Centre for Archaeology Report 7/2005

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ISSN 1473-9224

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Summary

This report examines glass and glassworking waste recovered from the site of an 18th-century glasshouse.
All of the samples are composed of high-lime low-alkali glass. The typological dating of the glass bottles show that bottle-glass composition changed during the course of the 18th century.

Keywords
Glass
Post Medieval

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Introduction

The Bristol glass industry was established in the early part of the 17th century (Witt *et al*. 1984) and, by the end of the century, it had 8 of the 88 English glasshouses recorded by Houghton (Hartshorne 1968: 457). The staple product of many of Bristol's glasshouses was the dark green/brown bottle. This report presents the chemical analysis of vessel glass (mostly bottle) and glassworking waste from the site at Limekiln Lane which was active from the latter part of the 17th century to the early part of the 19th century. The earliest evidence for the presence of the Limekiln Lane glasshouse (ST 5792 7238) is Millerd's *Prospect of Bristol* (figure 1) which was probably drawn in the 1680s or 1690s (Bob Jones personal communication). The glasshouse is shown on later maps such as Millerd's of 1710 and Rocque's of 1743 (figure 2). The glasshouse is also seen in a number of early 19th century watercolours (e.g. Witt *et al*. 1984: plate 1).

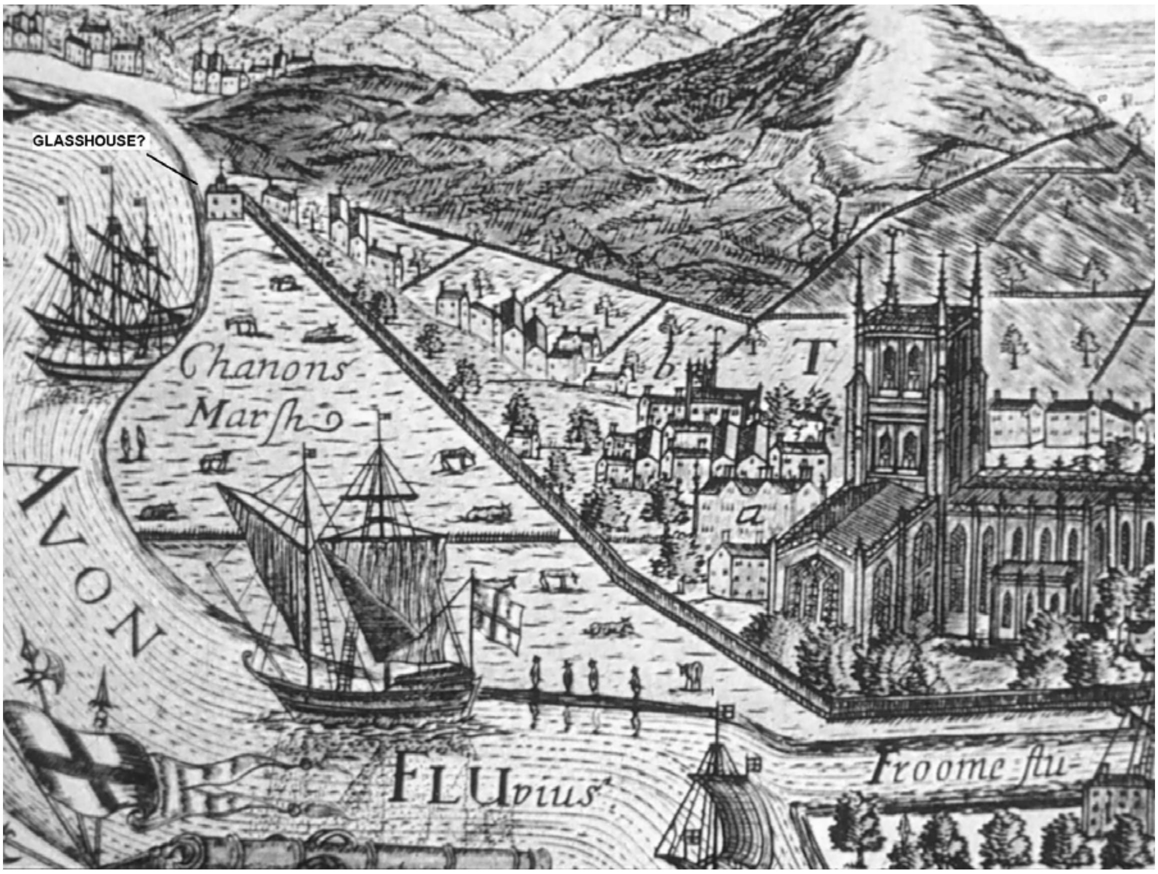

Figure 1. Extract from Millerd's Prospect of Bristol (*1680s or 1690s) looking west. The site of the glasshouse on the riverbank in the top left corner is indicated*

The documentary evidence for the glasshouse begins in 1722 when a William Wood 'glassmaker' was recorded in the parish of St. Augustine. As the Limekiln Lane glasshouse was the only one in the parish he probably worked there (Buckley 2003: 77–79), although it is possible that he worked at the Hotwell glasshouse further to the west. Workers and owners at the Limekiln glasshouse are recorded through the second half of the 18th century and into the early years of the 19th century (Witt *et al*. 1984: 53–4). The site was advertised as a bottle works in 1790 (Buckley 2003: 79) and bottles may always have been the principal product (Witt *et al*. 1984: 54). The site appears to have continued as a glasshouse until at least 1832 (it is shown as such on the Plumley and Ashmead plan of that year) but had ceased operation by 1838 when the occupiers (timber merchants) were granted permission to demolish the glasshouse cone (Witt *et al*. 1984: 54).

