Centre for Archaeology Report 6/2005

Examination of glassworking materials from Cheese Lane, Bristol

D Dungworth and C Mortimer

ISSN 1473-9224

The Centre for Archaeology Report Series incorporates the former Ancient Monuments Laboratory Report Series. Copies of Ancient Monuments Laboratory Reports will continue to be available from the Centre for Archaeology (see back cover for details).

Centre for Archaeology Report 6/2005

Examination of glassworking materials from Cheese Lane, Bristol

D Dungworth and C Mortimer

Summary
This report examines glassworking materials recovered from the site of an 18th-century glasshouse. The majority of the samples are mixed alkali glasses comparable with those produced at Silkstone, Yorkshire in the late 17th century. The detailed examination of three crucible fragments confirms that the composition of glass adhering to the inner surfaces of crucibles has been altered by glass-crucible reactions. The composition of the crucible fabrics are compared with data from other sites. The results suggest that 17th- and 18th-century glasshouses obtained clay from local sources.

Keywords
Glass
Post Medieval

Author's address
English Heritage, Fort Cumberland, Fort Cumberland Road, Eastney, Portsmouth, PO4 9LD.
Telephone: 02392 856783. Email: david.dungworth@english-heritage.org.uk

Introduction

Excavations carried out at Cheese Lane, Bristol (NGR ST 5938 7294) in 2001 by the Bristol and Region Archaeology Service revealed substantial quantities of glassworking waste (about 30kg in total), including cullet, waste, crucibles and furnace fragments in contexts dating from the 17th century to the 19th century. The site is known from historical documents to have had a glasshouse during the 18th century. A range of glass and glassworking debris was selected for chemical analysis to characterise the type(s) of glass made.

Historical evidence

The glasshouse cone on Cheese Lane is shown on a 1710 map (Witt *et al*. 1984: plate 6). Witt *et al*. (1984: 44) report that the site was built by Abraham Elton 1708–10 but admit that 'it cannot be said with certainty which Abraham Elton founded this glass house' (*ibid* 1984: 44). The second Abraham Elton died in 1742 and his will makes a mention of his 'Crown works'. The cone collapsed in 1736 during repair work but was rebuilt and continued in use during the rest of the 18th century. The glasshouse probably ceased working *c*.1809 (*ibid* 1984: 45).

Visual Examination

Figure 1. Examples of chunks of glass (Samples 37, 39, 40 and 56).

Figure 2. Chunk of glass (with trailed decoration: the letter P?). Sample 49.

The glassy materials submitted for examination consist of various types of working waste, in particular, chunks of glass (too large to be fragments of blown or moulded glass vessels, see figures 1 and 2), moils (figure 3), threads, off-cuts and crucibles. The off-cuts tend to be wavy rather than flat and resemble the waste produced during the trimming of glass from the bowl of a drinking vessel (figure 4). Therefore, the limited evidence for the types of artefacts manufactured at Cheese Lane points to vessel glass rather than window glass.

Figure 3. Moil (sample 29).

Figure 4. Production of off-cuts (Gurney 1956: plate 6).

Sample Selection

Material was selected for chemical analysis on two main criteria. Firstly examples were taken from each of the main phases of glass-working, Phases 2 and 3 (late 17th century to *c.*1720, and *c.*1720 to *c.*1809 respectively), avoiding the latest phases (4 to 6), where the deposits were clearly reworked. There is no evidence for glassworking in Phase 1. Secondly, examples of each type of debris were selected, including each colour and form (Table 1). The glass colours seen at the site are mainly colourless, pale green, dark green and black.

Table 1. Numbers of samples from each phase

Phase	Moil	Thread	Chunk	Off-cut	Crucible	Fragment	Total
2	2	5	7	3		8	25
3	1	4	16		4	11	36

Sample Preparation

The samples were embedded in acrylic resin; where possible fragments of glass were mounted perpendicular to weathered surfaces to allow the observation of the degree of weathering (Cox & Pollard 1977) and so helped avoid an analysis of weathered surfaces. The mounted samples were ground (silicon carbide abrasive papers) and polished (diamond slurry) to a 3 micron (μ) finish (*ibid* 1977).

Analytical Technique

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. The following were not detected in any of the samples: CoO, CuO, ZnO, As_2O_5, SnO_2, Sb_2O_5 and BaO.

