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ANALYSIS OF POST-MEDIEVAL GLASS AND GLASSWORKING DEBRIS FROM OLD BROAD STREET, CITY OF LONDON

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Summary

Crucibles, glass waste, vessel fragments and opaque-white canes were examined and analysed chemically. Most of the material was soda glass, but three potash glass beaker fragments and four high-lime, low-alkali glasses were also analysed (one beaker and three bottles). Six coloured glasses were also soda glass based, but two pieces with very unusual colours, one very dark brown and the other opalescent, were made of high-lime, low-alkali glass. A dark blue trail in a *vetro a fili* fragment was coloured by a cobalt oxide; arsenic and nickel oxides were also detected. All the material is from contexts dating from the first half of the seventeenth century, and may relate to a workshop clearout from Robert Mansell's glassworking premises.

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INTRODUCTION

The 1990 excavations at 90-94 Old Broad Street[1] produced vessel glass of various types, small amounts of window glass and waste from glass manufacture. 341 contexts at the site contained glass, with a total weight more than 2.5kg. The material was found in dumped deposits, used to infill ditches from the medieval city wall system. The contexts date to a period of expansion in the first half of the seventeenth century.

The excavated material probably relates to a documented period of glass production at this site, during the early seventeenth century. There is ample evidence that Sir Robert Mansell built a new glasshouse at a site known as Austin Friars in Old Broad Street, in the early stages of his monopoly over glass, probably before 1617 (Godfrey 1975, 81). Here, Venetian workers (under English management) produced 'crystal' vessels, especially drinking glasses. Crystal glass of this period is visually comparable with Venetian glass known as *cristallo* and with *façon de Venise* (Venetian-style) glass from other areas such as the Netherlands.

The discovery of debris which may come from Mansell's glasshouse is significant for reasons connected with the history of technology. During the first two decades of the seventeenth century, coal emerged as an important fuel for glassworking; prior to this, charcoal had been used. The change to coal, and other changes in the materials used, were largely adopted for economic and political reasons, rather than technical ones. The change of fuel was a significant element in establishing Mansell's monopoly, which was to last until his death in 1656. The use of coal is reflected in various aspects of the glass produced at this time, as is illustrated by the research below.

Mansell also had control of a 'green glass' (potash or forest glass) factory at Ratcliffe, which was supposed to supply all of London's requirements. However, glaziers frequently complained that supplies were not adequate and glass from other sources was in circulation. Various other 'green glass' factories are known outside London (Godfrey 1975, 91-3), some of which were coal-fired and run under a license from Mansell.

Chemical analysis of the Broad Street glass waste allows the characterisation of certain types of glass production during a relatively short period in the early seventeenth century. The waste glass compositions can be compared with the vessel glass at the site and with contemporary vessel material from occupation sites in the City of London which has already been analysed (Mortimer 1991). Chemical datasets for glass are unlikely to provide conclusive evidence for independent provenancing, but the hypothesis that the Broad Street glasshouse could have supplied contemporary glass products found in the City of London can be tested.

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[1] Site name BRO90, TQ33055/81500. Excavated by Liz Dyson (Museum of London), for the City of London Corporation.

RANGE OF MATERIAL

1) Waste glass and crucibles

The site produced several kilos of waste glass in various forms. Several contexts produced groups of waste material consisting of broken moils and other glass debris in a translucent glass. This glass is lightly-tinted brown or purple, often with strong iridescence (eg SFs 211 and 308). Other waste glass material at Broad Street is a darker green (eg SFs 224 and 225). These droplets and dribbles have much more heterogeneous texture, including bubbles, non-glass particles, ceramic (probably crucible) debris and ferrous matter (probably from pontils, stirring rods, tongs etc.).

Glass-working crucibles on the site are thickwalled (35-40mm), square-sided but rounded inside. Various types of glassy deposits are attached to the crucible walls. Crucible fragments from a single context often have more than one type of deposit on their surfaces. Most of these deposits are on the inside surfaces, although thinner but still glassy deposits are found on the outside surfaces. Examples from three contexts were examined in detail. On material from SF371, deposits observed include a) moss-green, streaked with brown smooth glass, b) pale green chunks of glass and c) 'crusty' black dribbles and accretions. Glass which settled into the bottom of crucible SF118 now has corroded into a pattern of green, brownish-mauve and opaque white streaks. The crucible fragment SF115 has glossy green glass, crizzled with brown lines on the outside and rough but shiny green glass on the inside.

