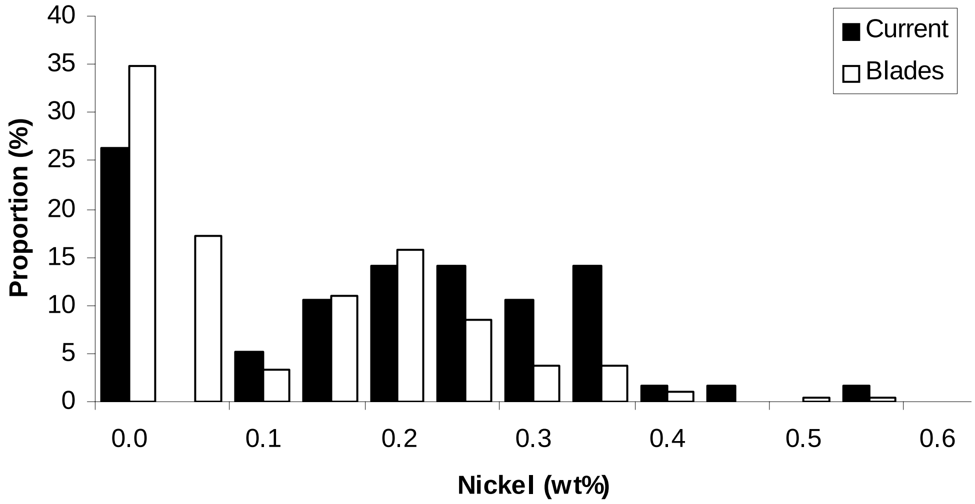

Figure 7. Distribution of nickel contents in copper alloys (with data from Blades 1995 for comparison)

Twenty-eight of the samples analysed quantitatively had previously been analysed qualitatively (Dungworth 2000). The qualitative analysis had been carried out on the uncleaned surfaces of the artefacts and alloy names assigned on the basis of the relative heights of the characteristic X-ray peaks. The alloy names were similar to those recommended by Bayley (1991) but included ‘hybrid’ names (such as brass/copper and brass/gunmetal) to reflect the level of uncertainty inherent in the qualitative analyses. Comparing the 28 samples analysed both quantitatively and qualitatively shows that in many cases the qualitative results are reliable, for example of the eighteen samples analysed qualitatively and classed as brass, sixteen were also classed as brass after quantitative analysis. The results do show, however, that qualitative analysis is less successful at identifying more complex alloys; the eight samples classed as gunmetal after quantitative analysis had previously been identified as brass (two), brass/copper (three), brass/gunmetal (one), copper/bronze (one) and gunmetal (one).

Discussion of Results by Artefact Type

The 62 lead-tin samples and 58 copper alloy samples were taken from fourteen buckles, sixteen hooked clasps, 37 spoons, 20 thimbles and 23 miscellaneous items. The results for these artefacts are discussed below following, where possible, the order of the catalogue.

Buckles

The fourteen buckles (seven lead-tin alloys and seven copper alloy examples) were analysed to determine if the contemporary complaints about the metals used had any basis. The seven lead-tin alloy buckles included five belt buckles and two shoe buckles. The belt buckles all have compositions close to the lead-tin eutectic (52–62% tin, 36–47% lead). This contrasts with Heyworth's (1991) results where the buckles were mostly made from tin rather than lead-tin alloys. The lead content of the buckles analysed here far exceeds the levels for Trifle metal (15% lead). The alloy used would have been convenient for the manufacturer as it would melt at a lower temperature than tin. The metal would also have been slightly stronger than pure tin and so would be less likely to break. The addition of lead, however, would tend to make 'the alloy dull and inclined to tarnish' (Hedges 1960: 16). Buckles made from lead-tin alloys would all be much weaker than copper alloy or iron ones. The two lead-tin alloy shoe buckles are, however, made from high-tin alloys. One of these shoe buckles (Cat. No. 120) also contains the highest level of antimony (6.6%) of all of the pewters analysed and this must be a deliberate addition of antimony. It remains to be seen whether this is an isolated example or represents a wider phenomenon. The addition of 6.6% antimony to tin would have made the metal considerably stronger than the high tin alloy used for the other shoe buckle (Cat. No. 121).

The seven copper alloy buckles were made from brass or gunmetal and the average compositions for them, other castings and wrought copper alloys is compared in table 4. There are some slight differences, in terms of the principal alloying elements, between the buckles and other castings. The buckles tend to be made from alloys containing more tin and lead and less zinc than either other cast artefacts or wrought artefacts. These differences, however, would not make the metal used for buckles significantly weaker than the other alloys.