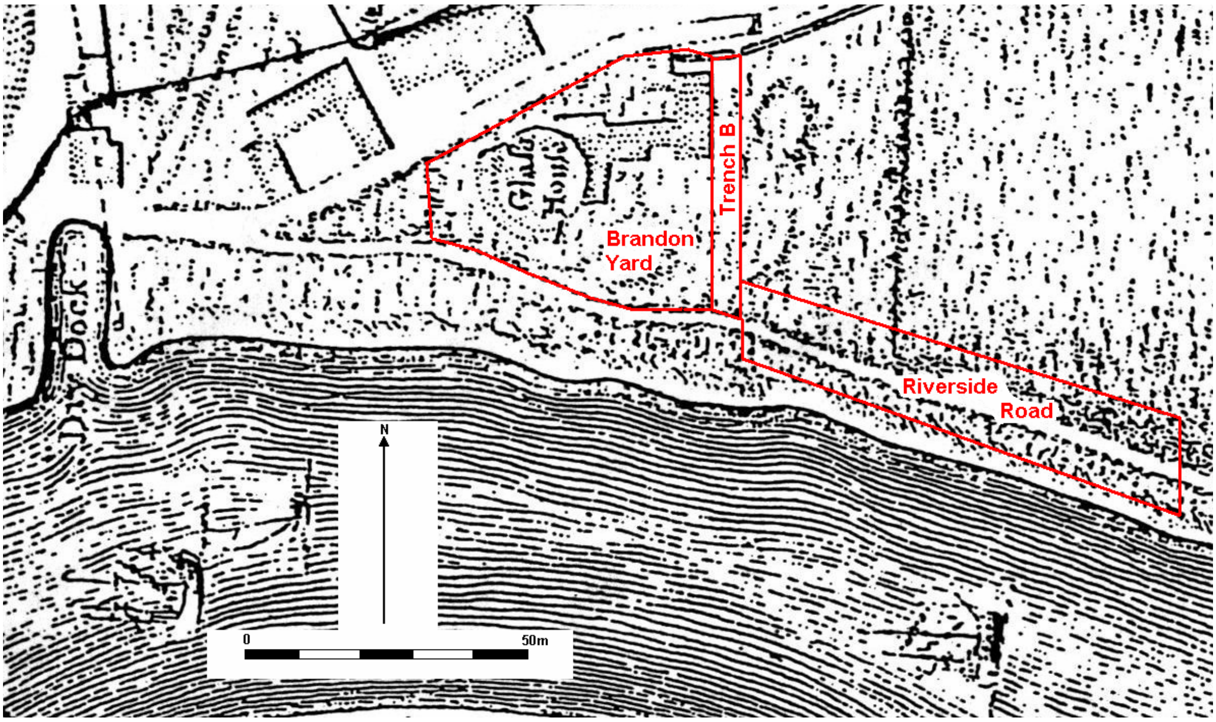

Figure 2. Extract from Rocque's map of Bristol (1743) showing the glasshouse and the approximate positions of the modern excavated trenches and areas

In the 1860s the site was taken over by the Canon's Marsh Gasworks. The land had become heavily contaminated as a result of the processes used to extract gas from whale oil and limited archaeological investigation was carried out as part of the remediation process (Michael Chapman, personal communication). Most of the contaminated deposits on the site were removed mechanically with some recording of archaeological features and artefacts. Excavation revealed a section of wooden piles underlying a curving brick wall at the approximate position of the glasshouse, which is likely to have been remains of the glasshouse cone itself.

Glass and glassworking debris were recovered from three separate zones during the archaeological investigation: **Brandon Yard** (the site of the glasshouse), **Trench B** (*c*. 50m east of the glasshouse) and **Riverside Road** (make-up for a road running along the river front [*c*. 50–100m east of the glasshouse]). The glass and glassworking finds were found with 18th century clay pipes and trailed-and-slipped wares. However, the glass finds were also found in mixed deposits containing 19th century and later pottery.

Description of Samples

Table 1. List of samples from Limekiln Lane

Sample	Area	Description	Date
1	Brandon Yard	Bottle, neck and shoulder	<1750
2	Brandon Yard	Bottle, neck	<1750
3	Brandon Yard	Bottle, neck and shoulder	<1750
4	Brandon Yard	Bottle, neck and shoulder (waster)	<1750
5	Brandon Yard	Large run	
6	Brandon Yard	Large lump	
7	Brandon Yard	Possible moil	
8	Brandon Yard	Possible moil	
9	Brandon Yard	Off-cut	
10	Brandon Yard	Bubbly glass	
11	Brandon Yard	Run, pull	
12	Brandon Yard	Small lump	
13	Brandon Yard	Small lump	
14	Brandon Yard	Small lump	
15	Trench B	Bottle, neck	<1750
16	Trench B	Bottle, body fragment	?
17	Riverside Road	Bottle, neck	1750–1821
18	Riverside Road	Bottle, neck and shoulder	?
19	Riverside Road	Bottle, neck (waster)	1750–1821
20	Riverside Road	Bottle, neck	1750–1821
21	Riverside Road	Distorted glass (bottle ?)	?
22	Riverside Road	Bottle, neck	1750–1821
23	Riverside Road	Bottle, neck and shoulders	1750–1821
24	Riverside Road	Bottle, base with kick	1750–1821
25	Riverside Road	Bottle, base with kick	1750–1821
26	Riverside Road	Bottle, neck and shoulders (waster)	?
27	Riverside Road	Run, pull	
28	Riverside Road	Neck of vessel ?	