Vessel-related material at this site includes wasters (parts of unsuccessful artefacts eg stems from cups which were malformed and hence discarded).

2) Part-formed items

Opaque-white glass canes are a small but interesting group of part-formed items at the site. When viewed in cross-section, the canes consist of a translucent glass centre, around which is a layer of opaque white glass and then another translucent glass layer. Comparable cross-sectional details can be seen on opaque white canes applied to vessels from the period, where these are broken and even occasionally where complete (see section on *vetro a filigrano* below).

This effect is achieved by rolling a flat piece of opaque glass around a transparent glass core and then coating this with another layer of transparent glass (eg Tait (ed) 1991, 217-220). It is generally difficult to see the join in the opaque glass, amongst cross-sections of finished items. However, at high magnification, the Broad Street examples show that opaque white glass was sometimes wrapped round the core more than once, creating a spiral section.

Translucent glass thus supported and protected the opaque white glass, which has a low melting temperature, because of its lead- and tin-rich composition (see below). This technique meant that opaque white canes could be safely manipulated, during the processes of drawing and marvering them into the surface of translucent or coloured glass, to form a variety of decorative designs.

At Broad Street, two diameters of canes were observed; it appears that the canes were first formed with a diameter of around 8-10mm (eg SF195) and then drawn down to 2-3mm before use (eg SF196). The small diameter of these pieces makes it clear that the canes were for trailed decoration or *vetro a filigrano*, rather than for mosaic or *millefiori* work.

There is no direct evidence for the manufacture of opaque white canes at the site (in the form of dribbles, splashes or cakes of opaque white glass), so the canes could have been imported, perhaps in the largest diameter, to be drawn down to the smaller size, when needed. However, the nature of the deposits means a firm conclusion cannot be made.

To achieve more complicated effects, such as those seen on SF4 (see below), a number of canes were grouped together, heated, then drawn and twisted. However, there is no concrete evidence for such work being practised at Broad Street.

3) Vessels

A range of vessel types were found at this site. For the analytical project, a small selection was made from amongst the beakers, cups and bottles, some of which could, on a visual basis, have been produced using the types of glass found in the first waste glass category (lightly-tinted). Similar material was found at other sites in the City of London. Two vessel fragments with very unusual appearances were also examined (SFs 309 and 329 (see discussion below)).

Where material is fragmentary, it is often difficult to determine whether individual pieces were successful (and were therefore present in a domestic capacity) or whether they were wasters, present as part of the manufacture process.

Summary

The Broad Street glassworking material probably represents a workshop clear-out rather than the demolition of an entire production system. Hence, despite the variety of evidence for glass melting and forming, it is not surprising that there is no evidence of furnace structure (ie fired clay or bricks), nor of glass manufacture (ie the raw materials, ash and sand) recovered from the site.

SEVENTEENTH-CENTURY *VETRO A FILIGRANO*

Various methods of using opaque white glass became popular in the sixteenth and seventeenth centuries. Opaque white glass was used initially to form whole vessels (known as *lattimo*), in imitation of porcelain which was imported from China from the fifteenth century. These vessels were normally decorated by enamelling with coloured glasses. Opaque white glass was also applied to vessels in the form of stripes, swirls, ribbing and in representational modes (*eg* in heraldry and dedications), along with other colours of glass. In these cases, the decoration often remained in relief, although it could be marvered into the surface.

The use of single and multiple canes of coloured glass, encased in clear glass, was a development of these simpler methods. Canes might be kept in high relief on the surface or marvered into the glass. Whole vessels were made up from such canes or plain vessels could be ornamented with groups of canes twisted together (*vetro a retorti*).

Venice was the centre for innovation in these techniques, producing a range of extremely complex effects (eg Tait 1979, 65-80), known collectively as *vetro a filigrano*. But, by the late sixteenth century, Venetians working in London (as well as in other northern European centres), produced *vetro a filigrano* vessels. However, the vessels produced in England are thought to be of a lower quality than those imported from Italy and the Netherlands (Charleston 1984, 63; 1990, 937). With additional chemical information from continental material, it may be possible to investigate whether such differences can be substantiated analytically. For the moment, comparing the compositional information from the opaque canes, the cristallo waste and *vetro a filigrano* vessels from Broad Street may help determine whether the *vetro a filigrano* vessels could have been made on site. The chemical dataset from Broad Street can also be compared with those from other sites, in London (eg Mortimer 1991) and elsewhere, when such data is available.