Table 2. Errors and detection limits (weight %)
(SrO content was determined using an EDAX Eagle I I X-ray spectrometer)*

	Error (1 standard deviation)	Detection limit
Na_2O	0.5	0.5
MgO	0.3	0.3
Al_2O_3	0.3	0.3
SiO_2	0.7	0.3
P_2O_5	0.1	0.2
SO_3	0.1	0.2
Cl	0.2	0.1
K_2O	0.4	0.1
CaO	0.3	0.1
TiO_2	0.1	0.1
MnO	0.1	0.1
Fe_2O_3	0.1	0.1
PbO	0.3	0.3
SrO*	0.02	0.02

Results

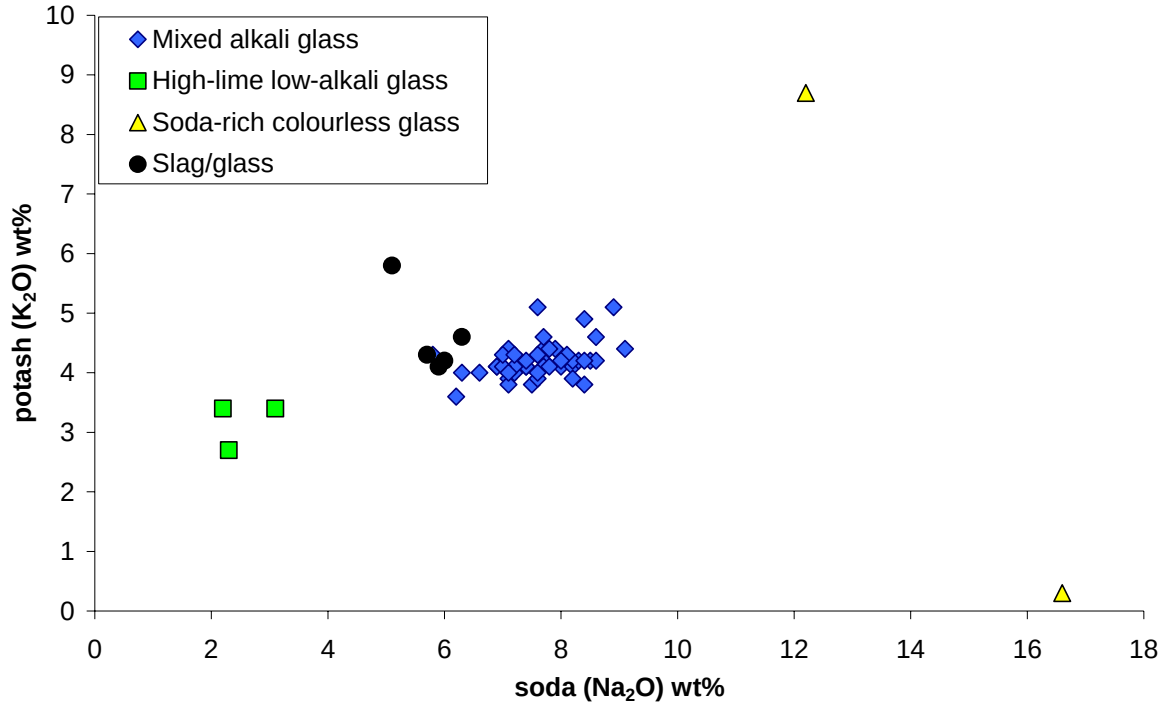

Figure 5. soda and potash content of the glass and glassworking samples

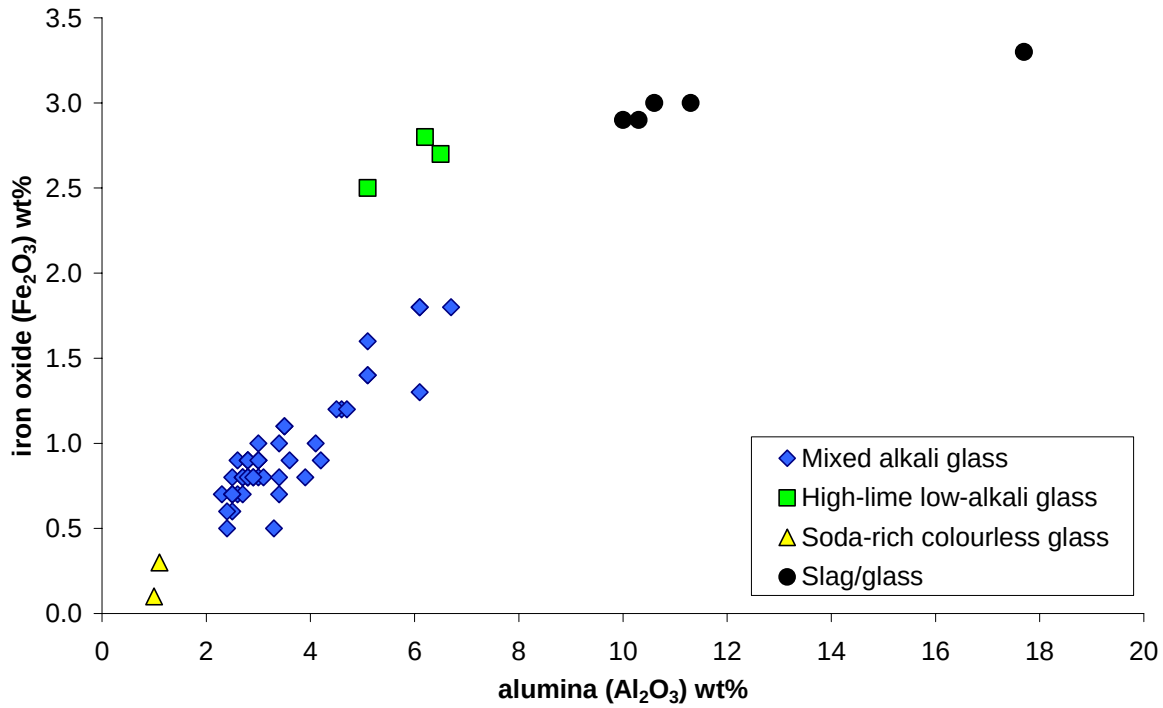

Figure 6. alumina and iron oxide content of the glass and glassworking samples

The 57 samples of glass and glassworking waste (the crucibles are examined separately, below) have been divided into groups depending on their chemical composition (figures 5–7). The largest group (47 examples) is a mixed alkali glass which contains moderate amounts of soda and potash. Five samples of glass/slag have high levels of alumina and iron oxide due to reactions with fuel ash and/or

crucibles. Three samples are of high-lime low-alkali glasses and two are soda-rich colourless glasses.