Twenty-eight samples of glass and glassworking waste from the Limekiln Lane site were selected for analysis (table 1). The samples from Brandon Yard and Trench B included bottles with tapering necks (figures 3.1 and 3.3) while the samples from Riverside Road included examples (figure 3.23) with almost straight necks. Tapering necks are seen on a variety of bottle shapes (e.g. ‘onion’ and ‘mallet’) from the end of the 17th century to the middle of the 18th, while straight necks begin to appear around the middle of the 18th century with the change to cylindrical-shaped bottles (Van den Bosche 2001: figure 2). The absence of seams on the bottles indicates that they were free-blown rather than mould blown and all certainly pre-date Rickett’s 3-piece mould (patented in 1821). The early bottles are made of a dark green glass while the later ones tend to be a more brownish glass. Sample 28 (Figure 3.28) consists of a long neck from an unidentified vessel. The form resembles distilling equipment and the colour of the glass is similar to the glassworking waste from the site.

The glassworking waste includes runs and pulls (figure 4) and small droplets of glass. Three bottle wasters were also identified (figures 5–8). These are heavily distorted and the glass has become almost opaque and grey or pale blue in colour. Such waste glass has been identified in the form of glassy lumps on other production sites, such as Silkstone (Dungworth 2003: figure 6), but it has rarely been seen in the form of vessel wasters.

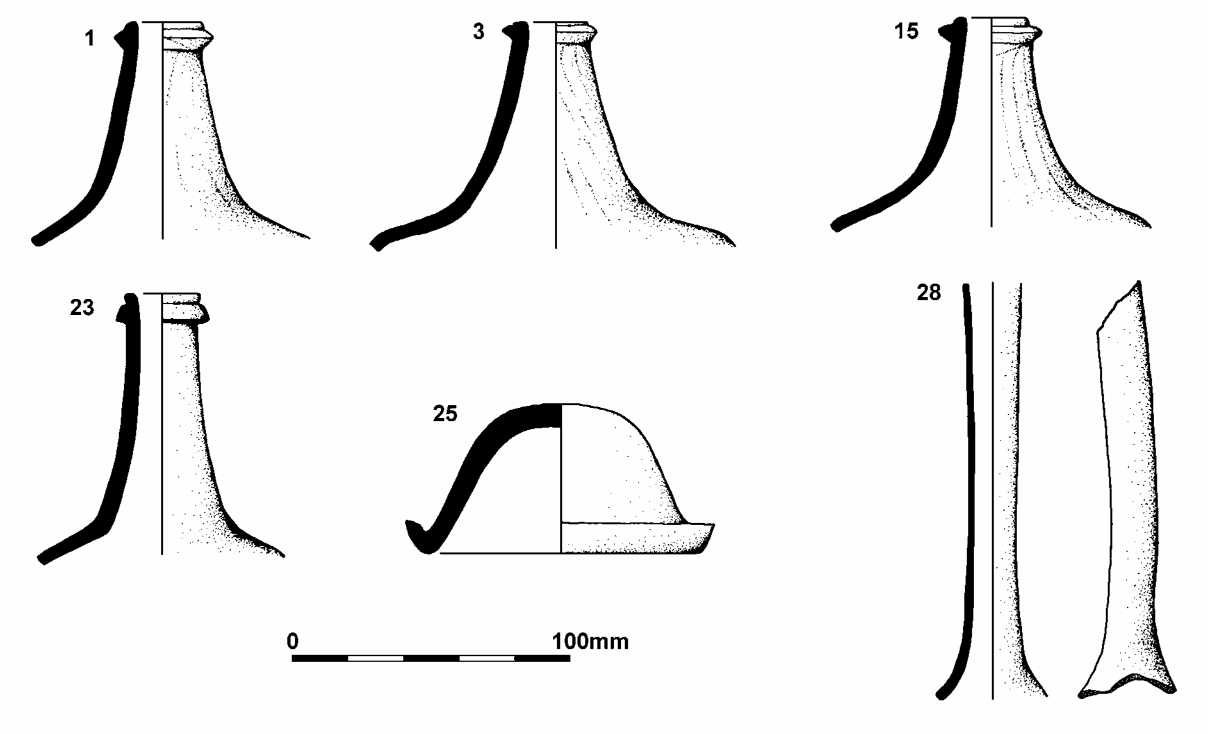

Figure 3. Drawings of a selection of vessel glass from Limekiln Lane

Figure 4. Run or pull of green glass (Sample 5)

Figure 5. Bottle waster (sample 4)

Figure 6. Bottle waster (sample 19)

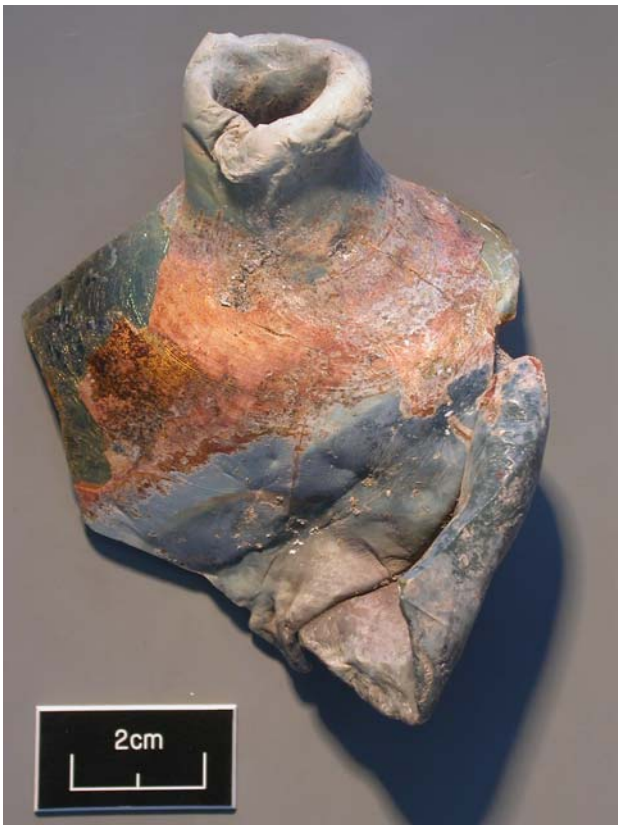

Figure: 7. Bottle waster, front (sample 26)

Figure: 8. Bottle waster, back (sample 26)

Methods

The samples were photographed and a selection drawn before small fragments were removed and mounted in epoxy resin to expose a cross-section. The mounted samples were ground and polished to a 3-micron finish and then coated in carbon for examination with the scanning electron microscope.