On fragment SF4, a group of very fine opaque white and blue threads (*latticino* or *vetro a retorti*) are marvered into a translucent, near-colourless vessel body. At other sites in England, where continental glassworkers were known to have worked (eg Buckholt, Hants), various types of coloured glass canes have been found, including some with more complex structures (*eg* with two colours of glass and examples where coloured glass layers are intermittent, not continuous). The English production-site material has not yet been chemically analysed and would yield important comparative information.

CHEMICAL ANALYSIS

Chemical analysis was performed using energy-dispersive X-ray micro-analysis on the Ancient Monuments Laboratory scanning electron microscope (a Cambridge S200 SEM with Link Systems AN10000 X-ray analyser) as in previous projects (Mortimer 1991). Analysis using inductively-couple plasma spectroscopy was also carried out on some of the material from this site; the results of this investigation will be included in a future report.

1) Translucent, lightly- and naturally-coloured glass

Amongst the vessel glass sampled in this category, thirteen pieces were from soda glasses, three were pieces of potash glass and four were high-lime, low-alkali glasses. Their compositions (Table 1) are generally similar to those of parallel groups of post-medieval vessel glass found at other sites in the City of London (Mortimer 1991, Table IV). Some patterning may be observed amongst the different types of glass in this category.

Soda glass

Post-medieval soda glass from the City of London was noted to be divisible into two compositional types, a small group relatively high in soda (group B in Mortimer 1991) and much larger group, lower in soda but higher in magnesia and lime (group A in Mortimer 1991, 11-12). The higher soda group are compositionally similar to the Venetian *cristallo* (Verità 1985) and may represent either Venetian imports or production in *façon de Venise* workshops in north-west Europe. Glass with the lower soda content was made throughout the medieval period, but the high-soda glasses are a post-medieval development.

The two pieces from Broad Street which most resemble the high-soda composition are both of unusually dark green glass, one a bottle fragment (SF235) and the other a piece of waste (SF224). The data from SF224 indicates that high-soda glass was being worked, if not produced, at the Broad Street glasshouse. The data from two other pieces of waste glass (SFs 211 and 308) indicates the use of soda glass with lower soda contents and higher levels of other oxide values, more comparable with the majority of the soda vessel glass found at the site. Contemporary glass from Tilbury Fort, Essex is mostly of the lower soda type (Mortimer 1992, Table 2).

It may be significant that, with the gradually increasing size of the English high-soda glass database (currently consisting of 10 pieces), discrepancies can be seen between the English and the Italian data; the Italian material is slightly higher in soda (16.9% ±1.7 *cf* 14.5% ±0.8) and lower in lime (4.9% ±0.8 *cf* 5.7% ±2.3). An increased database size and an assessment of analytical comparability are essential for an understanding the similarities and dissimilarities of these groups. Steps are being taken towards both of these aims.

Two other pieces of waste glass, originating from one context (157), are chemically similar to the soda glasses from the site, except that they are lower in soda and high in both iron and alumina. These unusual compositions may be the result of unusual corrosion or of analytical problems. It is possible that material from context 157 was subject to more intense leaching of alkalis during burial than other material at the site. Unfortunately no other material from this context has been analysed in this project, but the compositions are not notable for particularly low potash or particularly high silica contents (as would be expected if corrosion had been a significant factor). Furthermore, the analytical totals are within acceptable limits and the two different types of glass examined from the context (one dense and the other vesicular) are chemically closely comparable. Neither the hand samples or the mounted sections show evidence of unusually intense corrosion.

The data from waste glass in context 157 suggests that a second, lower quality soda glass may have been in use at the site, although this glass type has yet not been detected amongst the vessel glass analysed. Three of the vessels from the site (SFs 235, 333 and 340) also have high alumina levels, but normal soda levels. A low soda value was discovered in a single instance in previous research (from Swan Lane, SWA81, SF2762, Mortimer 1991, Table 5, piece dated to c.1650-1700) but this was not associated with high alumina levels.