Table 4. Composition of copper alloy buckles, other castings and wrought metal (wt%, average and standard deviations)

	Zn	Sn	Pb	Ni	Fe
Buckles (7)	10.4±4.9	2.7±1.6	1.4±1.2	0.13±0.12	0.96±0.44
Other castings (14)	16.3±7.6	1.6±1.7	1.0±1.0	0.20±0.16	0.43±0.15
Wrought metal (36)	17.0±6.8	0.8±1.2	0.6±0.6	0.23±0.14	0.27±0.24

Table 4 clearly shows that the buckles have much higher iron contents compared to either other castings or wrought metal. Iron is insoluble in copper at room temperature and so can make copper alloys brittle (Craddock 1977: 115). Iron is a common impurity in copper alloys that can be removed during refining. In this case, it appears that relatively unrefined copper was used. This is reinforced by the results for other impurities that would normally be removed during refining (arsenic and antimony). The minimum detectable levels of the analytical procedure (0.1% for arsenic and

0.2% for antimony) meant that these elements were detected in relative few samples and so averages could not be calculated. Table 5 shows the proportion of samples in which arsenic and antimony were detected. these data suggest the buckles analysed for this study were made from less refined copper than the rest of the objects.

Table 5. Proportion of samples in which arsenic and antimony were detected

	Arsenic (i.e. >0.1%)	Antimony (i.e. >0.2%)
Buckles (7)	57%	43%
Other castings (14)	14%	14%
Wrought metal (36)	22%	3%

Hooked clasps

The sixteen hooked clasps analysed included five lead-tin alloy examples and eleven copper alloy examples. Four of the five lead-tin alloy hooked clasps have compositions similar to the buckles discussed above (47–65% tin, 35–51% lead), while the fifth (Cat. No. 161) is made from pure lead.

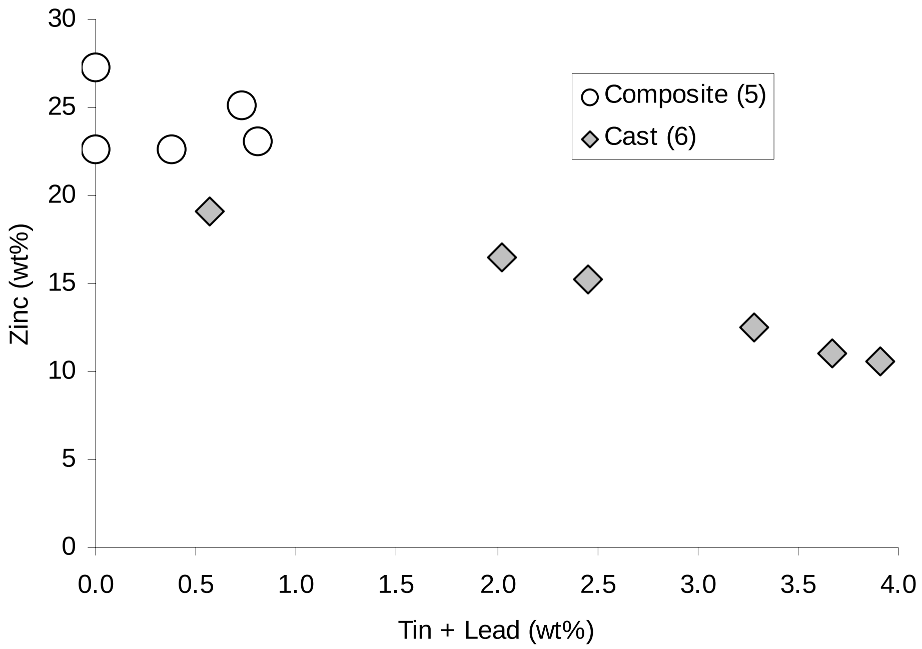

Figure 7. Zinc plotted against tin+lead for the copper alloy hooked clasps

The eleven copper alloy hooked clasps can be divided into different groups depending on the ways in which they were manufactured. Given the small number analysed, they are here divided into two simplified groups: cast (Cat. Nos. 151–6) and composite/wrought (Cat. Nos. 158, 159, 167–9). Figure 7 shows that the composite hooked clasps contain higher levels of zinc and the cast hooked clasps have significantly higher levels of tin and lead. These differences probably reflect the different techniques used to produce them. The composite hooked clasps would have required at least some components to be formed by hammering. Brasses of the composition used for the composite hooked clasps would have the ductility required for such hammering. The leaded brasses and gunmetals used for the cast hooked clasps would have been less well suited to wrought work but were ideal for casting.