The samples were examined using a Karl Zeiss S440 scanning electron microscope (SEM). Both secondary electron and back scattered electron detectors were used to asses the condition and homogeneity of the samples. The back scattered electron detector was most useful as it allowed the identification of weathered surface layers as well as heterogeneity.

The chemical compositions of the samples were determined using an Oxford Instruments energy dispersive X-ray spectrometer attached to the scanning electron microscope (SEM-EDS). The SEM was operated at a voltage of 25kV and a probe current of 1.5nA. The Oxford Instruments germanium X-ray detector allowed for the simultaneous detection of all elements from oxygen to uranium, providing the elements were present above the detection limits. Each spectrum was collected from an area approximately 200 by 300 microns for 100 seconds livetime. Each spectrum was calibrated using a cobalt standard and deconvoluted using the Oxford Instruments SEMQuant software (with phi-rho-z correction procedure). This made use of element profiles derived from single element or simple compound standards (pure iron, jadeite, etc). The profiles were standardised against appropriate glass reference materials (e.g. Corning standards). Energy dispersive X-ray spectrometry provides no direct information about the valence state of any elements present (e.g. FeO, Fe_2O_3 or Fe_3O_4). In each case, an appropriate valence state for the analysed material was chosen and the oxide weight percent calculated stochiometrically.

Results

The chemical compositions of the analysed samples are given in table 2. All of the samples are high-lime low-alkali (HLLA) glasses (Mortimer 1991). Compared to the 17th century HLLA glasses from London (Mortimer 1991), the Limekiln Lane 18th century HLLA glasses contain less phosphorus oxide and manganese oxide but more alumina, lime and iron oxide. The discussion of the results below looks first at the glassworking waste, then the bottles and lastly the glass bottle wasters.

Table 2. Chemical composition of the samples analysed

No.	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	Cl	K_2O	CaO	TiO_2	MnO	Fe_2O_3	BaO	SrO
1	1.5	2.5	4.1	58.2	1.3	0.58	0.25	2.1	27.0	0.22	0.15	2.1	0.0	0.08
2	1.3	2.6	4.1	56.3	1.5	0.59	0.17	2.1	29.0	0.24	0.16	1.8	0.2	0.11
3	1.9	2.6	3.7	57.0	1.4	0.45	0.29	2.2	28.0	0.19	0.21	1.9	0.1	0.10
4	1.7	2.4	4.2	57.2	1.2	0.71	0.22	1.8	27.8	0.22	0.20	2.1	0.2	0.08
5	1.7	2.9	3.7	61.9	2.2	0.45	0.48	6.0	17.9	0.22	0.26	1.6	0.7	0.09
6	1.6	2.9	3.6	58.7	1.6	0.56	0.34	2.2	26.2	0.17	0.18	1.6	0.2	0.10
7	1.9	3.2	3.7	58.2	2.5	0.32	0.46	8.2	19.7	0.26	0.06	1.5	0.0	0.08
8	1.1	3.1	3.7	56.9	2.0	0.69	0.20	3.3	25.9	0.21	0.38	2.2	0.2	0.08
9	1.6	2.8	3.7	59.0	1.5	0.54	0.30	2.0	26.3	0.23	0.14	1.7	0.2	0.10
10	1.5	3.2	3.7	55.6	2.2	0.41	0.32	3.5	27.0	0.23	0.27	1.9	0.2	0.10
11	1.3	3.1	3.7	55.4	2.0	0.58	0.21	3.7	26.6	0.24	0.37	2.5	0.1	0.08
12	1.3	3.7	3.8	55.3	3.1	0.34	0.44	8.1	21.5	0.24	0.30	1.8	0.1	0.10
13	1.5	3.0	4.2	56.1	2.0	0.48	0.25	3.2	26.3	0.21	0.28	2.3	0.1	0.08
14	3.6	4.1	5.2	55.7	2.8	0.33	0.65	5.4	19.7	0.25	0.35	1.9	0.0	0.09
15	1.7	2.7	4.2	57.3	1.5	0.51	0.26	2.0	27.3	0.24	0.25	2.0	0.0	0.09
16	1.5	2.4	4.4	58.5	1.5	0.29	0.29	2.0	26.4	0.23	0.22	2.2	0.1	0.09
17	2.0	4.8	5.7	55.0	1.6	0.42	0.39	2.3	24.8	0.27	0.27	2.5	0.0	0.12
18	1.9	4.6	5.5	57.2	1.6	0.20	0.42	2.5	23.4	0.28	0.22	2.2	0.0	0.11
19	2.2	4.3	5.5	56.7	1.7	0.36	0.40	2.7	23.2	0.29	0.27	2.5	0.0	0.11
20	2.3	4.6	5.1	58.1	1.6	0.22	0.37	2.7	22.1	0.23	0.26	2.3	0.0	0.14
21	2.2	3.5	4.8	57.9	1.6	0.31	0.50	2.4	23.9	0.29	0.22	2.4	0.0	0.11
22	2.0	4.5	5.3	56.9	1.4	0.30	0.27	2.5	23.8	0.29	0.26	2.4	0.1	0.13
23	1.6	4.7	5.3	58.3	1.1	0.33	0.29	2.4	23.0	0.29	0.25	2.5	0.0	0.11
24	1.9	5.0	5.5	57.6	1.5	0.29	0.30	2.5	22.7	0.23	0.24	2.2	0.0	0.13
25	2.0	4.8	5.4	57.7	1.4	0.25	0.30	2.3	22.9	0.27	0.24	2.4	0.0	0.10
26	2.0	4.8	5.4	56.8	1.5	0.24	0.27	2.5	23.5	0.29	0.25	2.3	0.0	0.12
27	1.7	4.5	5.4	57.6	1.4	0.36	0.22	2.4	23.5	0.27	0.28	2.4	0.0	0.11
28	2.1	4.4	5.4	57.3	1.4	0.38	0.27	2.5	23.3	0.26	0.24	2.5	0.0	0.12
mean	1.8	3.6	4.6	57.3	1.7	0.41	0.33	3.1	24.4	0.25	0.24	2.1	0.1	0.10
sd	0.5	0.9	0.8	1.4	0.5	0.14	0.11	1.7	2.7	0.03	0.07	0.3	0.2	0.02