Soda content in glass indicates the alkali source used in production. During the early seventeenth century, English crystal glass was largely produced using imported *barilla* (ash from marine plants) but Mansell and other glass producers of this period also used British soda sources, namely kelp (Godfrey 1975, 89). The glass produced using the British soda was a cheaper line. This may reflect lower transport costs, but may also signify the use of lower quality alkalis, which had lower soda contents and higher or more variable values of other elements (*eg* potash, alumina, iron); *barilla* had a reputation for good and reliable quality. It is difficult to establish which is more likely, using published analyses. Compositional variability has been confirmed by experimental work on British seaweed ash (Sanderson and Hunter 1981, Tab 1) but, although some experimental work has been carried out on ashes from marine plants known to have been used in Venetian glassmaking (Verità 1985, *Tab* I), the variability was not established. When the absolute concentrations of the crucial oxides are compared[2], ashes from British seaweed and from Italian marine plants seem to be similar; treatment of the ashes could have significantly increased the soda concentration (compare columns B and C in Verità 1985, *Tab* 1). From this, it seems that poorer quality glass was

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[2] Comparisons of oxide concentrations are made difficult by different methods of data presentation employed by the two different research teams. Verità calculated oxide percentages and included the concentrations of carbonates, phosphates, sulphates, silica, chlorine and alumina, giving analytical totals close to 100%. Sanderson and Hunter presented weight percent concentrations for the elements sodium, potassium, magnesium, calcium, manganese, iron, copper and zinc, giving analytical totals between 22% and 32%. If these elements are assumed to be present only in oxide form (which is unlikely to have been the case), the analytical totals are between 30% and 40%, indicating that further elements were not analysed for. Nonetheless, the element to oxide calculations for Sanderson and Hunter's data indicate that around 16% soda was present in unwashed seaweed ash.

not an inevitable result of using British soda sources, greater unpredictability may have been. The practise of using cullet (broken glass fragments from the furnace, or imported from elsewhere) in the melt would make variability even more likely.

The soda glass used to support and protect the opaque white glass of the *lattimo* canes is very similar to the type A soda-glass vessels found at this site. It is also similar to the *vitrum blanchum* glass used to manufacture three *vetro a filigrano* Venetian glass vessels dated to the fifteenth and sixteenth century (Verità 1985, *Tab* III, nos 6, 7 and 17). However, one further published sixteenth-century example has a typical *cristallo* glass composition, *ie* it is much higher in soda and chlorine and lower in lime, iron and manganese (*ibid*, Tab IV, no. 26).

On the basis of the analytical information, it seems possible that the glassworkers at the Broad Street site could have produced the opaque white canes and the *vetro a filigrano* vessels on site.

Potash glass

Two of the potash glasses analysed have very low soda levels (SFs 313 and 254, with 0.4% and 0.5% respectively). This seems to be rare amongst post-medieval glasses, but two similar examples were discovered amongst the City of London collections (Mortimer 1991, 31). Prior to the coal-fired process, potash for glass making was simply the ash from the firing of the furnace, hence glassworkers had a preference for particular types of wood and tended to keep their ashes clean and separate. After the introduction of coal, potash had to be bought and the ashes were often said to be poor and mixed (Godfrey 1975, 89). Again, this would lead to compositional variability in the final product, unless further steps were taken to purify the raw ingredients.

High-lime, low-alkali glass

The four high-lime low-alkali (HLLA) glass compositions determined here seem to represent a distinctive subgrouping, when compared with the rather heterogeneous compositional dataset of the HLLA type seen previously (eg Mortimer 1991; Kenyon 1967); the ranges of soda, magnesia and alumina in the Broad Street material are about half those in the medieval/post-medieval City of London dataset (Mortimer 1991).

It is possible that some of the non-soda glasses at Broad Street originated from Mansell's other furnaces. The restricted chemical ranges for the HLLA glasses might tend to confirm a single source. However, several production centres were active in the first half of the seventeenth century (Charleston 1984, 71ff) and four samples are too few on which to base much supposition. It is significant that HLLA glass was also used in the manufacture of some of the coloured glasses found at this site (see below).

2) Coloured glass

Opaque white glass

Most of the opaque white glass at Broad Street is made from soda-lime-silica glass with high levels of lead and tin oxides. There is no significant difference in the glass compositions used for a vessel body fragment (SF368), for opaque white canes discarded before use (SFs 195 and 196) and for canes used in vessel manufacture (SF286 and 265), given the analytical difficulties of analysing glasses with many inclusions (see note in Table 2).