Spoons

Thirty seven spoons were analysed; 35 lead-tin examples and two copper alloy examples. The 35 lead-tin spoons analysed generally have high levels of tin with low levels of lead and high levels of copper compared to the other lead-tin alloy objects analysed (table 6). The lead content varies from nil to over 40%, although only six have more than 10% lead. All but one of the spoons contained copper above the detection limit (0.2%). The composition of the spoons is comparable with those analysed by Brownsword & Pitt (1983a) and Gowland (published in Hilton Price 1908). Antimony was detected in five spoons but in only one case (Cat. No. 556) was there more than 1% antimony. Such low proportions of antimony in lead-tin alloys would have only a minor effect on the physical properties of the metal. It is likely, nevertheless, that the addition of antimony was deliberate as this element is not usually found in earlier lead-tin alloys. The antimony ingot (Cat. No. 784, see below) certainly demonstrates that metallic antimony was available.

The analysis of a reasonably large number of lead-tin alloy spoons provides the opportunity to examine changes in alloy over time and differences between spoons which were stamped with a maker's mark or 'touch' and those which were not (unfortunately just over half of the spoons were incomplete and so it was not possible to determine if they were stamped or unstamped). Table 4 shows that there are no significant differences between the composition of 16th and 17th century lead-tin spoons. The seven spoons that were clearly unstamped generally had lower copper and tin levels and higher lead levels than the ten stamped ones. If spoons were manufactured following Guild rules then the metal used should have been Trifle metal with a maximum lead content of 4%. Only one of the stamped spoons (Cat. No. 527) contained more than 4% lead, while five out of the seven unstamped spoons contained more than 4% lead. Those who produced spoons, but did not stamp them, added more lead than those who did stamp. The stamped spoons were presumably produced by members of the Guild of Pewterers who, on the whole, followed the regulations. Those that were not stamped, however, were either produced by less scrupulous members of the Guild or by people who were not members.

Table 6. Compositions of lead-tin spoons (wt%, averages and standard deviations)

	No.	Copper	Tin	Lead
All spoons	35	2.8±2.8	90.8±10.2	5.1±9.7
Other lead-tin artefacts	27	0.6±0.7	63.9±30.6	34.1±30.9
16th century spoons	24	2.9±2.9	90.9±9.9	4.8±9.6
17th century spoons	10	2.7±2.8	90.0±9.9	6.3±9.6
Unstamped spoons	7	1.6±1.3	82.3±18.6	14.9±17.3
Stamped spoons	10	2.5±2.5	93.3±5.8	2.9±5.8
Uncertain (incomplete)	18	3.4±3.3	92.7±5.8	2.6±4.0

The two copper alloy spoons analysed are both made of brass of a similar composition to that used for the two 17th century spoons analysed by Gowland (reported in Hilton Price 1908: 11). The first of the two spoons analysed here (Cat. No. 580) was identified and catalogued as copper alloy, however, the other (Cat. No. 572) was initially identified as being made from a lead-tin alloy and has been catalogued as such. Quantitative analysis of the core metal shows that it is actually made from a brass which has then been tin plated. Given the poor imitation of a precious metal London hallmark on the spoon it is possible that it was hoped to pass it off as a silver spoon. Simple testing would have shown that it was not made of silver, however, as the specific gravity of sterling silver is 10.4 while that of brass is about 8.5.

Thimbles

Seventeen thimbles and 3 sewing rings (all copper alloy) were analysed. It is usually assumed that the ones with makers' marks were produced in Nuremberg, Germany, while the machine-made examples were made in England or the Netherlands. In all cases the thimbles would not have been cast into shape but wrought (whether by hand or machine). The sewing rings and thimbles are all made from brass or copper; metals that would be sufficiently ductile given the high degree of deformation required during production. The tin levels in the thimbles are low compared to the sheet and wire waste (see table 7). The presence of more than a few percent of tin would lead to the formation of the brittle delta phase which would make stamping difficult.

Table 7. Composition of sewing rings, thimbles, sheet and wire (wt%, average and standard deviation)

	Zinc	Tin	Lead
Sewing rings and thimbles	17.4±6.1	0.5±0.6	0.8±0.8
Sheet and wire	13.1±6.8	2.1±1.5	0.4±0.4

Other artefacts

Four mounts were analysed, three lead-tin examples and one copper alloy. The two early 16th century lead-tin mounts (Cat. Nos. 140 and 142) were actually pure tin (copper and lead below the limits of detection). The late 17th century lead-tin mount (Cat. No. 145) is high-tin pewter with minor amounts of lead and copper. The strap end (Cat. No. 150) is high-tin pewter with a small amount of copper.