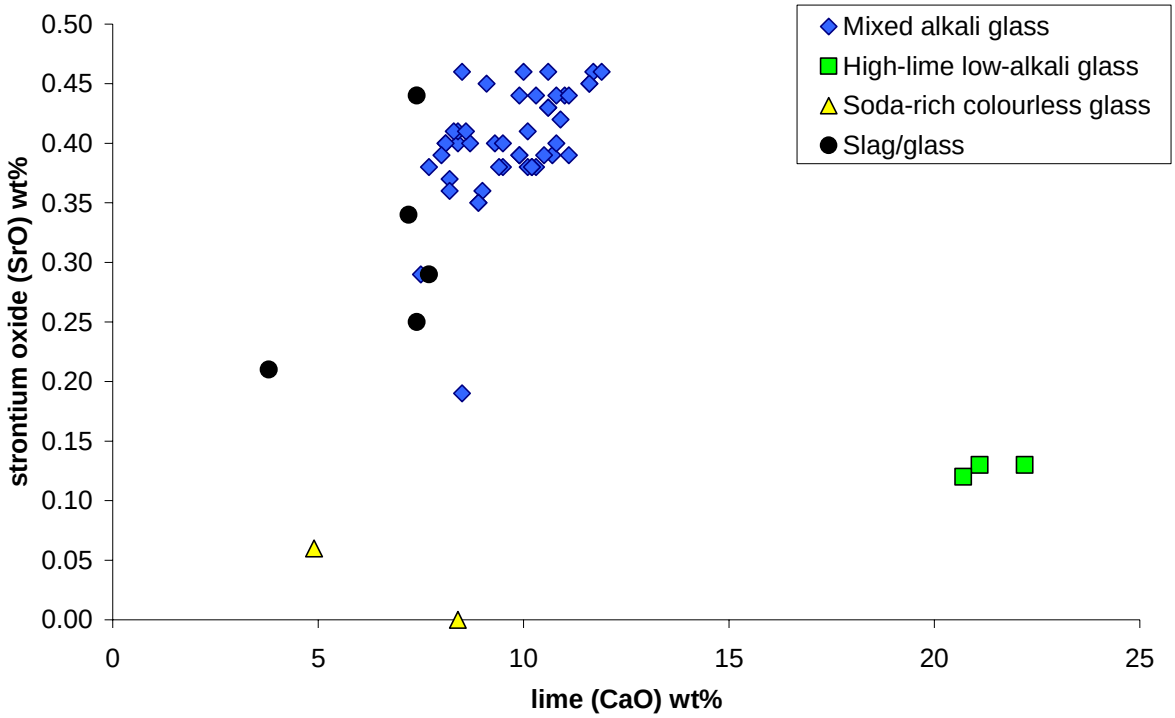

Figure 7. lime and strontium oxide content of the glass and glassworking samples

Mixed alkali glass

Most of the samples of glass and glassworking waste from Cheese Lane are pale green mixed alkali glasses. These glasses contains moderate levels of soda, potash and lime (table 3). A single sample of mixed alkali glassworking waste (sample 55) contained a small amount of lead oxide. The levels of lead oxide present (2.3%) is unlikely to have had any significant effect on the properties of the glass and the lead may have derived from the use of cullet containing some lead crystal glass.

Table 3. Average composition of mixed alkali glass from Cheese Lane compared with Silkstone

	Cheese Lane	Silkstone Phase 1	Silkstone Phase 2
Na_2O	7.6±0.7	8.3±0.4	6.9±0.4
MgO	5.3±0.5	5.5±0.3	2.9±0.1
Al_2O_3	3.5±1.1	3.1±0.1	1.4±0.3
SiO_2	67.0±1.3	62.7±0.2	68.2±2.1
P_2O_5	1.2±0.2	1.3±0.1	0.3±0.4
K_2O	4.2±0.3	5.9±0.1	6.7±0.1
CaO	9.7±1.2	9.3±0.2	10.6±0.1
TiO_2	0.1±0.1	0.2±0.0	<0.1
MnO	<0.1	0.4±0.0	1.0±0.1
Fe_2O_3	1.0±0.3	1.1±0.0	1.1±0.2
SrO	0.40±0.05	0.27±0.01	0.05±0.01
PbO	<0.3	1.4±0.1	<0.3

Mixed alkali glasses have compositions which are intermediate between ‘forest’ woodash glass (Mortimer in Welch 1997) and soda-lime glasses (Mortimer 1993a) made using saline plants (e.g. barilla). Mixed alkali glasses are virtually unknown until the 17th century. They have been recognised among the post-medieval glasses from Lincoln (Henderson 1998) and are known to have been produced at Silkstone *c*.1660–1680 (Dungworth 2003) and other sites in Yorkshire during the late 17th or early 18th centuries (Ashurst 1970 and 1987).

There are no significant differences in the compositions of the mixed alkali glasses from the Phases 2 and 3. It is likely that the same raw materials, recipe and techniques were used in both phases. The wide range of oxides present in the mixed alkali glass suggest the use of a plant ash as the flux. The relatively high levels of soda and strontium oxide (figures 5 and 7) may indicate the use of a marine plant. Kelp (a seaweed) ash was one of the materials used in bottle glass manufacture in Bristol during the 18th century (Berg & Berg 2001: 129) and it is probable that it was also used in the production of the mixed alkali at Cheese Lane. Some of the mixed alkali glass samples have slightly elevated iron oxide and alumina contents (figure 5); this is probably due to contamination from fuel ash and/or crucible. It is also notable that manganese was rarely present at detectable levels at Cheese Lane, whereas it was nearly always detectable at Silkstone. This suggests that no effort was made to de-colourise the Cheese Lane mixed alkali glass.

Mixed alkali glasses were used during the 17th and 18th centuries in the manufacture of drinking vessels and other forms of tableware, and probably correspond to the contemporary terms ‘ordinary’ or ‘white’ glass (‘crystal’ being reserved for soda or lead glasses).

Glass/Slag

Five samples have compositions which are similar to the mixed alkali glass discussed above but with significantly elevated alumina and iron oxide contents (figure 6). In most cases these samples are black or dark green. They are likely to have been mixed alkali glasses which became contaminated by reactions with fuel ash and/or crucibles.