Glassworking waste

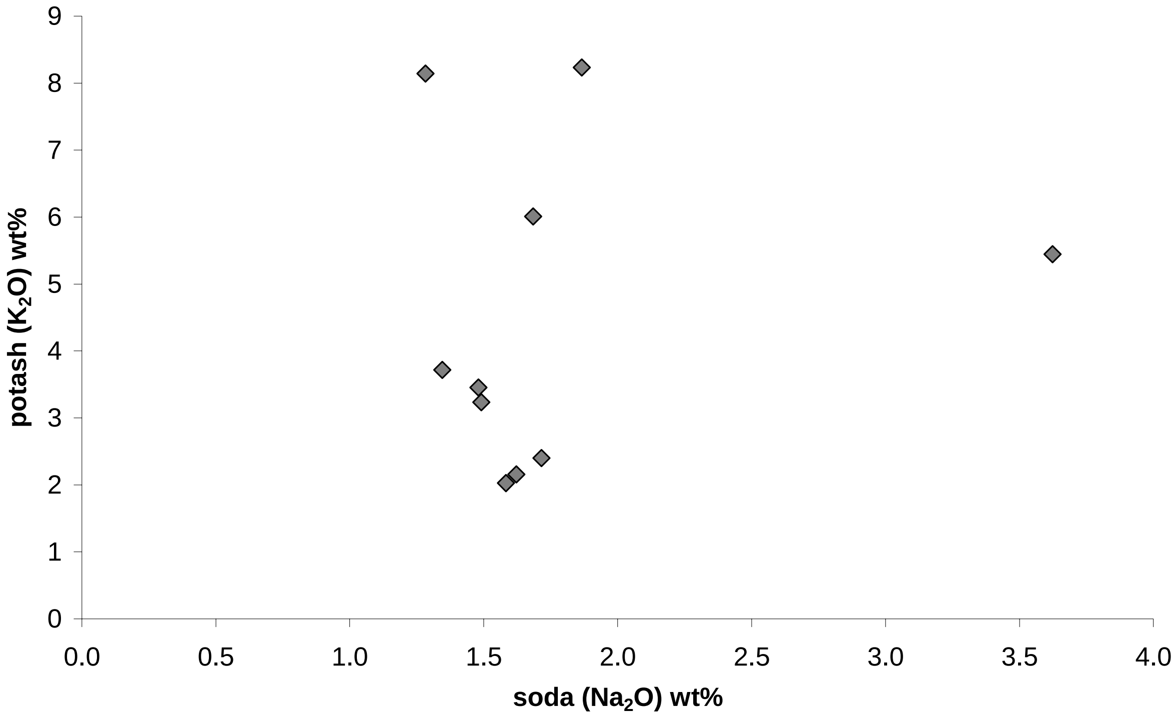

Figure 9. Plot of soda and potash contents for the glassworking waste

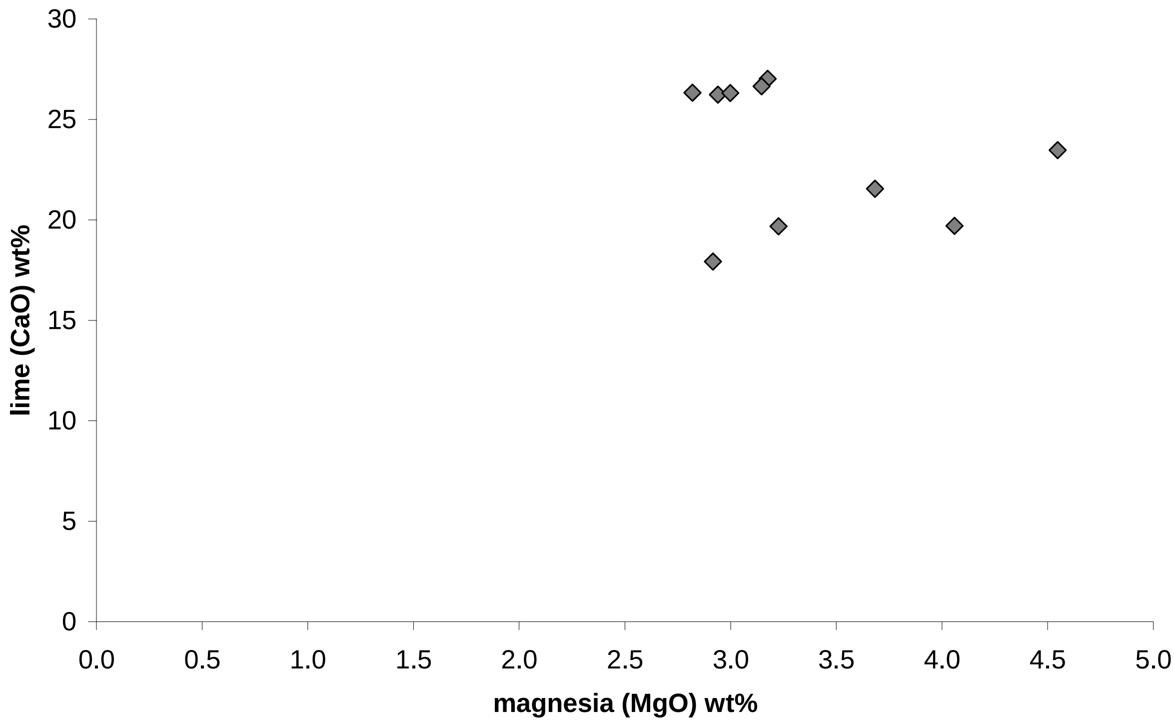

Figure 10. Plot of magnesia and lime contents for the glassworking waste

The glassworking waste samples show a fairly wide range of compositions (figures 9 and 10) but are all broadly HLLA glasses. There are no clear compositional groups within the glassworking waste, such as can be seen in waste from other post-medieval glasshouses (e.g. Dungworth 2003). Samples 6, 8–11 and 13 have compositions which are very similar to the early glass bottles (see below) while sample 27 has a composition similar to the late glass bottles. The remaining samples of glassworking waste (samples 5, 7, 12 and 14) contain relatively high levels of potash (5.4–8.2wt%) and phosphorus oxide (2.2–3.1wt%) and do not match any of the analysed glass bottles from Limekiln Lane (see below). These remaining samples of HLLA glassworking waste have compositions which are similar to those produced in the last half of the 17th century (e.g. Silkstone, Dungworth 2003 and Vauxhall, Tyler & Willmott forthcoming).

