Centre for Archaeology Report 29/2003

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ISSN 1473-9224

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Summary

This report deals with a post medieval assemblage (17th – 19th century) of metal working debris consisting of slag (ferrous and non-ferrous) and copper alloy working crucibles. The brass industry is one in which Birmingham built its reputation and wealth during the industrial era. Although a large amount of work has been carried out on medieval and earlier copper alloys (including brasses) relatively little is known about more recent alloys. Samples of the crucibles were analysed quantitatively (SEM-EDS).

Keywords
Copper alloy,
Lead/tin alloy,
Metal working non-Fe,
Metal working Fe,
Ceramic,
Technology,
Post Medieval

Archaeological Background

This study deals with an assemblage of metal working debris (copper alloy working crucibles, ferrous and non-ferrous slag) from Park Street (NGR SP 075 868), close to St Martins Church, the focus of medieval Birmingham. Birmingham University Field Archaeology Unit carried out an excavation from February to July 2001 prior to the construction of a multi-storey car park. The site is located within the city centre and surrounded by Park Street, the Bull Ring, Well Lane and Moor Street Station (figure 1). Earlier excavations have been carried out in the vicinity of the site at the Bull Ring Market, Moor Street and Edgbaston Street. These showed that the area had been laid out from 13th century onwards, and that from the medieval period onward property boundaries have been continuous. The excavations have shown a high rate of survival for a range of domestic and industrial activities from the 12th to 20th century.

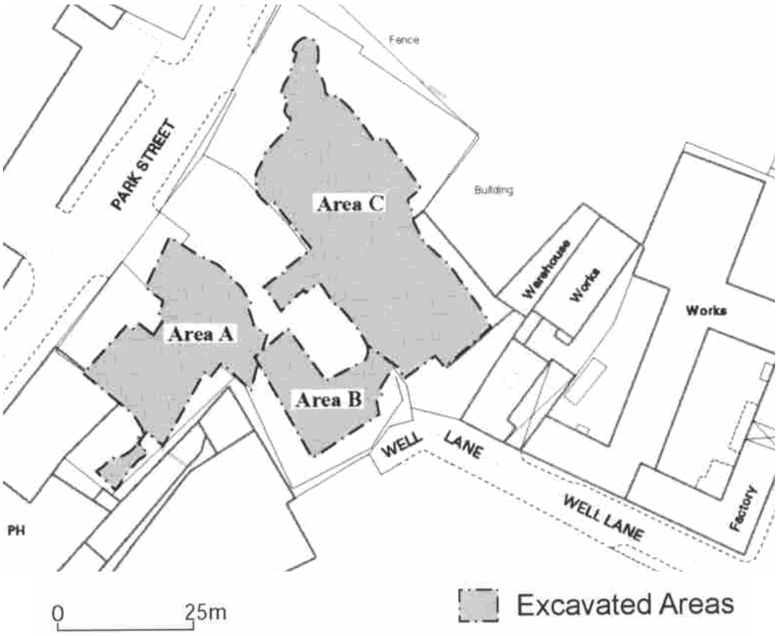

Figure 1: Map of excavation areas.

Within phase 1 and 2 (12th - 16th centuries) there were a number of features indicative of industrial activity which included a series of clay lined pits possibly linked with the textile or tanning industry. Other features include a large property boundary ditch and a sequence of layers with associated pits, postholes and a possible kiln linked with pottery production. Phase 3 (17th - 18th centuries) was characterised by a grey cultivation soil up to 0.70m deep and cut by many pits. Some of these pits contained crucibles and slag suggesting high temperature industrial activity. The rectangular shape and waterlogged fill of other pits may indicate tanning. Phases 4 and 5 (19th - 20th centuries) largely consisted of building phases, pipe trenches and layers of demolition, levelling and rebuilding. Perhaps the most important evidence was the continuity of boundaries from the medieval period up to the twentieth century.

Historical background

One of the most important brass-related trades carried out in the 17th and 18th century involved the production of buckles. The buckle trade was introduced to the Birmingham area in the middle of the 17th century (Hamilton 1926). Fashion can be a brutal master however and the industry collapsed quickly in 1790 with the introduction of the “effeminate shoe string” (Timmins 1866) or “slovenly ribbon” (Bates 1860). Such was the hardship caused by this change in style that in 1791 buckle makers petitioned the Prince of Wales to help the “more than 20,000 persons who in consequence of the prevalence of shoe strings and slippers” were in dire straits and unemployed (Timmins 1866).

Trade directories can provide useful information about the location of particular industries. One of the earliest detailed directories for Birmingham was compiled at the beginning of the 19th century (Wrightson 1969). The 63 brass founders listed in this directory mostly lived to the west, north and east of the city centre. This distribution follows closely the canals, which ring Birmingham’s city centre. It is unclear if these industries had been established in these areas for some time or had been attracted by the construction of the canals. The professions listed for Park Street include brass founders and iron smiths.

Research objectives / aims

The research aim for this project was to investigate the remains of medieval and later industrial activity.

Industrial activity was fundamental to the late medieval and post medieval growth of the town yet little is known about the detail of specific industries. The Park Street assemblage offers an important opportunity to investigate post medieval metal working in Birmingham during the start of its great expansion. The main objective was to determine the sorts of copper alloys that were being cast.

Visual assessment

A total of 92kg of material labelled as slag was visually assessed noting its morphology, colour and weight using the principles and systems set out in Bayley *et al* (2001). If required qualitative X-ray fluorescence analysis (EDXRF) was carried out. Table 1 below shows a breakdown of the results of the visual assessment (the full list is in appendix 1).

Table 1 - Summary of the slag

Interpretation	**Weight (g)**
Run slag	18
Tap slag	130
Hammerscale	146
Smithing hearth bottoms	8866
Undiagnostic ironworking slag	80493
Vitrified hearth lining	148
Vitrified ceramic material	1375
Copper Slag	897
Vitrified tile	54
Vitrified building debris	460
Pot	2
Total	92589

Some types of slag are visually diagnostic, providing unambiguous evidence for a specific metallurgical process. Other debris is less distinctive and it is not possible to say from which metallurgical, or other high temperature process it derives.

Explanation of slag classification

The diagnostic slag from Park Street comprised only a small percentage of the assemblage. However, this did include clear evidence of iron smithing (*i.e.* hot working) and copper alloy melting. There was no definite evidence that iron, or any other metal, had been smelted (reduced from the ore) on the site. As most of the diagnostic slag was produced by iron smithing, it is likely that the majority of the undiagnostic ironworking slag was also a by-product of smithing. Many pieces of slag and many of the smithing hearth bottoms contained varying sized fragments of coal, which must have been the fuel. Tap and run slag have a distinct shape resembling a flow of lava, and are a product of smelting. So little is present that it is not indicative of smelting on site. Vitrified hearth lining is clay from the hearth structure that has been exposed to high temperatures.

Smithing hearth bottoms have a distinctive shape, plano-convex to concavo-convex in section and circular or oval in plan. Sometimes (as is the case for Park Street) the upper surface has a depression produced by the air blast from the blowing hole. They are the slag that collects in the base of the smith's hearth, and are unlikely to be confused with the waste products of smelting and are therefore considered to be diagnostic of iron smithing. The Park Street smithing hearth bottoms contained lumps of coal.

Hammerscale (see appendix 2) is evidence of smithing and is produced when the oxidised surface of a hot iron object is struck. Concentrations of hammerscale can often indicate reasonably accurately where smithing took place on site. The majority of the hammerscale was recovered through environmental samples (presumably 20 litre soil samples). Floor deposits from within buildings used for iron smithing usually contain at least 10% hammerscale but the proportion of hammerscale from deposits in Park Street is relatively low (Mills and McDonnell 1992).

Over a kilogram of vitrified ceramic material (figure 2) was present, distinctly different from vitrified hearth lining. It is reduced fired, the outer is vitrified and the inner surfaces have up to three parallel indentations approx. 20mm wide. The surviving length is up to 140mm. A number of corners are present suggesting a cuboid structure. The exact function of this material is unknown, but it has been suggested that it may relate to the carburisation of iron objects. This is where iron objects are heated in a bed of charcoal, the carbon then entering the surface of the object and creating a steel shell.

The evidence for copper alloy melting came from slag and the vitrified tile as well as from the crucibles (see below). When analysed qualitatively by X-ray fluorescence the slag and tile both showed the presence of copper and zinc. The vitrified tile was probably part of the furnace structure. The vitrified building debris when analysed contained no copper, zinc or any other element indicative of a metallurgical use. The pot was a very small sherd with a brown glaze and also unrelated to metallurgical processes.