The composition of the opaque white glass in vessel SF4 may be slightly different; it has lower magnesia and lime contents. Higher lead and tin oxide contents were also calculated for this piece. This example was very finely decorated, with multiple white and blue threads (see below for note on unusual blue colourant).

SF368 is an opaque white glass with a distinctive blueish tint, however no copper or cobalt were detected (cobalt may be below detection limits for energy-dispersive X-ray analysis and still cause colouration).

Black/dark brown glass

SF309 comprises of five pieces from a vessel. The form may possibly originally have been a beaker - two rim fragments are extant. The appearance of this material is sufficiently unusual to merit a full description.

The vessel was quite finely made; the walls were only 2-3mm thick, except at the rim. Externally, the glass is mostly glossy black, with slight ridging; it appears rather like the outside of a fresh mussel shell, although with slight iridescence (green and purple). The glass is generally in a good condition, with little flaking, pitting or surface accretion. Some areas (especially on the edges, where broken and at the lip of the 'beaker') have creamy-white and silvery-white flaky corrosion products, which are easily detachable. The dark colour of the piece makes it possible to observe bubbles in the glass, as well as swirls and ripples in the vessel walls. The insides of some of these bubbles have gold- or silver-coloured iridescent coating. When a small sample was taken from the edge of the piece, the colour of the glass could be seen to be dark brown, rather than black.

The analysis of SF309 proved it to be a high-lime, low-alkali glass. The opacity of the piece is probably entirely due to the strong colour; no crystals could be discovered during SEM examination nor in X-ray diffraction analysis. Well-known opacifiers, such as tin, arsenic and antimony, were not detected by either XRF or SEM/X-ray analysis.

The chief colourant may be an iron compound, such as iron sulphide (Weyl 1976,280). A small amount of sulphur was detected. If it does contain iron sulphide, the glass should be a two-phase material and evidence of immiscibility should be present. However, no phase separation could be observed, on immersing the polished sample in 2% HF for 30 seconds and re-examining under in the SEM. The lack of crystallisation and brittleness, both common problems with iron sulphide black glasses, make the identification less likely.

The XRF spectrum was scanned for other potential colourants (chromium, cobalt, phosphides, selenium and uranium compounds (Weyl 1976, 530)) but these were absent.

Black and very dark-coloured glasses are unusual amongst early glass collections. However, open crucibles were used deliberately in coal-fired furnaces to cause dark colouration in glass used for mass-produced, thick-walled bottles (Godfrey 1975, 150). SF309 is certainly not from such a bottle, but another, finer vessel form but other 'green glasses' (a general term for any non-soda, non-leaded glass) could also have been darkened in this way.

An example from a crucible found at Haughton Green (near Manchester), was analysed by Newton and Davison (1989,58) and said to be coloured by iron, manganese and sulphur. The find is also dated to the first half of the seventeenth century. Unfortunately no further details are available about this find (such as the type of glass) but the implication is that the levels of iron and/or manganese are very high. In the case of SF309, the levels of iron and manganese are normal (1.3% and 0.3% respectively). Some more fragmentary examples are known from Bigo's furnace, Purbeck (Godfrey 1975, 150).

Opal glass

SF329 is another high-lime, low-alkali glass, with a curious opalescent appearance. On the surface are a series of unusual corrosion products; a mottled grey/cream/orange/black crust overlies an iridescent creamy-white flaky layer and a sky-blue compact layer. In some areas, a distinct black layer seems to be overlain by a separate grey/cream crust. Underneath these deposits, the glass itself is a pale blue opal. The piece may be from the base of a vessel.

Initial XRF analysis suggested the presence of copper, zinc, arsenic, bismuth and strontium, as well as the normal glass oxides. Several of these elements are likely to be present on the surface only, as a result of contamination during burial, although the presence of bismuth is not explicible. No crystal structure was observable in samples taken for XRD analysis (including samples from the crusts), nor could any crystals be observed in the section taken for SEM examination. Here again a sulphide, may be the crucial compound. However fluorides or phosphates could also be significant (Weyl, 47).