Glass Bottles

The glass bottles from the excavations at Limekiln Lane have been divided into early (*c*.1680–1750) and late (*c*.1750–1820) groups based on the shape of the necks and shoulders. All of the bottles were manufactured using HLLA glasses, however, the two groups of bottles have distinct chemical compositions (figures 11 and 12 and table 4). The early bottles have lower soda, magnesia, alumina, potash and iron oxide contents but higher sulphur and lime contents. These differences are likely to reflect slight variations in the composition of the raw materials used. The undated glass bottles have compositions which coincide with those of either the early or late bottles.

Table 4. Average compositions (and standard deviations) for the early and late types of bottles from Limekiln Lane

		Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	Cl	K_2O	CaO	TiO_2	MnO	Fe_2O_3
Early	mean	1.6	2.6	4.0	57.2	1.4	0.53	0.24	2.1	27.8	0.22	0.19	2.0
	sd	0.3	0.1	0.2	0.8	0.1	0.06	0.05	0.1	0.9	0.03	0.05	0.1
Late	mean	2.0	4.7	5.4	57.3	1.4	0.30	0.32	2.5	23.2	0.26	0.25	2.4
	sd	0.2	0.2	0.2	1.2	0.2	0.07	0.05	0.1	0.9	0.03	0.01	0.1