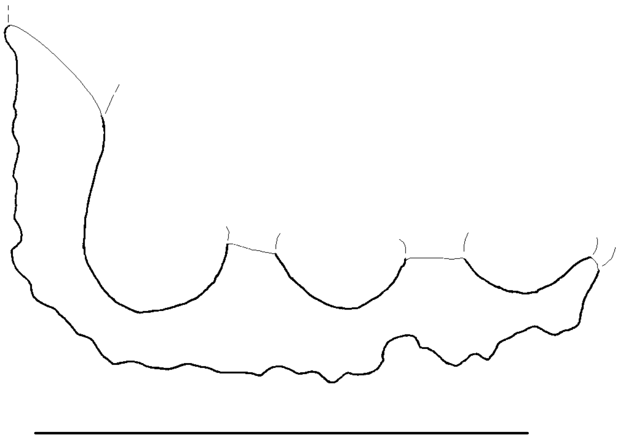

Figure 2: Cross section of vitrified ceramic material

Spatial Analyses

The metallurgical debris is split across the three areas as shown in table 2 (the iron slag category includes smithing hearth bottoms, vitrified hearth lining and non diagnostic slag). All of the copper alloy slag and the majority of the crucibles and were recovered from area A, whilst the majority of the iron slag came from areas B and C. Interestingly the hammer scale nearly all came from area A, and was not always associated with iron slag deposits. This suggests the iron slag is re-deposited in the context where it was found.

Table 2: Distribution of types by weight across areas

	A	**B**	**C**
Crucibles (g)	12140	2087	857
Iron slag (g)	20013	9187	60939
Vitrified ceramic (g)	0	0	1375
Hammerscale (g)	121	25	0
Copper alloy slag (g)	897	0	0
Total (g)	33284	11312	63171

No industrial features were recorded on site, all the metallurgical material came from the fill of pits. Pit F769 in area C was notable because of the large amount of slag and charcoal found in it (Mould *personal communication*). As inclusions within the slag were coal, the charcoal probably came from domestic sources. There were surprisingly few joins within the crucible assemblage and only a few of the crucibles appear to have failed whilst in the furnace. This suggests that the Park Street metallurgical debris was not associated with brass founding activity within the excavation area, but may have been dumped, perhaps as part of a ground levelling operation.

Examination of crucibles
(See appendix 3 for catalogue)

A total of 130 fragments weighing a total of 15kg were recovered. Every crucible fragment was examined and weighed and its colour, position within vessel body (e.g. base or rim) and vitrification noted. When a fragment was large enough the external diameter was measured. All were examined to see if any joins existed between the fragments. In total there are 17 base fragments, 41 rim fragments and 71 side fragments and one possible lid. All the fragments were given a unique catalogue number.

Form

The Park Street crucibles (figure 5) are very similar to assemblages recovered from Legge's Mount, Tower of London (Bayley 1992, fig 5) and Barnard Castle, County Durham (Bayley & Linton 1982). These crucibles tend to be deeper than they are wide; the walls are thick and near vertical or with a slight flare. Some of the rim fragments include a pinched-out lip. All the bases present are flat, in one case (crucible no. 29) an entire base is preserved with no sides. That the crucibles were used in the melting and casting of copper alloys was confirmed by qualitative EDXRF. In a couple of instances (crucible number 45 and 124) the fragments contained layers of slag over 10mm thick. Large proportions of the crucibles show evidence of being wheel thrown, as would be expected for this period (Bayley 1992, 5).

Not all the crucibles are of the deep, thick-walled style. Some sherds (e.g. crucible no. 25) appear very similar to the thinner-walled crucibles also from Legge's Mount (Bayley 1992, Fig 6) including a similar style of pulled lip. There are no base fragments of this type present, but if they are similar to those Legge's Mount, we could expect them to have a 'flower pot' shape, everted walls and a flat base (Bayley 1992, 5). These also appear to be wheel thrown.

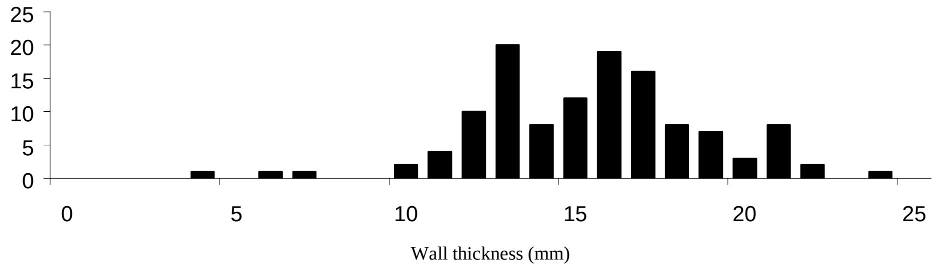

Figure 3: Histogram of crucible wall thickness

Figure 3 shows a histogram of the wall thickness. Distribution appears to be bimodal, this is probably a reflection of the variability in wall thickness with height above the base (see figure 5). The outliers below the main group represent the thin-walled crucibles.

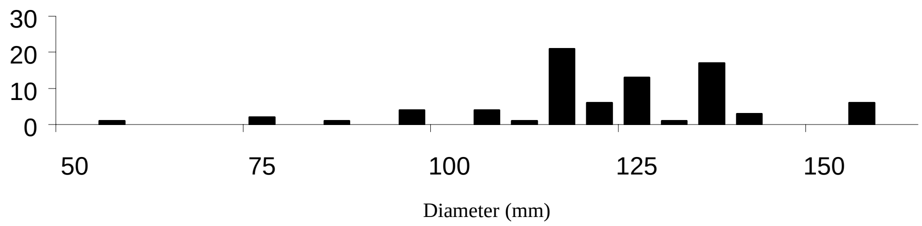

Figure 4: Histogram of crucible diameters

Figure 4 shows a histogram of diameters. The majority of crucibles have a diameter of 100 – 160mm. Those with small diameters are the thin-walled crucibles with the exception of crucible no. 29, a complete base with no walls which has the smallest diameter of all.

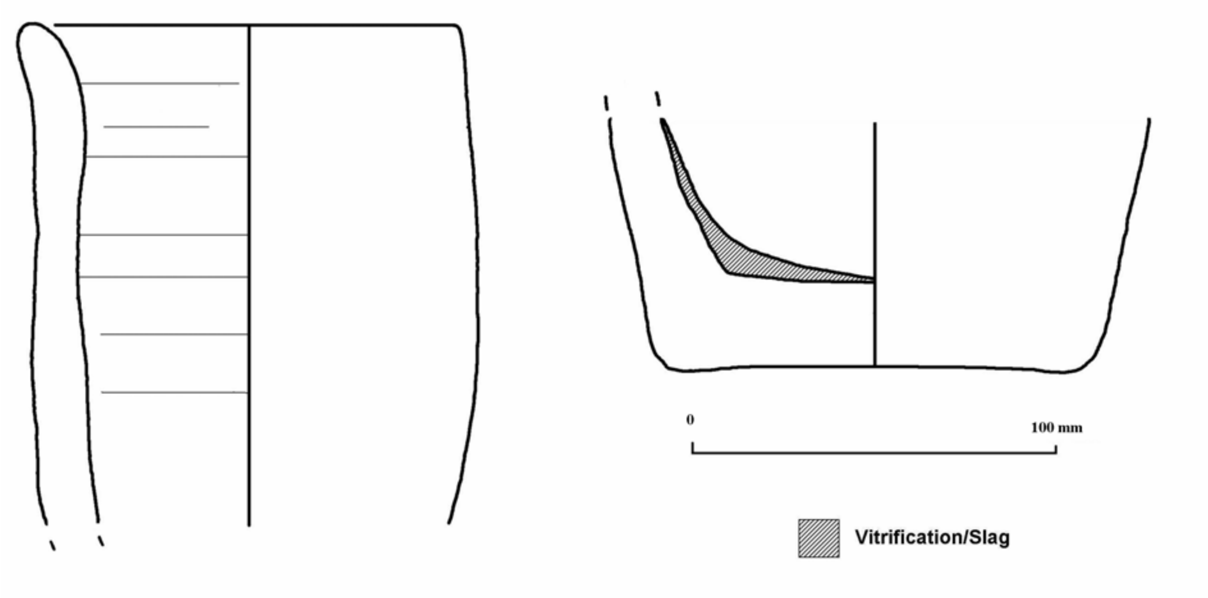

Figure 5:Two sketches of typical crucibles from Park Street

Fabric

The fabric of the crucibles appeared to be extremely uniform although there is a considerable variation in colour. Some pieces are a light brown whilst at the other end of the spectrum is a strong purple, the colour change usually occurs from the outside in with darker colours towards the outside. This variability in appearance is likely to be a consequence of the differing amounts of usage each crucible had received at the time of its failure and / or discard. A majority of the crucibles showed at least the beginning signs of some vitrification (where the heating of the crucible fabric has reached a point where the outer layers begin to change to a glassy or vitreous state [Bayley *et al* 2001]). These crucibles have spent a long time at high temperatures.

In crucible no. 124 fused within the deposit on the inner surface are two small lumps of coal. This implies that coal was being used as the fuel.

With a few exceptions (e.g. crucible no. 88) none of the crucibles appear to have failed whilst in the furnace. The vast majority of the breaks appear clean, suggesting that deposition occurred shortly after they were broken.