The brass casket mount (Cat. No. 312) is believed to have been manufactured in Germany but there is nothing particularly distinctive in the alloy used or the level of impurities present. The brass used is not the highest quality and the presence of 2% tin may indicate the use of recycled metal. The nickel content of the metal is intermediate between the low levels expected from Swedish Falun ores and the high levels expected from the German *kupferschiefer* ores. The copper may have derived from another source or may have been formed by mixing copper from more than one source.

Two fragments of pewter flatware (Cat. Nos. 468 and 472) were both tin-rich alloys with low levels of copper and lead, comparable to the results given by Brownsword & Pitt (1984; 1985).

The candlestick (Cat. No. 337) has a casting flaw which suggests that it may have been manufactured locally (in London?). The sample is a gunmetal that also contains a wide range of impurities (e.g. nickel, arsenic, silver and antimony) at levels higher than most of the other samples reported here. The metal is broadly similar to other the English candlesticks analysed by Blades (1995), Brownsword & Pitt (1983b) and Brownsword & Ciuffini (1988), although in this case the lead is lower than usual and the arsenic and antimony are a little higher.

Seven lead-tin leisure items were analysed, including a whistle (Cat. No. 595), a rattle (Cat. No. 598) and five toys (Cat. No. 599–601, 603, 605). The whistle has a lead content near the limit for Trifle metal (although no addition of copper), while the rattle contains no detectable lead (<0.3%) but enough copper to strengthen the metal. Four of the five toys have compositions close to the lead-tin eutectic (50–60% tin) and little or no copper.

The antimony ingot (Cat. No. 784) was analysed to determine whether it was indeed metallic antimony. Antimony sulphide has been reported as a waste product from the separation of gold and silver (Rehren 1996: 138–9). Analysis has shown that the ingot contains a small amount of sulphur but is essentially metallic antimony. Antimony was detected in few of the pewter samples analysed here and it appears to have been used only occasionally in the production of everyday items. It is possible that this antimony was intended for the production of type metal (an alloy of tin and antimony) for printing.

The analysed punch (Cat. No. 796) is almost pure copper with no detectable amounts of zinc or tin. This metal would have been very soft and was not well suited for use as a punch.

The two scabbard chapes (Cat. Nos. 1077 and 1083) were a brass and a lead-tin alloy. The lead-tin example is particularly rich in lead and contains only 6.6% tin.

The three samples of wire and seven of sheet (all copper alloy) were varied in their composition, and are presumably waste from the production of a wide variety of different artefacts.

The miscast badge (Cat. No. 1150) is made from almost pure lead.

Glass

Two samples of glass were analysed: one from a 16th century crystal glass stemmed drinking vessel (Cat. No. 501), and the other a fragment of glass working waste (a cylinder of *lattimo* set in crystal, Cat. No. 811). The stemmed drinking vessel (Cat No. 501) has a composition similar to that of Venetian 'cristallo' (cf. Verita 1985). The crystal portions of the *lattimo* waste (inner and outer) are similar to the transluscent soda glass in *lattimo* artefacts from the production site at Old Broad Street, London, although with less magnesia and lime (Mortimer (1993). The white coloured glass itself is opacified by the presence of tin oxide. The base glass used for the white *lattimo* is different to that of the white crystal (note the phosphorus oxide and calcium oxide levels).

Table 8. Composition of glass

Cat. No.	501	811	811	811
Area		Inner	Outer	White *lattimo*
Na_2O	16.9	13.2	13.4	13.0
MgO	1.9	2.2	2.2	2.8
Al_2O_3	1.3	1.1	1.2	1.1
SiO_2	68.5	66.2	67.0	52.4
P_2O_5	0.1	0.5	0.6	0.1
SO_3	0.4	0.2	0.1	0.2
Cl	1.1	0.9	0.8	0.6
K_2O	1.5	7.9	7.5	4.8
CaO	5.5	5.4	5.1	7.7
MnO_2	1.0	0.8	1.0	0.4
Fe_2O_3	0.5	0.5	0.4	0.5
SnO_2	nd	nd	nd	11.9
PbO	nd	nd	nd	4.9

Conclusions

The analysis of the 120 artefacts reported here has provided an insight to the use of lead-tin alloys (pewter) and copper alloys in London from the late 15th to the late 17th centuries. It has been particularly useful to compare the composition of artefacts with the written sources.