The imitation of precious and semi-precious stones was one of the Venetian glassworkers' passions and opal was imitated in two forms - opal and *vetri di girasol*. The precise difference between these glasses is not clearly defined and relatively few examples exist today. Tait implies that the finer, more transparent examples are Venetian (perhaps to be referred to as *vetri di girasol*, on the strength of documentary evidence) and the thicker, blue-tinted examples are *façon de Venise* (Tait 1979, 94-95, 106ff, Plate 13). The extremely corroded nature of the Broad Street example means it is difficult to determine what its original appearance may have been although the strong blueish tint suggests the latter. The HLLA composition would tend to suggest a northern or north-western European origin. An opal glass from Acton Court, Avon is nearly colourless and has a soda glass composition (work in progress).

It is interesting that relatively fine vessels were fashioned from high-lime, low-alkali glasses, and that these unusual colours could be created.

Blue

Vessel SF4 is decorated with fine threads of opaque white (see above) and blue glass. Although the fragment is small, it seems likely that the piece was of Venetian or *façon de Venise* origin. The blue glass proved to be soda glass, with significant quantities of cobalt, arsenic and nickel detected (Table 2).

This composition has similarities with smalt - glass coloured by cobalt oxide, which was an important pigment, used in paints from the fifteenth century and possibly earlier. The blue glass in SF4 resembles quoted compositions for smalt, in that it contains oxides of arsenic and nickel. These two elements are found in close association with cobalt, in several European ore sources, notably in smaltite and associated minerals (*eg* erythrite and cobaltite). Some sources, such as the 'Kobaltrücken' near Frankfurt, are known to have been used in medieval times (Lafitte 1984, 221, 240 and 319). There are other significant deposits of these ore types in southern Germany and Czechoslovakia. However, smalt is always described as potash glass coloured by cobalt, hence the blue glass of SF4 is not smalt, as defined by pigment specialists.

Cobalt is a strong colourant and it is possible that a soda-glass melt would be adequately coloured by quite a small addition of strongly-tinted potash-glass based smalt. On examination of the analytical data (Table 2), it can be seen that there is a small proportion of potash (2%) present. Furthermore, the $CoO:K_2O$ ratio in the Broad Street example (around

1:1) is not inconsistent with the ratios indicated in published analyses of smalt (from 1:0.1 to 1:1.8; data from Winckler 1959; Church 1901). Thus the potash in this glass could have been introduced with the smalt. However, other analyses (*eg* this paper; Mortimer 1991) suggest that at least 2% potash would be expected in soda glass of this period, without the addition of potash-glass based smalt.

Alternatively, cobalt blue glass could have been made using soda glass and cobalt minerals. This certainly had been the case in earlier periods, since cobalt-based blue glasses were produced when potash glass was unknown (*eg* in Egyptian and classical periods, Mühlethaler and Thissen forthcoming). During these periods, soda glass was used for most types of production, as it was during the medieval period in Italy.

According to Beckmann (1846), at least two distinct types of procedure were involved in the manufacture of cobalt-blue pigments during the medieval and post-medieval period. In the first procedure, refined cobalt ore was exported from the source area, for use in glazes and in glassworking, so that, in this case, the cobalt ore was only combined with glass when it reached the glass workshop. Alternatively, the same ores were refined and then combined with the local potash glass, ground to various grades and exported as 'smalt', when the final use was in paint preparation. It seems likely that SF4 reflects the former procedure.

PHASING

Most of the material examined in this project originated from contexts within Periods 6 and 7, which have been given dates of the second quarter of the seventeenth century (c. 1625-1650) and the mid-17th century (c. 1650-1660) respectively. Context 126 was from an isolated rubbish pit, dated by pottery to c.1650.

This relatively short activity span means that it is unlikely that chronologically-significant changes will be observable within the sampled material. Most of the material forms and composition types were found both early and late phases, including both types of soda glass, potash and HLLA glass. A larger sample from this material might provide a more statistically-valid dataset with which to investigate changes in production characteristics over this significant period in glass technology.

CONCLUSIONS

On the strength of these analyses and those carried out on other material from the City of London, it seems likely that much of the seventeenth-century soda-glass vessels in London could have been produced in England, at sites such as Broad Street. However, some soda glass was certainly imported from the Netherlands or Italy, even during the period of Mansell's monopoly over glass and some of the vessel material examined in this project may be from these sources. Similarly, *vetro a filigrano* glassware could have been prepared entirely at the site, or some of the preparative work (*eg* manufacture of the opaque white canes or cullet preparation) could have been carried out elsewhere.