Selection of crucibles for analyses

22 fragments were analysed; 15 from area A, 2 from area B and 5 from area C.

It was hoped the analyses would identify the alloys being melted so preference was given to fragments more likely to give positive results such as those containing slag, which could potentially contain metallic droplets.

Sample preparation and method of analyses

Before sampling occurred a digital photograph was taken of the inside, outside and edge for each crucible fragment. The photographs were saved as JPEG's in 24 (true) colour at 118 pixels per cm. Samples were taken using a rock saw, then mounted in resin and polished to a 1-micron finish. Before carbon coating it was noted that two samples (crucible nos. 45 and 26) contained what appeared to be metallic droplets visible to the naked eye.

Examination and analyses was carried out using a scanning electron microscope (Leo Stereoscan 440I) in backscatter mode. This provides an atomic number contrast image, allowing metallic droplets to be easily identified from the surrounding vitrified layers. The compositions of the crucibles, vitrified layers and metal droplets within the vitrified layers were determined using an energy dispersive spectrometer (with Germanium detector) attached to the scanning electron microscope. The spectra were collected at 25kV and 1.5nA for 50 seconds livetime and calibrated with a cobalt standard. The spectra were quantified using the Oxford Instruments SEMQuant software (ZAF correction procedure). Metal droplets were analysed using a small area (typically 10 by 20 microns). Some of these droplets had suffered from post-depositional corrosion; this could be seen in the levels of oxygen, sulphur and/or chlorine detected. The results reported here include only those droplets which had suffered no post-depositional corrosion. For the vitrified layers and crucible fabric larger areas were analysed (typically 100 by 200 microns). The composition of the vitrified layers and crucible fabrics were calculated stochiometrically as oxides. This involves making some assumptions about the oxidation state of some of the metals (e.g. iron). The vitrified layers and crucible fabrics contained variable amounts of porosity and so the analytical results for these areas tended to give low totals. To aid comparison between different vitrified layers and areas of crucible, the results were normalised to 100%. Other analytical work with this equipment and following the same procedures (e.g. Dungworth 2002) indicate that the results are accurate to within ±0.5% for minor elements or oxides (present but below ~5%) and ±1–2% for major elements or oxides.

Crucible no. 92 was investigated in great detail in order to help establish analytical procedures for the others. Each crucible was analysed and recorded systematically. First the inner and outer sides of the sample were investigated for metallic droplets, then inner and outer vitrified layers, and last the fabric.

Table 3: Minimum detection limits and errors for the metal droplets

	Fe	**Ni**	**Cu**	**Zn**	**As**	**Sn**	**Sb**	**Pb**
MDL	<0.1	<0.1	<0.1	<0.1	<0.5	<0.5	<0.5	<0.5
Error	±0.1	±0.1	±0.1	±0.2	±0.2	±0.4	±0.4	±0.4

Table 4: Minimum detection limits and error for the fabric and vitrified layers

	Na_2O	**MgO**	**Al_2O_3**	**SiO_2**	**P_2O_5**	**SO_3**	**K_2O**	**CaO**	**TiO_2**	**MnO_2**	**Fe_2O_3**	**CuO**	**ZnO**	**SnO_2**	**PbO**
MDL	<1.0	<0.4	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.5	<0.5
Error	±0.1	±0.5	±0.5	±0.5	±0.3	±0.3	±0.2	±0.3	±0.1	±0.1	±0.1	±0.1	±0.1	±0.3	±0.5

Discussion

Vitrified layers and Fabric

Crucible no. 92 – a case study
(See appendix 7)

A detailed analysis was carried out across crucible no. 92. A series of small areas (typically 100 – 200 microns) was analysed across the width of the crucible between the inner and outer vitrified layers.

The inner vitrified surface of crucible no. 92 (also 26, 24, 46, 95 and 118) contained an unexpectedly high amount of soda. Figure 6 shows a plot of crucible no. 92; the inner vitrification has a high soda content that disappears once inside the fabric. This suggests the possibility that crushed glass was being used as a flux in combination with charcoal in order to prevent zinc diffusion (Higgins 1974). Indeed many of the deposits inside the crucibles visually looked more like glass than slag.

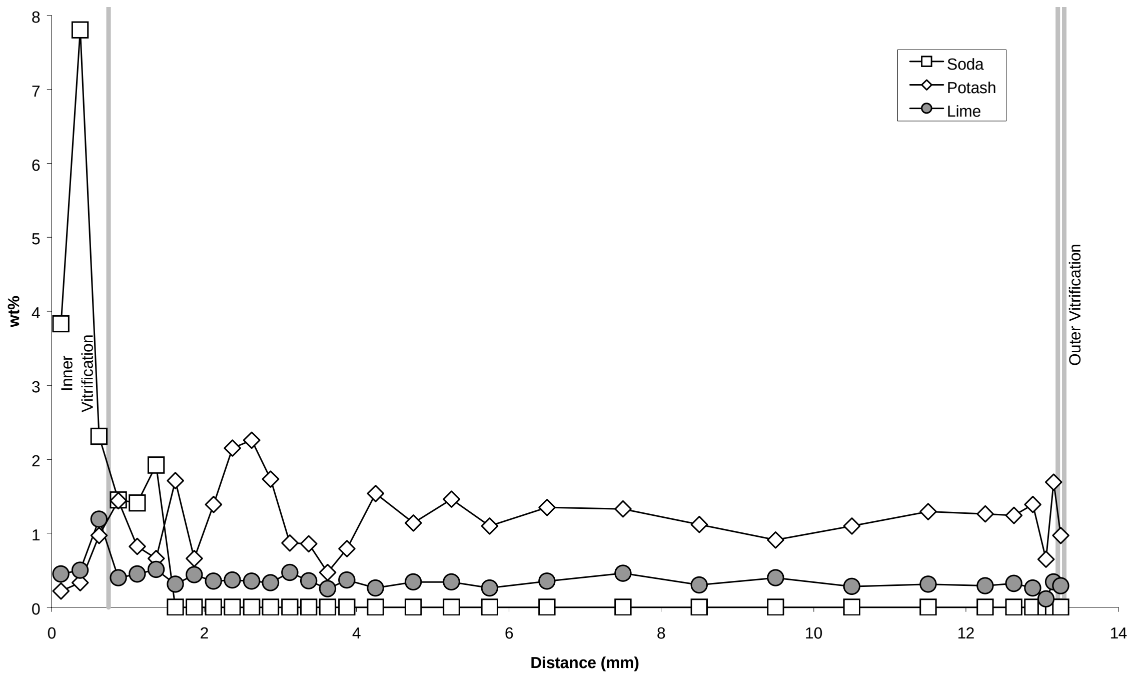

Figure 6: Variation in composition across the thickness of crucible no. 92

Figure 7 shows the variation of copper and zinc throughout the fabric of crucible no. 92 from inner to outer vitrification. Zinc, as is discussed below, is highly volatile so it is to be expected that crucibles used for brass would, on analysis, contain zinc, the amount decreasing steadily from inside to outside. This contrasts strongly with copper alloy working crucibles from Housesteads Roman Fort (Dungworth 2001), where the zinc had not diffused into the fabric as had been expected. Most likely this is due to different patterns of use. The Park Street crucibles were probably constantly in use while the crucibles from Housesteads would have had nowhere near the same frequency of employment.

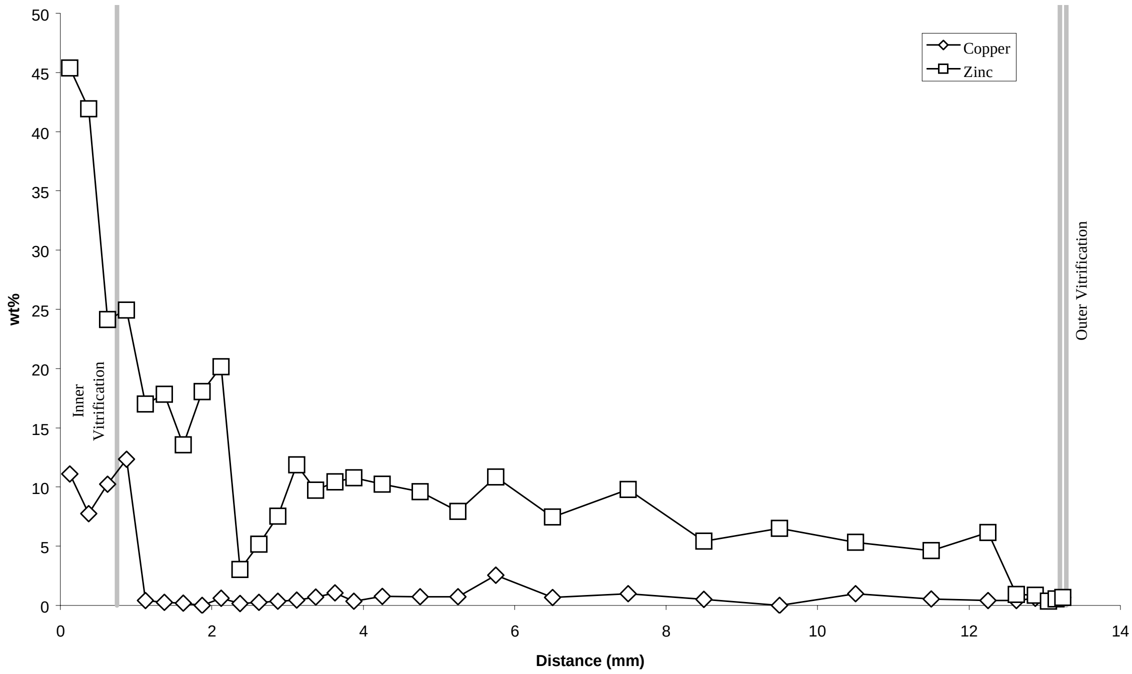

Figure 7: Metal content across the thickness of crucible no. 92

The crucibles
(See appendix 5 and 6 for results)