High-lime low-alkali glass

Three samples (30, 38 and 48) of dark green glass are high in lime (>20% CaO), and low in alkalis (<4% K_2O or Na_2O), and so can be classified as high-lime, low-alkali or HLLA glasses (Mortimer 1991). They also have high iron contents (2.5–2.8% Fe_2O_3), which contributes to their dark green or 'black' colour. High-lime low-alkali glass was probably known by the contemporary term ‘green’ glass. It was introduced to England in the late 16th century (Dungworth & Clark 2004) and was initially used in the production of both window and vessel glass (Mortimer 1993b; Dungworth 2003; Paynter & Doonan 2003) but from the late 17th century onwards it was used primarily for the production of bottle glass. The three HLLA glass samples include at least one fragment of glassworking waste and it is likely that HLLA glass was produced at Cheese Lane, however, the small number of HLLA samples suggests that this type of glass was produced in smaller quantities compared to the mixed alkali glass. It is also possible that these HLLA sample derive from one of the neighbouring glassworking sites.

Soda-rich colourless glass

Two fragments of colourless glass (samples 22 and 31) are soda-rich glasses although one of these (sample 22) also has high levels of potash (8.6% K_2O). Sample 31 has very low levels of impurities (magnesia, alumina, iron oxide, etc) compared to other 17th and 18th century glasses. During the 19th century chemical processes (e.g. the Le Blanc process for the production of soda ash from salt) developed and allowed the use of fairly pure raw materials (cf. Hatton 2004). The composition of this sample is more typical of 19th century glass than 17th or 18th century glass and it may be intrusive in this context. There is no evidence that these soda-rich glasses were produced at Cheese Lane.

Crucibles

Four samples of crucible were examined; none of these fragments were large enough to show the full size and form. Nevertheless, the walls are vertical, 35–50mm thick and the largest fragment shows that the crucibles would have been at least 0.25m tall. None of the crucibles were of the closed type (Ashurst 1987: 184–188). The rim diameters are estimated to be approximately 1m. Thus, the Cheese Lane crucibles were slightly larger than contemporary crucibles used in Yorkshire (Ashurst 1970: 129–133; 1987: 183–190). The outer surfaces of these crucibles are black or dark red in colour due to the action of coal fumes (cf. Dungworth 2003): Analysis of the glass adhering to the inner surfaces of the crucibles (see below) shows that they were all used to melt mixed alkali glass.

Glass-Crucible interactions

Three samples of crucible with glass adhering to the inner surfaces were examined in detail. The SEM image (figure 8) shows the layer of adhering glass above and the ceramic fabric of the crucible below. The ceramic fabric of the crucible contains numerous silica grains (medium grey) and porosity (black) within a clay matrix (light grey). In order to examine the ways in which the glass and crucible had interacted a series of areas were analysed in a line perpendicular to the glass-crucible interface (figures 8–10). Some areas gave totals that were significantly less than 100% and measurements of porosity for the same areas (using image analysis software on the backscattered electron image) showed that the low totals were due to the porosity.

Magnesia, phosphorus oxide and lime are richer in the glass compared to the crucible fabric. The maximum values for these oxides are seen at the furthest distance from the crucible-glass interface (figure 9). These oxides decline rapidly through the adhering glass as the interface is approached and show no penetration into the ceramic fabric of the crucible.

Soda and potash are high in the glass and either absent or very low in the crucible fabric (figure 10). However, both of these alkalis (unlike magnesia, lime and phosphate) have penetrated into the crucible fabric. Alkalis are generally more reactive than alkali earths and so likely to have played an important role in the ways that glass attacked crucibles and eventually caused them to fail.