Compositional subgroupings are beginning to emerge amongst the post-medieval potash glasses and possibly amongst the high-lime, low-alkali glasses. Again, this may indicate a variety of origins but variability in raw materials was suggested above as a potential source of variation in final composition.

The colourant source of a single example of cobalt blue glass was suggested to be Central Europe indicating trade from this area, presumably to Venice or to *façon de Venise* workshops.

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Table 1: Translucent, lightly- and naturally-coloured glass

Type	SF	Colour	Cont	Phase	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	Cl	CaO	K_2O	TiO_2	MnO	Fe_2O_3	SnO_2	PbO	Total
1) Soda vessel glass																		
bot[1]	235	dk gr[2]	146	7[3]	*15.6	2.1	2.4	61.8	0.7	0.4	10.3	2.8	-[4]	2.0	0.8	-	-	99.3
b	333	?grey	239	7	13.1	3.3	2.1	64.2	0.3	0.3	9.4	5.1	-	1.1	0.7	-	-	100
b	340	br/pur	239	6	13.1	2.9	2.3	62.9	-	0.3	8.2	5.0	-	0.9	0.9	-	-	96.9
b	241	?grey	187	7	13.3	2.5	0.8	62.7	-	0.4	10.0	5.4	-	1.2	0.7	0.3	0.3	98
b	341	tr gr	126	-	*11.8	2.7	0.9	63.9	-	0.3	10.3	6.3	-	0.9	0.7	-	-	98.2
c	348	tr ?br	297	6	12.9	2.6	0.6	62.4	0.4	0.3	9.8	5.6	0.3	1.1	0.4	0.5	-	97.1
c	249	grey?	188	7	11.7	2.8	0.5	61.7	-	0.3	10.9	6.1	-	0.7	0.5	-	-	96.5
					13.07	2.7	1.3	62.8	0.2	0.3	9.84	5.2	0	0.9	0.7	0.1	0	
2) Translucent soda glass, in lattimo artefacts (part-formed or completed vessels)																		
rod	195	tr	154	7	12.3	3.2	1.3	64.7	0.4	0.4	8.5	7.2	-	0.5	0.5	-	-	99.4
rod	196	inner	156	7	13.9	2.7	0.9	64.0	0.3	0.4	9.4	2.6	-	1.1	0.5	0.4	-	96.6
rod	196	outer	156	7	14.1	2.9	1.0	65.4	0.4	0.4	9.6	2.6	-	0.9	0.7	-	-	98.6
b(r)	265	sl br	205	6	12.1	2.9	1.0	63.8	0.4	0.3	10.1	5.3	-	0.8	0.6	-	-	97.6
b(r)	286	?grey	165	7	12.4	2.0	0.7	63.3	0.5	0.3	9.7	7.1	-	-	0.5	-	-	97
v	4	tr	172	7	14.3	2.9	0.6	63.9	-	0.4	10.0	2.4	-	-	0.5	-	-	95.8
3) Waste soda glass																		
w+	225	tr gr	157	7	9.8	2.6	2.5	65.2	0.3	-	8.2	4.9	-	1.2	1.4	-	-	96.6
w+	225	tr gr	157	7	9.6	2.8	4.0	67.7	0.4	-	7.8	3.0	-	0.8	1.9	-	0.3	98.7
w*	308	sl br?	230	6	12.5	3.6	0.9	61.8	-	0.5	10.6	2.1	-	1.2	0.8	0.3	-	94.8
w	211	sl br?	188	7	12.2	2.9	0.9	65.7	-	0.3	11.0	5.7	-	1.3	0.8	-	-	101.5
w	224	dk gr	156	7	15	2.4	1.3	66.3	0.3	0.4	8.1	2.3	-	1.1	0.7	-	-	98.1
4) Glass from crucible																		
w	118	gr/red	185	6	13.2	2.8	0.9	66.5	0.3	0.4	11.0	6.2	-	1.2	0.5	-	-	103.4

+ Glass from identical context, with different external appearance
* Slightly devitrified?

Table 1 cont.