Zinc is the metallic element most consistently present in the inner vitrified layers (average [mean] 12.3% ZnO). This is as to be expected due to zinc's high volatility, it has a boiling point of 907°C compared to copper's melting point of 1084°C. By the time copper has melted, zinc will be a gas. Zinc is also more readily oxidised than copper, tin or lead (Dungworth 2000, table 2) and can act as glass-forming element, chemically binding it into the vitrified layer (Bayley *personal communication*).

The fabric of the majority of the crucibles is relatively uniform. Alumina is present at 23 - 30%, silica within the range of 62 – 70%. These high proportions ensure the fabric is refractory enough (can withstand high temperatures without vitrification [Bayley *et al* 2001]) for use in a furnace. Other oxides that are consistently present are titania (TiO_2, approx. 1 – 1.5%), a trace of lime (CaO) and potash (K_2O) and approximately 2% iron oxide (Fe_2O_3). The best way of identifying an unusual fabric was when the titania dipped below 1%.

There was no clear evidence to help identify the reason for the purple coloration within the fabric. It is likely to be the product of a redox reaction possibly involving iron and manganese, but it is impossible to say using this analytical method as it provides no direct evidence for the oxidation state of elements present.

Crucible no. 24

The vitrified surfaces of crucible no. 24 contained significant amounts of lead (inner 31.3%, outer 15.9%) and tin (inner 15%). There was no copper or zinc present. The composition of the vitrified surfaces of this crucible would have been fully molten at around 700°C (Molera *et al* 1999) and so the crucible is unlikely to have been heated above this temperature. All this suggests that pewter was being melted.

Metallic Droplets
(See appendix 4 for results)

Nine crucibles produced a total of 51of uncorroded droplets. The analyses can be divided into three categories: copper, brasses and gunmetals. There is considerable variation and overlapping within this classification.

The samples categorised as ‘copper’ contained between 95 and 98.9% copper and less than 1% of any other element. The majority of these droplets came from crucible no. 45, and there were no droplets of any other composition from this sample. There are two possibilities: the metal once contained zinc and/or tin/antimony/lead but this has been preferentially oxidised and hence lost, or the crucibles were sometimes used for melting unalloyed copper. On analysis, the slag in crucible no. 45 was found to be rich in zinc strongly suggesting that latter is unlikely. Copper alloys, probably some form of brass, were being melted in these crucibles.

The brasses are copper-zinc alloys that contain between 19 and 25% zinc. As has already been indicated zinc is easily oxidised so there is a possibility that the droplets will have a lower zinc content than that of the brass originally melted (Dungworth 2000).

Gunmetals are copper alloys that contain significant amounts of both zinc and tin. There are three distinct groups within the gunmetals, those that contain antimony, those that contain lead and those that contain neither (see table 5).

Table 5: Mean composition and standard deviation for the gunmetals

Crucible no.		Fe	Ni	Cu	Zn	As	Sn	Sb	Pb
26	**Mean**	0.7	0.3	81.7	12.5	0.8	2.8	1.7	
	sd	0.3	0.1	2.2	2.8	0.2	0.9	0.9	
36	**Mean**	1.3		83.0	8.8		6.9		
	sd	0.1		1.0	1.4		2.5		
46	**Mean**		0.2	82.9	9.0		5.2		2.7
	sd		0.0	0.7	0.5		0.0		0.6
84	**Mean**	1.0	0.1	79.8	16.2		3.0		
	sd	0.6		6.3	7.0		1.2		

The addition of lead lowers the melting point of copper alloys and increases the fluidity (Dungworth 2001) making them easier and more economical to work when casting. Lead also affects the malleability when the alloy is solid and consequently makes it less suited to drawing, rolling and hammering.

Crucible no. 26

The antimony gunmetal droplets all come from crucible no. 26. This crucible had two vitrified layers on the inner surface, one contained the antimony gunmetals whilst the other contained a gunmetal with no antimony, but some lead in its place. In 1866 Samuel Timmins makes reference to a metal called Tutania “which was said to take its name from one Tutin, the inventor”, and was used primarily in the production of shoe buckles. Fleming and Honour (1977) give this definition: ‘Tutania. An alloy of copper, calamine [zinc oxide], antimony and tin patented in 1770 by William Tutin whose Birmingham firm (Tutin and Haycroft) produced small domestic articles in it’. However an inquiry with the patent office elicited only one patent (No. 1019) by Mr Tutin in 1772 for a method of varnishing buckles.

The Oxford English Dictionary defines Tutania as being ‘an earlier name for Britannia-metal [pewter]’. It then proceeds to give several ‘recipes’ for its production that contain considerable variation. However Bates (1860) suggests that Tutin’s Tutania was originally named Tutinic (its main rival being the Chinese alloy Tutenac, a brass containing nickel). The introduction of Britannia metal from Sheffield led to the renaming of Tutinic to Tutania, enabling it to still indicate its paternity whilst imitating the new arrival.

There is also a Tutania song. Composed by Mr John Freeth (1790) it is perhaps best viewed as a prototype advertising jingle rather than a work of art, and offers the following insights:

‘*Some for* Pinchbeck, *some for* Plated,
Some for Soft-White, *some for* Hard;
Everyone is overrated,
With Tutania, *when compared.*

* * * * * * * * * * * * * * *

‘*All to one good soul must truckle,*
He that does the rest eclipse,
Makes a Song *and forms a* Buckle,
Whilst a Pipe’s *between his* Lips.’

The Soft-White and Hard are most likely variants of pewter whilst Pinchbeck is a brass, composed of approx. 83% copper and 17% zinc. It is possible that the antimony gunmetal detected in crucible 26 is Tutania.

Whether antimony was added deliberately or not it, it helps us to define the purpose for which the alloy is used. Antimony increases the tenacity and hardness of copper, but if there is more than 0.2% present the metal will crack at the edges when rolled (Gowland 1921). The alloy that was being produced could therefore not have been intended for any use such as drawing or rolling, but would have been fit for casting purposes only.

Conclusion

The metal working debris from Park Street represents a broad range of secondary metal working, including iron smithing and the casting of copper alloys. There was no indication of any primary activity such as the smelting of either iron or copper on the site. The majority of the crucibles were used in the melting of a range of copper alloys including brass and gunmetals. There were two exceptions, the ‘Tutania’ of crucible no. 26 and the pewter from crucible no. 24. All of the non-ferrous alloys melted in the Park Street crucibles would have most likely been used in the production of items such as buckles, spoons, buttons, skillets and other small to medium sized personal and household goods.

The vitrified ceramic material recovered from area C has no published parallels. The most likely suggestion is that they are related to the carburisation of iron objects.

No industrial features were recorded on site and there were surprisingly few joins within the crucible assemblage. The suggestion remains that the Park Street metallurgical debris was not associated with iron smithing or brass founding activity within the excavation area, but was dumped, perhaps as part of a ground levelling operation.