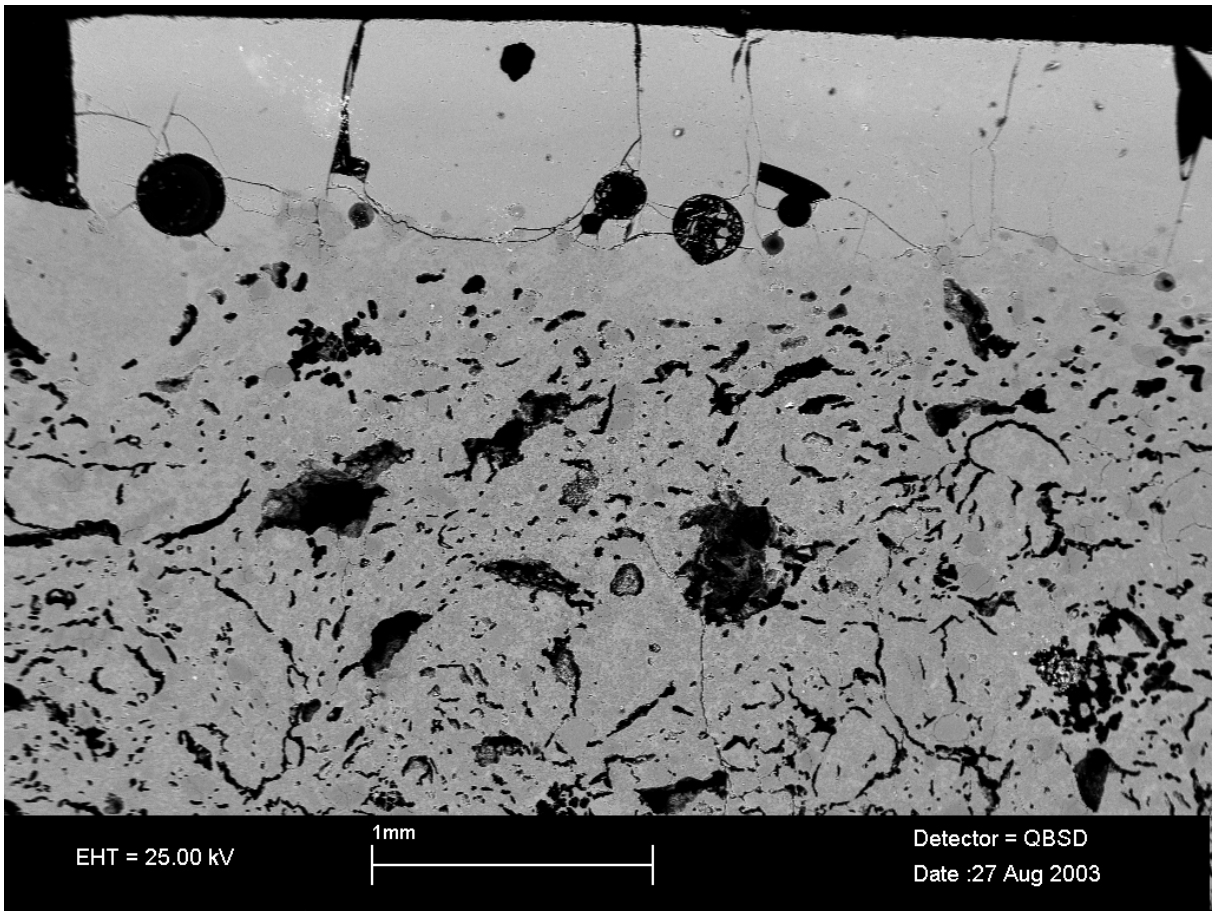

Figure 8. Back-scattered SEM image of a crucible (sample 18) showing the glass adhering to its inner surface at the top of the picture. Note the porosity (darker areas) within the glass and the ceramic fabric of the crucible below