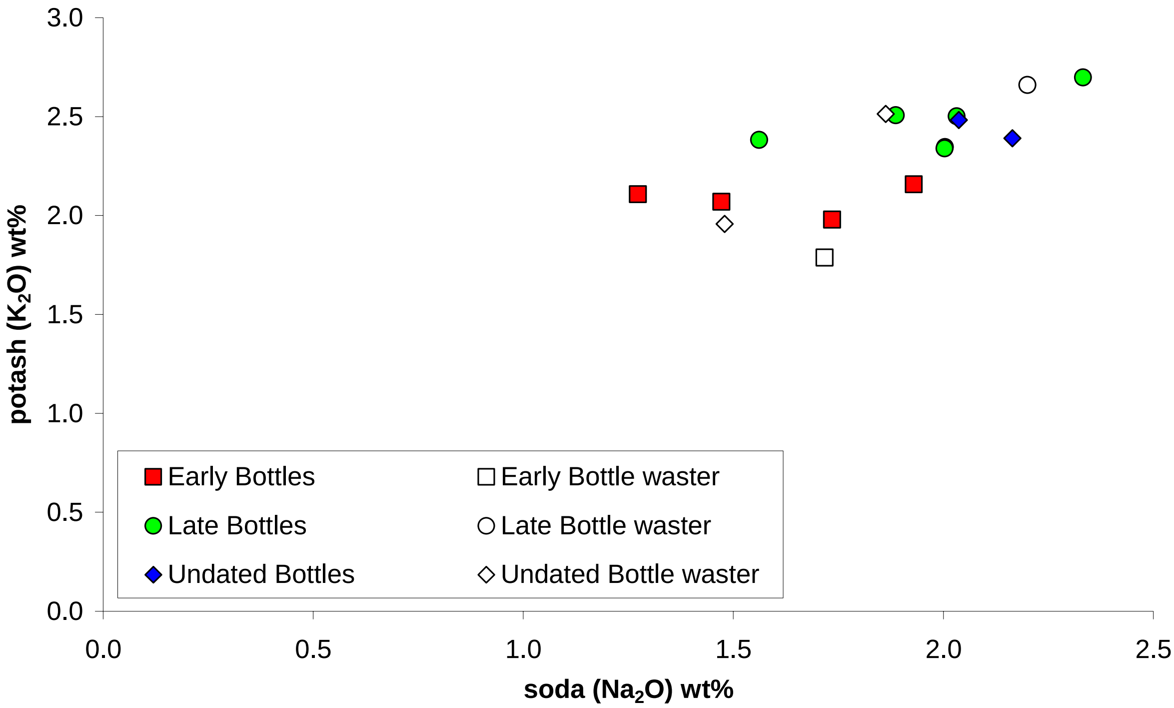

Figure 11. Plot of soda and potash contents for the bottles and bottle wasters

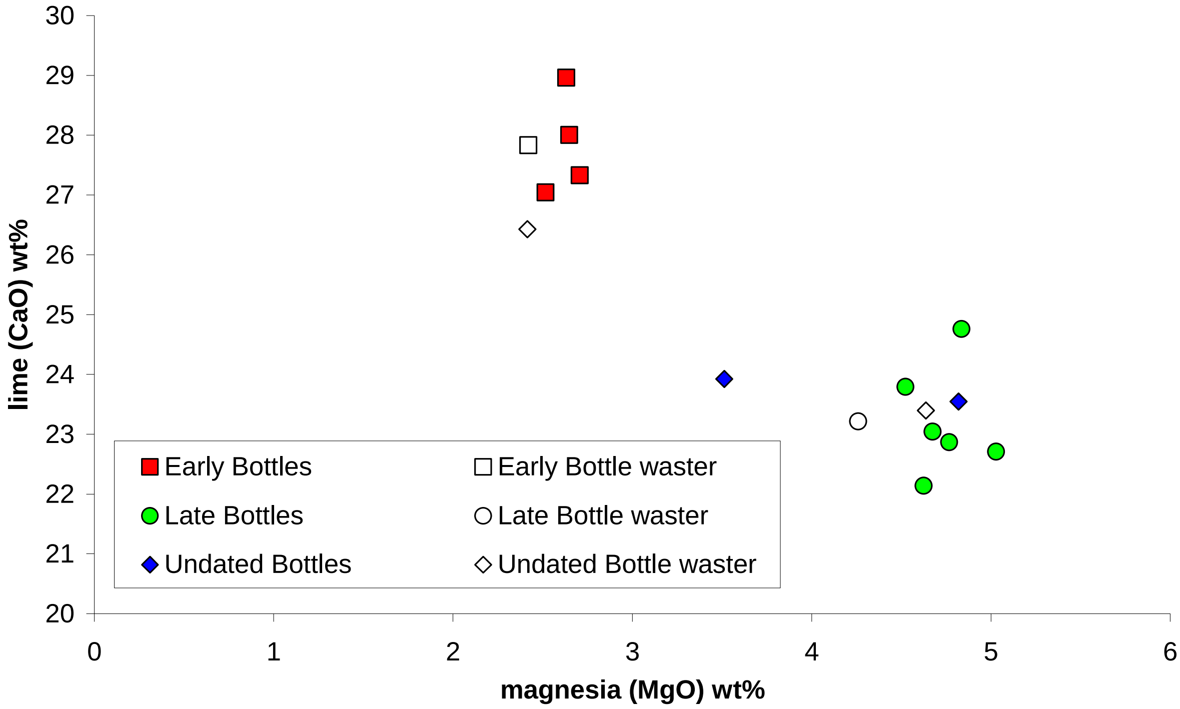

Figure 12. Plot of magnesia and lime contents for the bottles and bottle wasters

Glass Bottle Wasters

The three glass bottle wasters (samples 4, 19 and 26, figures 5–8) were deformed to varying degrees, are pale-blue or cream-grey in colour and almost opaque. Opaque cream blue glassy waste has been encountered at a number of glassworking sites (e.g. Silkstone, Dungworth 2003: figure 6; and Bedminster, Blakelock *et al*. forthcoming) where it is usually in the form of amorphous lumps rather than blown vessel wasters. The opaque cream blue lumps from Silkstone and Bedminster tend to have similar compositions to the HLLA glass produced at those sites, but with higher alumina and titania contents. A likely source of for these oxides is the ceramic fabric of the crucibles used to melt the glass. If glass was left in the crucibles for very long periods then alumina and titania would tend to dissolve into the glass (Dungworth 2003: figures 15 and 21). The Limekiln Lane opaque cream blue bottle wasters, however, have chemical compositions that are indistinguishable from the contemporary bottles. It should be noted that opaque cream blue glassy waste was not found at Cheese Lane (Jackson forthcoming) or at Vauxhall (Tyler & Willmott forthcoming) but that soda or mixed alkali glasses were the primary products at these glasshouses.

The three waster samples from Limekiln Lane were examined with the SEM in an effort to identify signs of devitrification or crystallisation. Samples 4 and 26 appeared to be completely uniform with no signs of crystals. Sample 19, however, contained a number of areas where some devitrification had occurred (figure 13). The crystals are either brighter than the surrounding glass (i.e. higher average atomic number) or darker (lower average atomic number). These crystals were too small to allow quantitative chemical analysis using the X-ray detector, however, X-ray mapping indicates that the bright phase is a calcium silicate (probably wollastonite) while the dark phase is an aluminium silicate.