References:

Bates, W 1860 Sept 15 ‘Tooth and Egg’ Metal. *Notes and Queries* **Vol. 10 2nd S. (246)**, 214

Bayley, J 1992 ‘Metalworking Ceramics’. *Medieval Ceramics* **16,** 3 - 10

Bayley, J and Linton, R 1982 *Technological Samples from Barnard Castle, Co Durham*. Ancient Monuments Laboratory Report 3810. London: English Heritage

Bayley, J, Dungworth, D and Paynter, S 2001 *Archaeometallurgy*. Centre for Archaeology Guidelines. London: English Heritage

Dungworth, D 2000 ‘A note on the analysis of crucibles and moulds’. *Historical Metallurgy* **34**, 83 - 87

Dungworth, D 2001 *Metal Working Evidence from Housesteads Roman Fort, Northumberland*. Centre for Archaeology Report 109/2001. London: English Heritage

Dungworth, D B 2002 *Analysis of post-medieval lead-tin alloy, copper alloy and glass artefacts from Southwark, London*. Centre for Archaeology Report 64/2002. London: English Heritage

Fleming, J and Honour, H 1977 *The Penguin Dictionary of Decorative Arts* London: Viking

Freeth, J 1790 ‘The political Songster, or a Touch at the times &c’, *quoted by* Bates, W 1860

Gowland, W 1921 *The Metallurgy of the Non-Ferrous Metals*. London: Charles Griffin and Company Limited

Hamilton, H 1926 *The English Brass and Copper Industries to 1800.* London: Longmans, Green and Co Ltd

Higgins, R A 1974 *Engineering Metallurgy 2. Metallurgical Process Technology* London: Edward Arnold (Hodder & Stoughton)

Mills, A and McDonnell, J G *1992 The Identification and Analysis of the Hammer Scale from Burton Dasset, Warwickshire*. Ancient Monuments Lab Rep 47/92. London: English Heritage

Molera, J, Pradell, T, Salvadó, N & Vendrell-Saz, M 1999 Evidence of tin oxide recrystallization in opacified lead glazes. *Journal of the American Ceramics Society* **82**: 2871–5

Onions, C T (*ed*.) *The Shorter Oxford English Dictionary* Oxford: Clarendon Press

Timmins, S 1866 ‘The Industrial History of Birmingham’ in Timmins S (ed) *Birmingham and the Midland Hardware District* (Cass Library of Industrial Classics No. 7) London: Robert Hardwicke

Wrightson, R 1969. *Wrightson's New Triennial Directory of Birmingham: 1818*. Facsimile reprint of 1st ed., Birmingham, R. Wrightson, 1818. Newcastle upon Tyne: Graham

Appendix 1: Catalogue of slag (weights in grams)

Context	Smithing Hearth Bottoms	Non Diagnostic	Cu Slag	Vitrified ceramic material	Other	Crucibles	Area	Feature	Phase
1030							A		
1101		1592	399			956	A		
1103						135			
1104		1159					A		
1108			106			186	A		3 or 4
1110			72			87	A	F123	3 or 4
1111		3					A	F124	3
1115						139			
1116		145					A	F128	3
1118		305					A		4
1125	763	2982	320			6277	A	F133	3
1126		181					A	F134	3
1130							A	F137	3
1132		262				91	A	F138	3
1133		8				133	A	F139	4
1139					VHL 28	1221	A	F138	3
1143					TAP 38		A		3 or 4
1153		43					A		
1157		34					A	F148	3 or 4
1158		413					A		
1162	494	926					A	F157	1 or 2
1165		8					A	F174	1 or 2
1166		510					A	F234	4
1167	846	113			VHL 120	989	A	F154	3
1175		2754					A	F158	3
1176	227					1523	A	F159	3
1177		320					A	F160	1 or 2
1187		29				323	A		
1197		6					A	F174	1 or 2
1203		117					A	F183	3
1204		191					A	F182	3
1205		579					A	F180	1 or 2
1210		23					A		4
1213		517					A	F174	1 or 2
1219		13					A	F187	3
1220		61			18 RUN		A	F188	1 or 2
1225		21					A	F170	3
1234		8					A	F194	3
1239	2742	33					A		1 or 2
1240		76					A	F193	3
1241		114					A	F194	3
1243						60	A		
1252		730					A	F201	1 or 2
1297		311					A	F233	
1312		6					A	F196	
1326		11					A	F201	
1367		133					A	F245	
1381		3					A	F233	
U/S						36	A		

Context	Smithing Hearth Bottoms	Non Diagnostic	Cu Slag	Vitrified ceramic material	Other	Crucibles	Area	Feature	Phase
1505		118					B		Non assigned
1505		503			92 TAP		B		Non assigned
1506		211					B	F503	3
1512		474					B	F500	3
1515	1074	2132					B	F504	
1519		468					B	F506	1 or 2
1520		119				39	B		3 or 4
1521		19				180	B	F503	3
1522		21				35	B	F509	3
1526		142					B	F511	3
1530		75					B	F520	3
1531		374				20	B	F510	3
1580						634			
1596		197					B		1 or 2
1621		765				848	B	F542	3
1622		60					B	F542	3
1631		87					B		1 or 2
1632		41					B	F546	1 or 2
1634	1027	731				333	B	F542	3
1635		342					B	F542	3
1646						33			
1659		44					B	F562	1 or 2
1690		87					B		1 or 2
1708		23				419	C	F700	3
1711						50			
1721		42179					C	F702	3
1725		110					C	F705	3
1726		38					C	F706	3
1727						58			
1738		1329				147	C		
1739						VBD 460	C	F713	3
1772		39					C	F752	1
1784	1368						C	F746	1 or 2
1787		7					C	F745	3
1795		55					C	F775	3
1798				18			C	F749	3
1807		28					C	F759	4 or 5
1818		3					C	F765	3
1819		138					C	F761	3
1820		450		7			C	F762	3
1825		591				3	C	F769	3
1826		6896					C	F789	3
1827		159					C		
1834		19					C		
1839		676					C	F773	3
1841		1647					C		1 or 2
1842		8					C	F775	3
1851		171					C	F782	3 or 4
1857		96					C	F783	3
1872		210				11	C	F789	3

Context	Smithing Hearth Bottoms	Non Diagnostic	Cu Slag	Vitrified ceramic material	Other	Crucibles	Area	Feature	Phase
1888		6				27	C	F810	3
1908		2143		434			C	F811	3
1913		955		652			C	F816	3
1916				20	Vitrified tile 54		C	F808	3
1918				78			C	F816	3
1920		5					C	F829	1 or 2
1930		3					C	F823	3
1931		160				126	C	F824	3
1938	325	474		136			C	F828	3
1941		171		30			C	F828	3

Key:

Run - Run slag
Tap - Tap slag
VHL - Vitrified hearth lining
VBD - Vitrified building debris

Appendix 2: Catalogue of hammerscale (weights in grams)

Context	Weight	Area	Feature	Environmental sample number
1176	36		F159	24
1312	1	A	F195	22
1144	11	A	F144	14
1141	1	A	F141	4
1219	8	A	F187	20
1175	14		F158	6
1157	5	A	F148	5
1030	1			1
1220	4	A	F188	15
1133	6	A	F139	1
1126	9	A	F134	
1213	1	A	F174	18
1367	3	A	F245	29
1033	2			2
1175	19	A	F158	6
1515	25	B	F504	

Appendix 3: Catalogue of crucibles (weights in grams)

Context No.	Area	Feature	Phase	Crucible No.	Sampled	Position	Weight	Width (side, mm's)	Width (base, mm's)	Diameter (mm's)
1101	A			18		Side	223	15		120
1101	A			61		Side	125	17		
1101	A			62	Y	Rim	74	16		120
1101	A			63		Lid?	109	28		
1101	A			64		Side	85	19		
1101	A			65		Base	154	18	20	124
1101	A			66		Side	89	17		140
1101	A			67		Side	27	13		
1101	A			68	Y	Side	70	16		140
1103	A			39		Side	135	21		120
1108	A		3 or 4	38		Base	186	16	21	144
1110	A		4 or 5	41	Y	Side	87	35		
1115	A	F127		48		Side	81	16		130
1115	A	F127		50		Side	58	18		124
1125	A	F133	3	69	Y	Side	153	15		142
1125	A	F133	3	70		Side	273	20		124
1125	A	F133	3	71		Side	182	19		
1125	A	F133	3	72		Rim	128	15		130
1125	A	F133	3	73		Rim	236	13		124
1125	A	F133	3	74		Rim	87	13		
1125	A	F133	3	75		Base	104	16	9	100
1125	A	F133	3	76		Rim	127	15		130
1125	A	F133	3	77		Side	160	17		
1125	A	F133	3	78		Side	121	19		120
1125	A	F133	3	79		Base	121	18	20	
1125	A	F133	3	80		Rim	130	15		
1125	A	F133	3	81	Y	Rim	72	13		120
1125	A	F133	3	82		Rim	93	13		110
1125	A	F133	3	83		Rim	155	13		110
1125	A	F133	3	84	Y	Side	76	13		120
1125	A	F133	3	85		Side	186	20		
1125	A	F133	3	86		Rim	75	15		120
1125	A	F133	3	87		Rim	134	14		140
1125	A	F133	3	88		Rim	90	15		120
1125	A	F133	3	89		Side	73	14		140
1125	A	F133	3	90		Rim	89	13		120
1125	A	F133	3	91		Rim	174	12		130
1125	A	F133	3	92	Y	Side	58	12		128
1125	A	F133	3	93		Side	174	19		140
1125	A	F133	3	94		Base	93	22	30	
1125	A	F133	3	95	Y	Side	197	21		120
1125	A	F133	3	96		Rim	122	13		160
1125	A	F133	3	97	Y	Rim	82	14		140
1125	A	F133	3	98		Side	98	12		148
1125	A	F133	3	99		Side	94	13		140
1125	A	F133	3	100		Base	168	21	21	
1125	A	F133	3	101		Side	251	21		110
1125	A	F133	3	102		Side	120	18		124
1125	A	F133	3	103		Side	248	16		128
1125	A	F133	3	104		Rim	329	17		160