Documentary evidence shows that the manufacture of lead-tin alloys was, at least in part, controlled by a guild. The present work has shown the use of two major alloys: the first consists of tin with a small addition of copper and very little lead, the second consists of a lead-tin alloy (close to the eutectic composition) with the occasional addition of a small amount of copper. Spoons that were stamped with a maker's mark were usually made from the former alloy (conforming to Guild regulations) while unstamped spoons were usually made from the latter alloy. Most of the small everyday objects (buckles, etc) were also made from this latter alloy. This alloy contains higher levels of lead than allowed for by the Guild of Pewterers. While documentary evidence indicates that pewterers were beginning to experiment with the use of alloys using new metals, such as bismuth and antimony, the analyses presented here provide little evidence of this.

The copper alloys in use in London at this time were predominantly brasses. The popularity of brass compared to other copper alloys increased through the medieval period and into the post-medieval period. Early post-medieval brass was made by the cementation process which gave a maximum zinc content of around 30%. These alloys are very ductile and well suited to a wide range of manufacturing processes. The assemblage includes small cast items (e.g. buckles) and wrought artefacts (e.g. thimbles) as well as waste from wrought manufacturing processes. In contrast with results from provincial towns (Blades 1995; Dungworth 2001; 2002), there was no evidence for the manufacture of large copper alloy castings, such as cauldrons or bells. The assemblage examined may be largely composed of domestic rubbish from the City and large-scale metal casting was mainly carried out on the outskirts, e.g. Whitechapel. The analysis of the copper alloy buckles has shown that the alloys used differed only slightly from other cast objects, however, they did contain higher levels of iron. This iron may have made the metal more brittle and may have been the cause of the complaints against the manufacturers of buckles. The source of this metal, and the reasons why it was not used in the manufacture of other items (where physical properties such as tensile strength were less critical) is unclear. While these analyses had provided some new insights, much still remains to be learnt about copper alloys at this time.