Type	*SF*	*Colour*	*Cont*	*Phase*	*Na_2O*	*MgO*	*Al_2O_3*	*SiO_2*	*P_2O_5*	*Cl*	*CaO*	*K_2O*	*TiO_2*	*MnO*	*Fe_2O_3*	*SnO_2*	*PbO*	*Total*
5) Potash vessel glass																		
b	254	tr	188	7	0.5	3.2	1.5	64.6	1.6	-	14.7	17.7	0.3	1.0	0.4	-	-	105.6
b	256	tr gr	171	7	2.5	3.3	2.4	57.4	2.3	-	18.0	8.4	-	1.1	0.5	-	-	96.4
b	313	tr gr	227	6	0.4	3.1	2.3	60.8	1.4	-	18.5	9.7	0.4	2.0	0.5	-	-	99.2
6) High-lime low-alkali vessel glass																		
b	343	tr gr	239	6	3.3	2.7	2.3	56.0	2.4	0.3	20.6	2.2	0.3	0.8	1.2	-	-	92.4
bot	234	tr gr	233	6	1.7	2.9	2.5	57.5	2.5	-	22.2	4.2	0.5	0.8	1.4	-	-	96.7
bot	253	tr gr	188	7	1.8	2.4	1.9	58.7	2.6	-	22.2	5.5	-	1.1	-	-	-	97
bot	250	dk gr	188	7	1.3	2.2	1.7	59.9	2.4	-	21.6	6.1	-	-	1.1	0.8	-	97.7

Table 2: Coloured glass

Type	SF	Colour	Cont	Phase	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	Cl	CaO	K_2O	TiO_2	MnO	Fe_2O_3	SnO_2	PbO	Total
1) Opaque white glass used in vessel body[5]																		
v	368	op wh	209	6	12.9	2.5	0.4	54.0	0.3	0.3	6.7	3.3	-	0.4	0.3	7.7	10.7	99.7
2) Opaque white glass used in vessel decoration																		
owc	196	op wh	156	7	11.6	2.0	0.8	47.8	-	0.3	6.8	1.9	-	0.9	0.7	8.2	18.0	99.3
owc	195	op wh	154	7	10.2	2.1	0.8	46.2	-	0.3	6.2	4.5	-	1.0	0.6	15.9	14.2	102.4
b	265	op wh	205	6	9.3	2.0	0.8	43.4	-	0.5	8.1	3.1	-	-	0.5	14.0	21.0	103.3
v	4	op wh	172	7	11.1	-	-	38.3	-	0.4	1.5	1.4	-	-	-	20.1	28.0	101.5
b	286	op wh	165	7	11.3	1.8	0.8	49.8	0.3	0.3	7.3	5.5	-	-	0.3	14.4	9.5	101.5
3) Other colours																		
b	309	black	239	6	2.8	3.0	2.5	63.0	3.1	-	23.8	5.4	-	0.3	1.3	-	-	106.4
v	329	opal	239	6	0.4	2.2	2.8	65.5	2.6	-	29.7	3.8	-	0.4	0.8	-	-	109.0
v**	4	tr blue	172	7	11.8	4.4	-	59.4	0.4	-	8.0	2.0	-	-	1.8	-	-	88.1

** Blue trail only, see also vessel body and lattimo data. As, Co, Ni also detected, at percentage levels, but not quantified satisfactorily.
A small amount of Cr2O3 was detected in SF329, the opal glass.

Notes

1. Vessel types are: v vessel, b beaker, b(r) beaker with rod decoration, c cup, w waste, owc opaque white cane, bot bottle

2. Colours are: gr green, dk gr dark green, br brown, pur purple, tr translucent, op wh opaque white, tr blue translucent blue.

3. Phase 6 = second quarter of seventeenth century, phase 7 = mid-seventeenth century.

4. In these tables, "not detected" and "below detectable limits" are represented by "-". Oxides which were calculated at levels of 0.2% or less are quoted as not detected.

5. Analytical totals are often not equal to 100% ±2% amongst the opaque-white glasses. The ZAF program calculates the glass composition assuming that the material is entirely homogeneous, which is not the case here. Furthermore, the electron beam samples the lead-tin inclusions which, although they are probably oxides, may not be simple lead and tin oxides (SnO2 and PbO) as quoted here. During the earlier analytical programme (Mortimer 1991), an attempt was made to analyse the matrix of opaque-white glasses avoiding the inclusions. Since these glasses contain extremely small crystals as well as large ones, this was unrealistic and so it was not attempted in this study. Larger crystal clusters were avoided during analysis, however. This may mean that the earlier analyses have lower figures for lead and tin oxide figures.