Context No.	Area	Feature	Phase	Crucible No.	Sampled	Position	Weight	Width (side, mm's)	Width (base, mm's)	Diameter (mm's)
1125	A	F133	3	105	Y	Rim	57	14		120
1125	A	F133	3	106		Rim	102	14		136
1125	A	F133	3	107		Rim	135	12		130
1125	A	F133	3	108		Rim	168	13		140
1125	A	F133	3	127		Side	416	21		140
1125	A	F133	3	128		Rim	326	17		
1132	A	F138		17	Y	Side	56	16		
1132	A	F138		52		Rim	35	15		130
1133	A	F139		46	Y	Side	24	15		
1133	A	F139	4 or 5	47		Rim	93	16		120
1139	A	F139	3	109		Base	219	18	23	100
1139	A	F139	3	110		Base	228	19	16	
1139	A	F139	3	111		Rim	188	15		112
1139	A	F139	3	112		Side	23	14		120
1139	A	F139	3	113		Side	215	22		120
1139	A	F139	3	114		Rim	96	16		120
1139	A	F139	3	115		Side	12	12		160
1139	A	F139	3	116		Side	37	13		140
1139	A	F139	3	117		Rim	99	16		128
1139	A	F139	3	118	Y	Side	65	16		
1139	A	F139	3	119		Side	39	12		120
1139	A	F139	3	123		Side	16	11		
1167	A	F154	4	45	Y	Side	482	16		
1167	A	F154	4	53		Base	160	21	22	
1167	A	F154	4	54		Side	20	17		144
1167	A	F154	4	55		Side	73	16		
1167	A	F154	4	56		Base	254	21	26	140
1176	A	F159	3	1		Side	47	16		100
1176	A	F159	3	57		Side	170	13		120
1176	A	F159	3	58		Side	69	18		148
1176	A	F159	3	59		Side	100	15		132
1176	A	F159	3	60		Rim	183	18		
1176	A	F159	3	120		Side	260	21		120
1176	A	F159	3	121		Side	140	18		140
1176	A	F159	3	122		Rim	200	14		110
1176	A	F159	3	124	Y	Side	103	17		
1176	A	F159	3	125		Rim	92	13		128
1176	A	F159	3	126		Side	159	17		120
1187	A	F176	3	32		Side	59	14		
1187	A	F176	3	33		Rim	161	12		160
1187	A	F176	3	49		Side	103	20		
1243	A			43		Rim	60	11		
1520	B	F505		2		Side	39	17		128
1521	B	F503	3	3		Side	69	13		140
1521	B	F504	3	40		Rim	111	16		
1531	B	F510	3	4	Y	Side	20	10		90
1580	B	F520	3	5		Base	276	24	26	80
1580	B	F520	3	6		Base	358	17	30	
1621	B	F542	3	7		Base	50	12	17	116
1621	B	F542	3	19		Side	374	19		160
1621	B	F542	3	23	Y	Side	42	19		140
1621	B	F542	3	34		Side	136	16		140

Context No.	Area	Feature	Phase	Crucible No.	Sampled	Position	Weight	Width (side, mm’s)	Width (base, mm’s)	Diameter (mm’s)
1621	B	F542	3	35		Rim	246	18		124
1634	B	F542	3	8		Rim	48	17		
1634	B	F542	3	29		Complete base	285		31	60
1646	B		3 or 4	9		Side	33	17		
1708	C	F700	3	10		Side	24	15		
1708	C	F700	3	11		Rim	101	13		140
1708	C	F700	3	13		Side	46	16		130
1708	C	F700	3	14		Side	37	17		
1708	C	F700	3	15		Side	17	17		80
1708	C	F700	3	16		Side	20	13		
1708	C	F700	3	25		Side	10	6		
1708	C	F700	3	31		Side	48	11		
1708	C	F700	3	36	Y	Base	16	12	10	
1708	C	F700	3	37	Y	Base	65	13	14	
1711	C		4	12		Side	50	17		
1727	C	F707	3	28		Base	58	13	13	100
1738	C			21		Rim	107	13		148
1738	C			44		Side	40	No measurable dimensions		
1825	C	F769		24	Y	Side	3	7		
1872	C	F789	3	30	Y	Rim	11	4		
1888	C	F810	3	26	Y	Side	27	11		
1931	C	F824	3	27		Rim	126	12		130
Over cleaning area 1621				22		Side	51	17		160
1205	A			129		Side	13			
1104	A			130		Side	79			
1125	A	F133	3	131		Rim	21			
1580	B	F520	3	132		Side	13			
U/S	A			20		Rim	36	1		116

Appendix 4: Analyses of metal droplets found within the Park Street crucibles

Crucible no.	S	Fe	Ni	Cu	Zn	As	Sn	Sb	Pb	Alloy type
68	<0.2	0.2	<0.1	99.8	<0.1	<0.5	<0.5	<0.5	<0.5	Copper
68	<0.2	<0.1	<0.1	100.0	<0.1	<0.5	<0.5	<0.5	<0.5	Copper
68	<0.2	<0.1	<0.1	100.0	<0.1	<0.5	<0.5	<0.5	<0.5	Copper
68	<0.2	0.2	<0.1	99.8	<0.1	<0.5	<0.5	<0.5	<0.5	Copper
105	<0.2	0.5	0.2	98.2	0.7	<0.5	<0.5	<0.5	<0.5	Copper
105	<0.2	0.8	0.2	95.0	<0.1	2.3	0.7	0.9	<0.5	Copper
84	<0.2	0.6	0.1	84.3	11.2	<0.5	3.8	<0.5	<0.5	Gunmetal
84	<0.2	1.4	<0.1	75.3	21.1	<0.5	2.1	<0.5	<0.5	Gunmetal
17	<0.2	0.8	<0.1	75.1	21.5	<0.5	1.1	<0.5	1.5	Brass
17	<0.2	0.2	<0.1	99.8	<0.1	<0.5	<0.5	<0.5	<0.5	Copper
17	<0.2	0.3	<0.1	98.3	<0.1	1.0	<0.5	<0.5	<0.5	Copper
46	<0.2	0.2	<0.1	99.8	<0.1	<0.5	<0.5	<0.5	<0.5	Copper
46	<0.2	0.1	<0.1	97.2	0.5	<0.5	2.1	<0.5	<0.5	Copper
46	<0.2	0.1	<0.1	98.5	0.5	<0.5	0.9	<0.5	<0.5	Copper
46	<0.2	0.2	<0.1	97.9	1.1	<0.5	0.5	<0.5	<0.5	Copper
46	<0.2	<0.1	0.1	83.2	8.6	<0.5	5.1	<0.5	3.0	Gunmetal
46	<0.2	<0.1	0.2	83.5	8.9	<0.5	5.2	<0.5	2.0	Gunmetal
46	<0.2	<0.1	<0.1	82.1	9.5	<0.5	5.2	<0.5	3.2	Gunmetal
45	0.8	<0.1	0.2	97.7	<0.1	<0.5	1.2	<0.5	<0.5	Copper
45	<0.2	<0.1	<0.1	99.2	<0.1	<0.5	0.7	<0.5	<0.5	Copper
45	<0.2	0.4	<0.1	98.8	<0.1	<0.5	<0.5	0.6	<0.5	Copper
45	<0.2	0.1	<0.1	99.9	<0.1	<0.5	<0.5	<0.5	<0.5	Copper
45	<0.2	<0.1	0.2	99.8	<0.1	<0.5	<0.5	<0.5	<0.5	Copper
45	<0.2	<0.1	0.1	98.2	<0.1	0.6	0.5	0.6	<0.5	Copper
45	<0.2	0.5	0.2	96.4	<0.1	1.6	<0.5	0.8	<0.5	Copper
45	<0.2	0.1	<0.1	97.6	<0.1	1.4	<0.5	<0.5	<0.5	Copper
45	<0.2	0.1	<0.1	99.0	<0.1	0.9	<0.5	<0.5	<0.5	Copper
45	<0.2	0.2	<0.1	98.4	<0.1	0.9	0.5	<0.5	<0.5	Copper
45	<0.2	<0.1	0.2	98.4	<0.1	0.9	<0.5	<0.5	<0.5	Copper
124	<0.2	1.2	<0.1	76.0	19.8	<0.5	3.0	<0.5	<0.5	Brass
124	<0.2	1.7	<0.1	74.0	20.9	<0.5	3.4	<0.5	<0.5	Brass
124	<0.2	1.3	<0.1	71.7	25.3	<0.5	1.7	<0.5	<0.5	Brass
36	<0.2	1.2	<0.1	81.9	7.2	<0.5	9.7	<0.5	<0.5	Gunmetal
36	<0.2	1.2	<0.1	83.7	9.5	<0.5	5.6	<0.5	<0.5	Gunmetal
36	<0.2	1.4	<0.1	83.6	9.8	<0.5	5.2	<0.5	<0.5	Gunmetal
26	<0.2	0.3	<0.1	81.1	17.8	<0.5	<0.5	<0.5	0.5	Brass
26	<0.2	0.6	<0.1	80.2	17.8	<0.5	<0.5	<0.5	0.9	Brass
26	<0.2	0.3	0.1	80.2	19.2	<0.5	<0.5	<0.5	<0.5	Brass
26	<0.2	0.3	<0.1	80.1	19.3	<0.5	<0.5	<0.5	<0.5	Brass
26	<0.2	1.3	0.1	78.1	13.8	<0.5	5.4	<0.5	1.0	Gunmetal
26	<0.2	0.3	0.3	86.0	8.4	<0.5	3.8	1.2	<0.5	Gunmetal (Sb)
26	<0.2	0.4	0.4	82.3	8.7	<0.5	4.5	3.8	<0.5	Gunmetal (Sb)
26	<0.2	0.2	0.2	84.9	9.5	0.8	2.1	1.8	<0.5	Gunmetal (Sb)
26	<0.2	0.5	0.3	81.3	11.7	0.7	3.4	2.0	<0.5	Gunmetal (Sb)
26	<0.2	0.7	0.3	81.7	11.9	<0.5	3.2	2.2	<0.5	Gunmetal (Sb)
26	<0.2	0.7	0.3	80.0	12.5	0.7	3.2	2.6	<0.5	Gunmetal (Sb)
26	<0.2	0.7	0.3	80.6	14.2	<0.5	2.7	1.5	<0.5	Gunmetal (Sb)
26	<0.2	0.8	0.3	79.4	14.5	1.1	2.5	1.4	<0.5	Gunmetal (Sb)
26	<0.2	1.0	<0.1	81.1	15.7	<0.5	1.6	0.6	<0.5	Gunmetal (Sb)
26	<0.2	1.0	0.4	78.8	16.9	<0.5	1.8	1.0	<0.5	Gunmetal (Sb)
26	<0.2	0.8	<0.1	82.3	13.1	<0.5	2.0	0.8	1.0	Gunmetal (Sb)