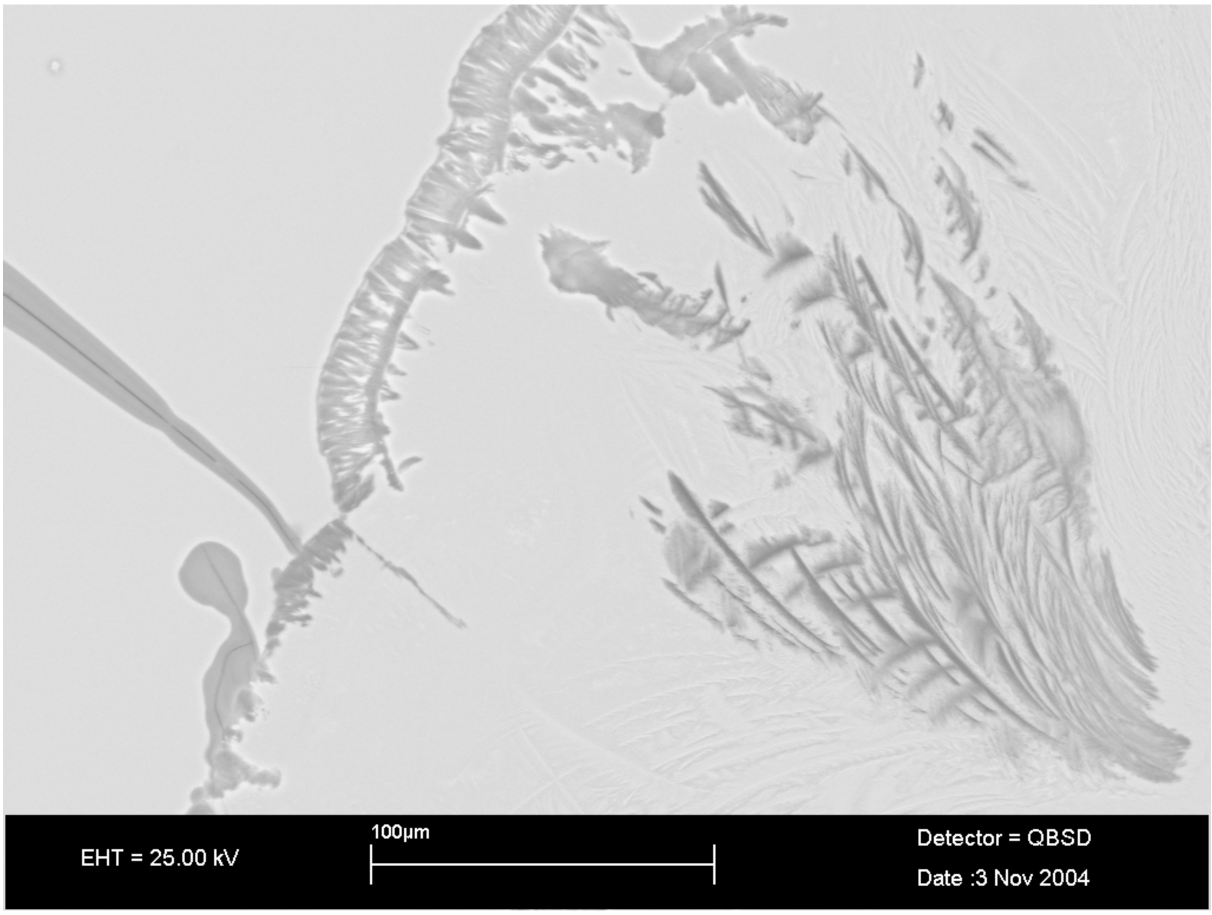

Figure 13. SEM image (back scattered electron detector) of sample 19 showing devitrification

The absence of crystalline phases in samples 4 and 26 accords with the results for the Silkstone opaque cream blue glassy waste which also appeared to be homogenous and lacking crystals. The formation of this type of glass waste is probably related to the formation of two immiscible liquids at high temperature (see Blakelock *et al*. forthcoming for a fuller discussion). Like devitrification, in its strictest sense, the formation of opaque cream blue waste probably results from maintaining the glass at a high temperature over a long period.

Discussion

The documentary evidence suggests that glass manufacture began at Limekiln Lane in the late 17th century and continued until the early 19th century. All of the glass and glassworking waste analysed are HLLA glass. The differences in composition between the early and late glass bottles follow trends in HLLA glass. Between the early 17th century and the late 19th century alumina and iron oxide contents increase while phosphorus oxide and manganese oxide decrease.

The 17th century HLLA glasses appear to develop out of traditional 'forest' glass and were made using sand and plant ashes. HLLA glasses emerge in France and Germany in the medieval period and the first HLLA production sites in England are in forested regions such as the Weald (Dungworth & Clark 2004). The phosphorus oxide and manganese oxide content of 17th century HLLA glasses indicate that these were made using ash from terrestrial plant(s). From the beginning of the 18th century the phosphorus oxide and manganese oxide contents in HLLA glass decline which may indicate that the alkalis were not obtained primarily from terrestrial plant sources. Writing in the middle of the 18th century, Angerstein (Berg & Berg 2001: 129) provides a list of the ingredients used in a Bristol glasshouse for the production of bottle glass:

1 sea sand, as ordinarily found on the seashore
2 soap ash, or potash, which is extracted from wood, with some limestone added
3 'shrope', a bluish iron slag
4 kelp, a kind of soda or barilla, burnt from seaweed in Wales
5 Limestone
6 Old bottles

This shows that terrestrial plants formed only a small proportion of glass batch. This trend (away from terrestrial plant sources) is continued in the 19th century. 19th-century green bottle glass manufacture stresses the use of varied ingredients such as basalt, blast furnace slag, bricks and clay (e.g. Muspratt 1863: 208). Such ingredients allowed the formation of glass suitable for green, brown or black bottles and would have been cheap.

Four samples of glassworking waste do not match the composition of the early or the late bottles (and associated glassworking waste). These samples have compositions which are closer to late 17th-century glassworking waste. These samples probably derive from glass production at Lime Kiln Lane during the late 17th century.

Conclusions

The assemblage of glass and glassworking waste from the Limekiln Lane glasshouse provides information about the types of glass manufactured there during the 18th century. All of the samples are HLLA glasses, a type of glass which was used in the 18th century almost exclusively for the manufacture of dark green/brown bottles. The glassworking waste (runs, droplets, moils, etc) have rather varied chemical compositions but some samples match the glass bottles from the site. The bottles can be divided on typological grounds into two groups: the first manufactured before *c*.1750, and the second between *c*.1750 and 1821. These two groups have very distinct chemical compositions which probably reflect slight differences in the raw materials used in glass making. The composition of this 18th century glass reflects the search for ingredients that would furnish an acceptable glass at minimum cost. The glassmakers avoided the use of expensive alkalis and instead made increasing use of materials that were waste products of other industries (e.g. soaper's ashes and blast furnace slag).

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