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Appendix 1

Chemical composition of copper alloy and pewter samples

Cat	Description	S	Fe	Ni	Cu	Zn	As	Ag	Sn	Sb	Pb	Total
81	Buckle	<0.5	<0.1	<0.1	0.2	<0.2	<1.0	<0.5	62	<0.5	36	98.2
82	Buckle	<0.5	<0.1	<0.1	1.4	<0.2	<1.0	<0.5	60	<0.5	37	98.4
84	Buckle	<0.1	0.7	<0.03	91	3.5	0.6	0.3	3.3	<0.2	1.0	100.4
87	Buckle	<0.1	0.14	<0.03	81	18	<0.1	<0.2	<0.2	<0.2	<0.2	99.1
92	Buckle	<0.5	<0.1	<0.1	2.4	<0.2	<1.0	<0.5	50	0.5	47	99.9
93	Buckle	<0.5	<0.1	<0.1	0.3	<0.2	<1.0	<0.5	55	<0.5	44	99.3
94	Buckle	<0.5	<0.1	<0.1	0.8	<0.2	<1.0	<0.5	52	<0.5	45	97.8
99	Buckle	<0.1	1.2	<0.03	84	11	0.5	<0.2	1.3	<0.2	1.4	99.4
100	Buckle	<0.1	1.4	0.2	83	9.1	0.2	0.3	2.9	0.5	3.3	100.9
101	Buckle	<0.1	0.8	0.2	82	12	<0.1	<0.2	2.8	<0.2	2.5	100.3
111	Buckle	<0.1	1.2	0.3	87	5.7	0.7	<0.2	4.1	0.4	<0.2	99.4
119	Buckle (shoe?)	<0.1	1.3	0.2	79	13	<0.2	<0.2	4.5	0.3	1.7	100.0
120	Buckle (shoe)	<0.5	<0.1	<0.1	0.8	<0.2	<1.0	<0.5	92	6.6	<0.3	99.4
121	Buckle (shoe?)	<0.5	<0.1	<0.1	1.3	<0.2	<1.0	<0.5	97	<0.5	<0.3	98.3
140	Mount	<0.5	<0.1	<0.1	<0.2	<0.2	<1.0	<0.5	100	<0.5	<0.3	99.7
142	Mount	<0.5	<0.1	<0.1	<0.2	<0.2	<1.0	<0.5	100	<0.5	<0.3	100.1
145	Mount	<0.5	<0.1	<0.1	1.0	<0.2	<1.0	<0.5	97	<0.5	0.6	98.6
150	Strap end	<0.5	<0.1	<0.1	1.1	<0.2	<1.0	<0.5	98	<0.5	<0.3	99.1
151	Hooked clasp	<0.1	0.4	0.19	84	11	<0.2	<0.2	3.2	<0.2	0.4	99.7
152	Hooked clasp	0.2	0.5	0.4	81	15	<0.1	<0.2	<0.2	<0.2	2.5	100.0
153	Hooked clasp	0.2	0.5	0.4	80	17	0.4	<0.2	<0.2	<0.2	2.0	100.2
154	Hooked clasp	<0.1	0.5	0.18	85	11	<0.2	<0.2	3.0	<0.2	0.9	99.8
155	Hooked clasp	<0.1	0.3	0.17	84	13	<0.1	<0.2	2.7	<0.2	0.6	99.8
156	Hooked clasp	<0.1	0.6	0.4	79	19	<0.1	<0.2	0.2	<0.2	0.4	100.1
158	Hooked clasp	<0.1	0.4	0.3	76	23	<0.1	<0.2	0.2	<0.2	0.6	100.2
159	Hooked clasp	<0.1	0.4	0.2	77	23	<0.2	<0.2	<0.2	<0.2	0.4	100.2
161	Hooked clasp	<0.5	<0.1	<0.1	<0.2	<0.2	<1.0	<0.5	<0.5	<0.5	100	100.0
162	Hooked clasp	<0.5	<0.1	<0.1	<0.2	<0.2	<1.0	<0.5	60	<0.5	39	99.0
163	Hooked clasp	<0.5	<0.1	<0.1	0.9	<0.2	<1.0	<0.5	47	<0.5	51	98.9
165	Hooked clasp	<0.5	<0.1	<0.1	2.9	<0.2	<1.0	<0.5	54	<0.5	42	98.9
166	Hooked clasp	<0.5	<0.1	<0.1	<0.2	<0.2	<1.0	<0.5	65	<0.5	35	100.0
167	Hooked clasp	<0.1	0.5	0.3	77	23	<0.1	<0.2	<0.2	<0.2	<0.2	100.0
168	Hooked clasp	<0.1	0.6	0.3	74	25	<0.1	<0.2	0.4	<0.2	0.4	100.2
169	Hooked clasp	<0.1	0.5	0.3	72	27	<0.1	<0.2	<0.2	<0.2	<0.2	100.2
173	Mount	<0.1	0.6	0.3	77	21	<0.1	<0.2	0.4	<0.2	<0.2	99.3
241	Wire (spiral)	<0.1	0.3	<0.03	84	14	<0.1	<0.2	0.5	<0.2	0.6	99.8
284	Chatelaine	<0.1	0.3	<0.03	76	23	<0.1	<0.2	<0.2	<0.2	0.7	100.1
312	Casket mount	<0.1	0.5	0.17	80	16	<0.1	<0.2	2.0	<0.2	0.4	99.5
337	Candlestick	<0.1	0.4	0.4	88	2.3	1.2	0.3	5.4	1.2	<0.2	99.4
396	Scale tang/handle	<0.1	0.3	0.2	75	24	<0.2	<0.2	<0.2	<0.2	0.8	100.3
468	Vessel (dish ?)	<0.5	<0.1	<0.1	0.6	<0.2	<1.0	<0.5	99	<0.5	<0.3	99.6
472	Vessel (flatware)	<0.5	<0.1	<0.1	0.5	<0.2	<1.0	<0.5	96	<0.5	2.2	98.7
520	Spoon	<0.5	<0.1	<0.1	6.7	<0.2	<1.0	<0.5	91	<0.5	1.0	98.7
521	Spoon	<0.5	<0.1	<0.1	<0.2	<0.2	<1.0	<0.5	98	<0.5	<0.3	98.0
522	Spoon	<0.5	<0.1	<0.1	1.8	<0.2	<1.0	<0.5	96	<0.5	0.5	98.3