Appendix 5: Analyses of the vitrified layers

Crucible No.	Description	Notes	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	K_2O	CaO	TiO_2	MnO_2	Fe_2O_3	CuO	ZnO	SnO_2	PbO	Total
4	Inner vitrification		<1.0	<0.4	13.6	50.9	<0.2	<0.2	1.2	2.5	0.5	0.4	16.1	0.2	13.6	<0.5	<0.5	98.9
17	Outer vitrification		4.5	<0.4	20.7	39.1	1.2	<0.2	4.0	1.2	0.9	<0.2	3.8	5.4	14.6	3.6	0.9	100.0
23	Inner vitrification		<1.0	<0.4	34.0	60.4	<0.2	<0.2	0.6	0.7	1.4	<0.2	2.4	<0.2	0.3	<0.5	<0.5	99.8
24	Inner vitrification		3.3	2.1	2.3	33.4	<0.2	<0.2	5.0	5.5	<0.2	<0.2	1.4	<0.2	<0.2	15.7	31.3	100.0
24	Outer vitrification		2.3	1.5	4.2	52.3	1.2	<0.2	3.9	3.9	0.2	0.4	3.2	<0.2	<0.2	8.6	15.9	97.6
26	Inner vitrification	Layer 1 (Tutania)	3.1	1.2	10.9	48.7	1.0	0.4	3.4	2.5	0.6	<0.2	12.5	15.4	<0.2	<0.5	<0.5	99.7
26	Inner vitrification	Layer 2 (brass)	5.9	2.5	1.7	31.6	4.3	0.3	0.8	6.4	<0.2	0.4	2.6	2.5	40.8	<0.5	<0.5	99.8
30	Inner vitrified surface		1.9	<0.4	34	52.4	<0.2	<0.2	5.6	1.0	1.5	<0.2	1.3	0.3	1.6	<0.5	<0.5	99.6
30	Outer vitrified surface		<1.0	0.8	37.4	36.2	1.3	<0.2	0.3	11.5	1.5	<0.2	8.6	0.4	1.4	0.5	<0.5	99.9
36	Inner vitrification		<1.0	0.9	18.7	60.8	1.3	<0.2	2.9	4.2	1.0	0.2	5.4	2.1	2	<0.5	<0.5	99.5
36	Outer vitrification		<1.0	0.4	20.4	60.4	0.5	<0.2	1.7	3.0	1.0	0.3	5.3	4.3	2.3	0.5	<0.5	100.1
37	Inner vitrification		1.8	<0.4	24.4	54	<0.2	<0.2	0.2	<0.2	0.8	<0.2	1.7	<0.2	17.3	<0.5	<0.5	100.2
37	Outer vitrification		1.3	<0.4	10.4	64.7	0.6	<0.2	0.2	0.5	0.5	<0.2	13.6	<0.2	7.9	<0.5	<0.5	99.7
37	Rim vitrification		<1.0	0.6	3	20.4	3.9	<0.2	0.3	2.5	<0.2	<0.2	0.9	5.2	3.7	53.8	2.2	96.5
41	Outer vitrification		1.7	<0.4	22.6	56.2	<0.2	<0.2	0.9	0.3	0.8	<0.2	1.8	<0.2	15.7	<0.5	<0.5	100.0
42	Inner vitrification		<1.0	8.2	8.1	73.8	<0.2	<0.2	2.4	2.9	0.6	<0.2	3.2	0.3	0.4	<0.5	<0.5	99.9
45	Slag	Bulk	3.5	0.6	18.1	42.6	0.9	<0.2	1.0	4.8	0.6	<0.2	10.7	1.9	13.9	<0.5	0.7	99.1
46	Vitrified surface		5.8	0.4	15.3	20.1	<0.2	<0.2	0.3	<0.2	0.3	<0.2	0.9	9.0	44.6	1.4	1.1	99.1
62	Outer vitrification		<1.0	<0.4	21.3	46.6	0.4	<0.2	0.3	0.6	0.7	<0.2	4.3	16.7	1.4	7.8	<0.5	100.1
68	Inner vitrification		<1.0	<0.4	22.2	59.9	<0.2	<0.2	0.9	<0.2	1.6	<0.2	4.4	<0.2	10.9	<0.5	<0.5	99.9
69	Outer vitrification		8.5	0.7	24.8	49.5	0.7	<0.2	0.8	2.9	1.3	<0.2	9.3	<0.2	1.3	<0.5	<0.5	99.8
84	Inner vitrification		1.5	<0.4	16.8	40.3	<0.2	<0.2	1.3	1.0	0.5	<0.2	1.7	16.3	19.6	0.6	<0.5	99.6
92	Inner vitrification		6.4	<0.4	3.2	25.3	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	0.8	9.7	54.0	<0.5	0.6	100.0
92	Outer vitrification		1.5	1.5	15.8	47.5	4.8	<0.2	2.4	4.1	1.9	<0.2	5.0	2.8	9.9	<0.5	0.9	98.1
95	Inner vitrification		7.2	<0.4	7.5	21.6	<0.2	<0.2	0.1	0.5	0.3	0.2	2.6	2.8	54.6	0.7	1.0	99.1
95	Outer vitrification		<1.0	0.9	31.2	51.9	0.9	<0.2	1.2	2.7	1.4	<0.2	6.8	1.2	0.8	0.8	<0.5	100.0
97	Inner vitrification		<1.0	<0.4	11.4	42.6	<0.2	<0.2	0.9	0.3	0.7	<0.2	2.4	22.3	16.1	<0.5	3.3	100.0
97	Outer vitrification		<1.0	0.8	22.6	55.7	1.4	<0.2	1.4	1.0	1.0	0.8	10.0	1.0	3.0	<0.5	1.4	100.1
105	Vitrified surface		2.7	0.5	10.4	36.6	<0.2	<0.2	0.9	0.6	1.0	0.2	4.7	8.6	27.8	5.3	1.1	100.3

Crucible no.	**Description**	**Notes**	**Na_2O**	**MgO**	**Al_2O_3**	**SiO_2**	**P_2O_5**	**SO_3**	**K_2O**	**CaO**	**TiO_2**	**MnO_2**	**Fe_2O_3**	**CuO**	**ZnO**	**SnO_2**	**PbO**	**Total**
118	Outer vitrification		10.5	0.6	17.6	39.0	0.5	<0.2	0.3	2.1	1.2	20.6	0.9	6.6	<0.2	<0.5	<0.5	99.9
118	Inner vitrification		11.9	<0.4	7.4	55.4	<0.2	0.3	0.7	1.5	0.4	6.1	<0.2	16.4	<0.2	<0.5	<0.5	100.1
124	Outer vitrification		2.7	0.5	16.3	48.6	0.5	<0.2	2.1	2.9	0.8	<0.2	5.4	2.8	13.6	1.4	<0.5	97.6

Appendix 6: Analyses of the crucible fabric

Crucible no.	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	K_2O	CaO	TiO_2	Fe_2O_3	CuO	ZnO	PbO	Total
4	<1.0	<0.4	21.3	64.3	<0.2	0.2	0.7	0.5	1.2	2.5	<0.2	7.5	<0.5	98.3
17	1.1	0.5	27.4	62.3	0.3	<0.2	1.4	0.3	1.6	2.4	<0.2	2.3	<0.5	99.6
23	<1.0	<0.4	27.0	66.7	<0.2	<0.2	1.0	0.3	1.3	2.6	0.3	0.5	<0.5	99.7
24	<1.0	1.6	17.0	55.0	1.4	<0.2	0.8	16.8	0.8	6.7	<0.2	<0.2	<0.5	100.0
26	<1.0	<0.4	23.4	70.8	<0.2	0.3	0.7	0.3	1.2	2.1	0.2	0.6	<0.5	99.6
30	<1.0	1.1	28.8	61.9	<0.2	<0.2	1.2	0.3	1.5	1.8	<0.2	2.7	<0.5	99.3
36	<1.0	0.4	26.6	68.3	<0.2	<0.2	0.6	0.2	1.3	2.1	0.2	0.3	<0.5	100.0
37	<1.0	<0.4	26.5	67.9	<0.2	<0.2	0.7	0.3	1.1	1.9	<0.2	0.7	<0.5	99.2
41	<1.0	<0.4	25.6	51.1	<0.2	<0.2	0.3	0.2	1.0	1.8	<0.2	20.0	<0.5	100.0
42	<1.0	9.3	17.6	54.3	0.3	<0.2	3.6	4.1	0.8	9.5	0.3	0.3	<0.5	100.1
45	<1.0	<0.4	22.1	61.3	<0.2	<0.2	0.5	0.4	1.3	2.2	<0.2	11.0	<0.5	98.7
46	<1.0	<0.4	23.0	73.3	<0.2	<0.2	0.4	0.1	1.0	1.3	<0.2	0.9	<0.5	100.0
51	<1.0	0.9	11.4	79.5	<0.2	<0.2	2.8	0.4	0.6	4.1	<0.2	<0.2	<0.5	99.5
62	<1.0	1.0	23.4	69.4	<0.2	<0.2	0.9	0.2	1.4	2.4	0.7	1.0	<0.5	100.3
68	<1.0	1.1	23.5	67.7	<0.2	<0.2	0.9	0.3	1.1	2.0	2.6	0.5	<0.5	99.6
69	2.9	0.9	26.9	64.1	<0.2	<0.2	0.8	0.3	1.4	1.5	<0.2	0.4	<0.5	99.1
81	<1.0	1.0	25.6	63.5	<0.2	<0.2	1.0	0.4	1.2	4.2	1.9	0.9	<0.5	99.7
84	<1.0	0.9	23.1	67.5	<0.2	<0.2	0.9	0.3	1.3	2.9	<0.2	2.7	<0.5	99.5
92	1.5	<0.4	17.1	38.2	<0.2	<0.2	1.4	0.4	0.7	2.6	12.4	25.0	0.8	100.0
95	<1.0	<0.4	26.7	60.8	<0.2	<0.2	1.3	0.4	1.1	3.3	0.2	5.5	<0.5	99.3
97	1.1	1.3	26.5	55.0	<0.2	<0.2	1.2	0.4	1.3	3.3	0.7	8.6	<0.5	99.5
105	<1.0	1.1	27.8	61.6	<0.2	<0.2	1.3	0.3	1.2	4.7	0.6	1.5	<0.5	100.0
118	<1.0	<0.4	28.7	60.9	<0.2	<0.2	1.8	0.3	1.5	2.4	<0.2	4.4	<0.5	100.0
124	<1.0	1.2	26.5	61.3	<0.2	<0.2	1.2	0.4	1.3	3.2	0.8	3.1	<0.5	98.8

Appendix 7: Crucible no. 92 line trace data

Description	Na_2O	MgO	Al_2O_3	SiO_2	K_2O	CaO	TiO_2	Fe_2O_3	CuO	ZnO	SnO_2	PbO	Total
Inner vitrification	3.8	<0.4	8.4	23.4	0.2	0.5	0.3	3.0	11.1	45.4	0.8	1.4	98.2
Inner vitrification	7.8	<0.4	6.8	30.4	0.3	0.5	<0.2	1.7	7.8	41.9	0.0	1.0	98.2
Inner vitrification	2.3	<0.4	21.2	26.6	1.0	1.2	0.6	5.1	10.3	24.1	0.6	2.3	95.2
Crucible	1.5	<0.4	17.1	38.2	1.4	0.4	0.7	2.6	12.4	25.0	0.0	0.8	100.0
Crucible	1.4	<0.4	24.5	52.0	0.8	0.5	0.8	2.2	0.4	17.0	0.0	0.0	99.6
Crucible	1.9	0.4	26.3	48.5	0.7	0.5	1.1	2.3	0.3	17.8	<0.5	<0.5	99.9
Crucible	<0.1	<0.4	27.9	52.4	1.7	0.3	1.4	1.8	0.2	13.6	<0.5	<0.5	99.3
Crucible	<0.1	<0.4	17.9	58.8	0.7	0.4	1.1	2.4	0.0	18.1	<0.5	<0.5	99.2
Crucible	<0.1	<0.4	23.4	47.7	1.4	0.4	1.2	3.8	0.6	20.1	<0.5	<0.5	98.7
Crucible	<0.1	0.4	31.8	58.4	2.2	0.4	0.9	2.9	0.2	3.0	<0.5	<0.5	100.1
Crucible	<0.1	0.4	29.6	58.1	2.3	0.4	1.0	2.6	0.2	5.2	<0.5	<0.5	99.7
Crucible	<0.1	<0.4	27.6	58.6	1.7	0.3	1.1	2.1	0.4	7.5	<0.5	<0.5	99.4
Crucible	<0.1	<0.4	22.8	53.3	0.9	0.5	4.6	3.7	0.5	11.9	<0.5	<0.5	98.0
Crucible	<0.1	<0.4	19.8	63.3	0.9	0.4	1.1	3.2	0.7	9.7	<0.5	<0.5	99.0
Crucible	<0.1	0.5	20.3	58.1	0.5	0.3	1.0	6.4	1.1	10.4	<0.5	<0.5	98.5
Crucible	<0.1	0.7	24.0	53.5	0.8	0.4	1.8	6.5	0.4	10.8	<0.5	<0.5	98.8
Crucible	<0.1	0.5	25.5	56.0	1.5	0.3	1.0	3.2	0.8	10.2	<0.5	<0.5	99.0
Crucible	<0.1	0.9	26.9	55.2	1.1	0.3	1.1	3.1	0.7	9.6	<0.5	<0.5	99.0
Crucible	<0.1	<0.4	24.5	60.0	1.5	0.3	1.3	2.8	0.7	7.9	<0.5	<0.5	99.1
Crucible	<0.1	<0.4	25.0	53.1	1.1	0.3	0.9	4.3	2.6	10.8	<0.5	<0.5	98.0
Crucible	<0.1	<0.4	24.9	59.6	1.4	0.4	0.9	2.8	0.7	7.5	<0.5	<0.5	98.1
Crucible	<0.1	<0.4	23.7	58.5	1.3	0.5	1.1	3.7	1.0	9.8	<0.5	<0.5	99.5
Crucible	<0.1	<0.4	23.9	63.7	1.1	0.3	1.1	2.6	0.5	5.4	<0.5	<0.5	98.7
Crucible	<0.1	<0.4	27.2	60.1	0.9	0.4	1.3	3.3	0.0	6.5	<0.5	<0.5	99.6
Crucible	<0.1	<0.4	27.3	57.2	1.1	0.3	1.2	5.0	1.0	5.3	<0.5	<0.5	98.3
Crucible	<0.1	<0.4	26.3	62.2	1.3	0.3	1.1	2.7	0.6	4.6	<0.5	<0.5	99.0
Crucible	<0.1	<0.4	24.5	62.4	1.3	0.3	1.2	3.1	0.4	6.2	<0.5	<0.5	99.3
Crucible	<0.1	0.4	20.3	73.1	1.2	0.3	1.4	1.9	0.4	0.9	<0.5	<0.5	99.9
Crucible	<0.1	<0.4	23.9	69.0	1.4	0.3	1.4	2.1	0.6	0.9	<0.5	<0.5	99.5
Crucible	<0.1	<0.4	15.3	80.6	0.7	0.1	0.7	1.3	0.4	0.3	<0.5	<0.5	99.5
Crucible	<0.1	0.5	32.9	59.0	1.7	0.3	1.5	2.6	0.6	0.6	<0.5	<0.5	99.6
Outer vitrification	<0.1	<0.4	37.5	56.3	1.0	0.3	0.9	2.5	0.7	0.7	<0.5	<0.5	99.7