Cat	Description	S	Fe	Ni	Cu	Zn	As	Ag	Sn	Sb	Pb	Total
523	Spoon	<0.5	<0.1	<0.1	0.9	<0.2	<1.0	<0.5	98	<0.5	<0.3	98.9
524	Spoon	<0.5	<0.1	<0.1	1.0	<0.2	<1.0	<0.5	86	<0.5	12	99.0
525	Spoon	<0.5	<0.1	<0.1	6.5	<0.2	<1.0	<0.5	91	<0.5	1.1	98.6
526	Spoon	<0.5	<0.1	<0.1	5.7	<0.2	<1.0	<0.5	92	<0.5	1.6	99.3
527	Spoon	<0.5	<0.1	<0.1	1.1	<0.2	<1.0	<0.5	79	<0.5	19	99.1
528	Spoon	<0.5	<0.1	<0.1	3.1	<0.2	<1.0	<0.5	53	0.7	42	98.8
529	Spoon	<0.5	<0.1	<0.1	0.7	<0.2	<1.0	<0.5	93	<0.5	5.2	98.9
530	Spoon	<0.5	<0.1	<0.1	0.5	<0.2	<1.0	<0.5	95	<0.5	4.1	99.6
531	Spoon	<0.5	<0.1	<0.1	1.6	<0.2	<1.0	<0.5	98	<0.5	<0.3	99.6
532	Spoon	<0.5	<0.1	<0.1	1.8	<0.2	<1.0	<0.5	96	<0.5	1.1	98.9
533	Spoon	<0.5	<0.1	<0.1	3.4	<0.2	<1.0	<0.5	77	0.5	18	98.9
534	Spoon	<0.5	<0.1	<0.1	0.9	<0.2	<1.0	<0.5	97	<0.5	0.6	98.5
535	Spoon	<0.5	<0.1	<0.1	1.3	<0.2	<1.0	<0.5	98	<0.5	<0.3	99.3
536	Spoon	<0.5	<0.1	<0.1	1.8	<0.2	<1.0	<0.5	95	<0.5	1.7	98.5
537	Spoon	<0.5	<0.1	<0.1	8.4	<0.2	<1.0	<0.5	89	<0.5	0.7	98.1
538	Spoon	<0.5	<0.1	<0.1	10	<0.2	<1.0	<0.5	87	<0.5	0.4	97.2
540	Spoon	<0.5	<0.1	<0.1	0.4	<0.2	<1.0	<0.5	98	<0.5	<0.3	98.4
542	Spoon	<0.5	<0.1	<0.1	8.2	<0.2	<1.0	<0.5	90	<0.5	0.7	98.9
543	Spoon	<0.5	<0.1	<0.1	1.3	<0.2	<1.0	<0.5	94	<0.5	2.1	97.4
544	Spoon	<0.5	<0.1	<0.1	1.3	<0.2	<1.0	<0.5	98	<0.5	<0.3	99.3
552	Spoon	<0.5	<0.1	<0.1	2.1	<0.2	<1.0	<0.5	96	<0.5	0.6	98.7
554	Spoon	<0.5	<0.1	<0.1	2.3	<0.2	<1.0	<0.5	93	<0.5	4.1	99.4
555	Spoon	<0.5	<0.1	<0.1	1.3	<0.2	<1.0	<0.5	97	<0.5	0.6	98.9
556	Spoon	<0.5	<0.1	<0.1	11	<0.2	<1.0	<0.5	75	1.1	13	99.7
560	Spoon	<0.5	<0.1	<0.1	1.6	<0.2	<1.0	<0.5	98	<0.5	0.6	100.2
561	Spoon	<0.5	<0.1	<0.1	2.2	<0.2	<1.0	<0.5	62	<0.5	35	99.2
566	Spoon	<0.5	<0.1	<0.1	2.5	<0.2	<1.0	<0.5	95	<0.5	1.3	98.8
567	Spoon	<0.5	<0.1	<0.1	1.1	<0.2	<1.0	<0.5	91	<0.5	6.7	98.8
568	Spoon	<0.5	<0.1	<0.1	1.0	<0.2	<1.0	<0.5	97	<0.5	1.2	99.2
569	Spoon	<0.5	<0.1	<0.1	1.3	<0.2	<1.0	<0.5	93	0.7	3.6	98.6
570	Spoon	<0.5	<0.1	<0.1	2.2	<0.2	<1.0	<0.5	96	<0.5	<0.3	98.2
572	Spoon	<0.1	0.4	<0.03	71	27	<0.1	<0.2	<0.2	<0.2	1.5	99.8
576	Spoon	<0.5	<0.1	<0.1	1.2	<0.2	<1.0	<0.5	96	0.6	0.6	98.4
580	Spoon	<0.1	0.6	0.14	75	20	<0.1	<0.2	1.5	<0.2	3.3	99.6
595	Whistle	<0.5	<0.1	<0.1	<0.2	<0.2	<1.0	<0.5	84	<0.5	16	100.0
598	Rattle	<0.5	<0.1	<0.1	0.8	<0.2	<1.0	<0.5	98	<0.5	<0.3	98.8
599	Toy (plate)	<0.5	<0.1	<0.1	0.2	<0.2	<1.0	<0.5	59	0.5	40	99.7
600	Toy (plate)	<0.5	<0.1	<0.1	0.3	<0.2	<1.0	<0.5	60	0.8	37	98.1
601	Toy (casket)	<0.5	<0.1	<0.1	<0.2	<0.2	<1.0	<0.5	50	<0.5	47	97.0
603	Toy (cupboard)	<0.5	<0.1	<0.1	<0.2	<0.2	<1.0	0.6	56	<0.5	42	98.6
605	Toy (bench)	<0.5	<0.1	<0.1	<0.2	<0.2	<1.0	<0.5	28	<0.5	71	99.0
622	Thimble	<0.1	0.12	0.09	92	6.0	0.2	<0.2	0.5	<0.2	0.4	99.5
624	Thimble	<0.1	0.3	<0.03	90	5.6	<0.1	<0.2	2.9	0.2	<0.2	99.5
625	Thimble	<0.1	0.16	<0.03	77	21	<0.1	<0.2	<0.2	<0.2	0.4	99.1
626	Thimble	<0.1	0.09	0.3	79	20	<0.1	<0.2	0.4	<0.2	0.6	100.0
627	Thimble	<0.1	0.13	0.3	80	21	<0.1	<0.2	<0.2	<0.2	0.6	102.8
629	Thimble	<0.1	0.10	0.4	94	4.0	0.5	<0.2	<0.2	<0.2	0.6	99.3
632	Thimble	0.2	0.7	0.3	79	18	<0.1	<0.2	0.6	<0.2	1.1	99.8
633	Thimble	<0.1	0.2	0.3	80	19	<0.1	<0.2	0.4	<0.2	0.4	99.8

Cat	Description	S	Fe	Ni	Cu	Zn	As	Ag	Sn	Sb	Pb	Total
634	Thimble	<0.1	0.2	0.18	83	16	0.2	<0.2	0.4	<0.2	0.3	99.8
635	Thimble	<0.1	0.15	0.6	79	18	<0.1	<0.2	0.7	0.3	0.8	99.5
636	Thimble	<0.1	0.10	0.2	79	19	<0.1	<0.2	0.4	<0.2	0.7	99.8
637	Thimble	<0.1	0.13	0.4	80	19	<0.1	<0.2	0.3	<0.2	0.2	100.0
639	Thimble	<0.1	0.11	0.3	81	17	<0.1	<0.2	0.7	<0.2	1.3	100.6
641	Thimble	<0.1	0.18	0.4	81	17	<0.1	<0.2	0.4	<0.2	0.3	99.9
643	Thimble	<0.1	0.3	0.3	77	21	<0.1	<0.2	0.4	<0.2	0.7	100.0
645	Thimble	<0.1	0.11	0.11	79	20	0.25	<0.2	<0.2	<0.2	0.2	99.8
646	Thimble	<0.1	0.08	<0.03	68	30	<0.1	<0.2	0.3	<0.2	1.5	99.9
648	Thimble	<0.1	1.3	0.10	76	21	<0.1	<0.2	0.3	<0.2	0.9	99.9
649	Thimble	<0.1	0.5	0.4	78	17	<0.1	<0.2	0.3	<0.2	3.5	99.7
652	Sewing ring	<0.1	0.4	0.09	81	17	<0.1	<0.2	0.3	<0.2	0.6	99.6
659	Sheet (waste)	<0.1	0.12	0.2	77	19	<0.1	<0.2	2.3	<0.2	0.5	99.9
662	Sheet (waste)	<0.1	0.08	<0.03	81	17	<0.1	0.2	1.5	<0.2	<0.2	99.9
663	Sheet (waste)	<0.1	0.19	0.3	90	4.4	0.15	0.4	3.5	<0.2	0.3	99.3
663	Sheet (waste)	<0.1	<0.02	0.3	81	15	0.76	<0.2	2.6	<0.2	<0.2	99.6
663	Sheet (waste)	<0.1	0.19	<0.03	87	8.6	<0.1	<0.2	3.9	<0.2	0.3	99.6
677	Sheet (waste)	<0.1	0.13	0.2	93	1.0	0.64	0.4	4.1	<0.2	0.5	99.5
698	Sheet (waste)	<0.1	0.5	0.18	85	11	0.11	0.3	3.0	<0.2	0.3	99.4
704	Wire	<0.1	0.09	0.3	80	18	<0.1	<0.2	<0.2	<0.2	1.1	99.9
710	Wire	<0.1	0.14	<0.03	78	22	<0.1	<0.2	<0.2	<0.2	<0.2	100.1
784	Ingot	3.0	<0.1	<0.1	<0.2	<0.2	<1.0	<0.5	<0.5	96.7	<0.5	99.7
796	Punch	<0.1	0.18	0.2	99	<0.05	<0.1	<0.2	<0.2	<0.2	<0.2	99.7
1077	Scabbard chape	<0.1	0.2	<0.03	79	21	<0.1	<0.2	<0.2	<0.2	<0.2	100.0
1083	Scabbard chape	<0.5	<0.1	<0.1	0.2	<0.2	<1.0	<0.5	6.6	<0.5	92	98.8
1150	Badge (miscasting)	<0.5	<0.1	<0.1	<0.2	<0.2	1.5	<0.5	<0.5	<0.5	98	99.5