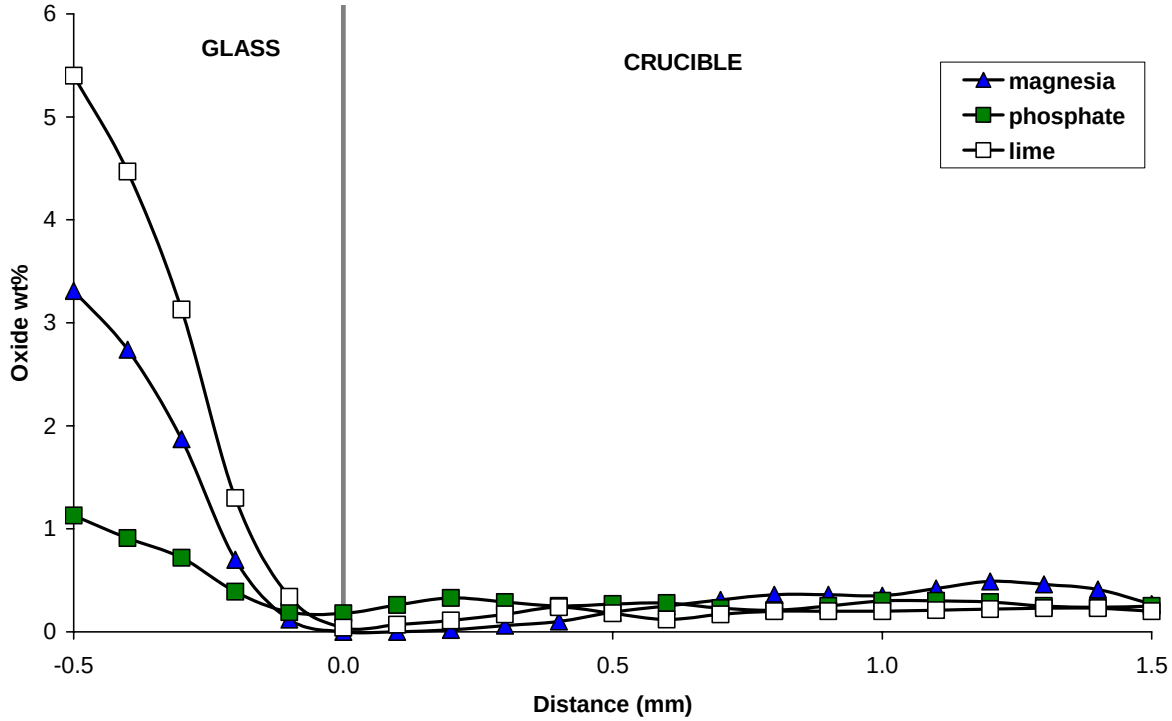

Figure 9. Analysis of the crucibles and adhering glass (magnesia, phosphorus oxide and lime). This figure is based on the average results for three samples (18, 19 and 20)

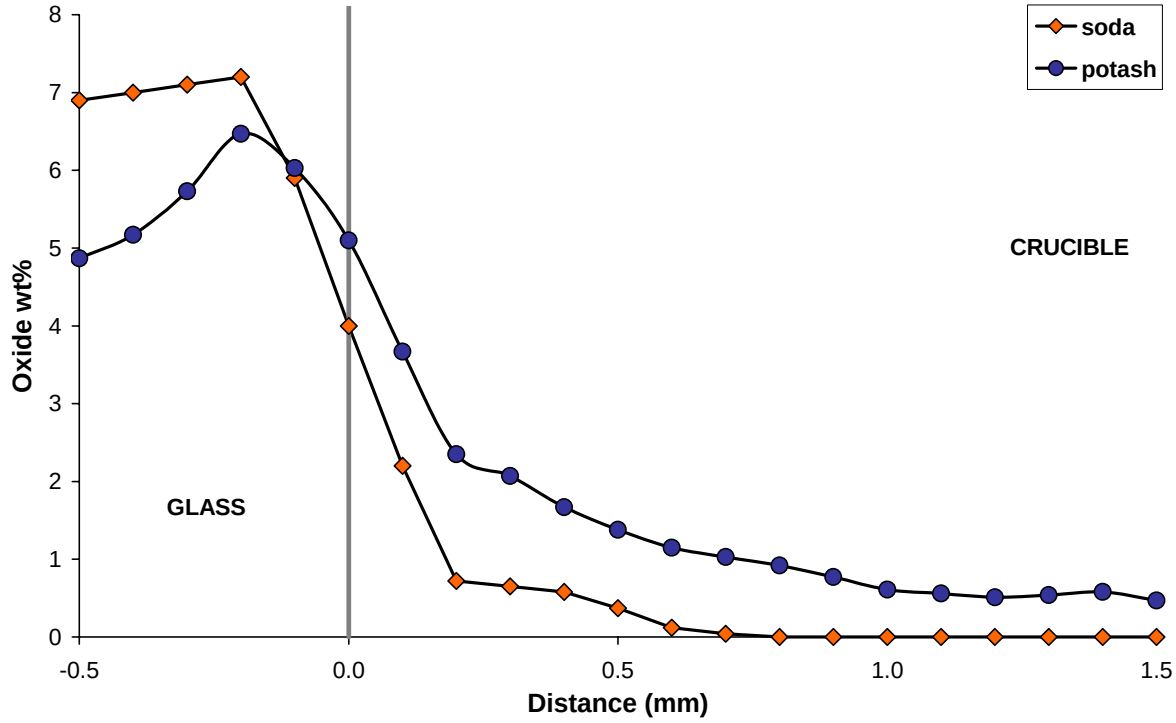

Figure 10. Analysis of the crucibles and adhering glass (soda and potash). This figure is based on the average results for three samples (18, 19 and 20)

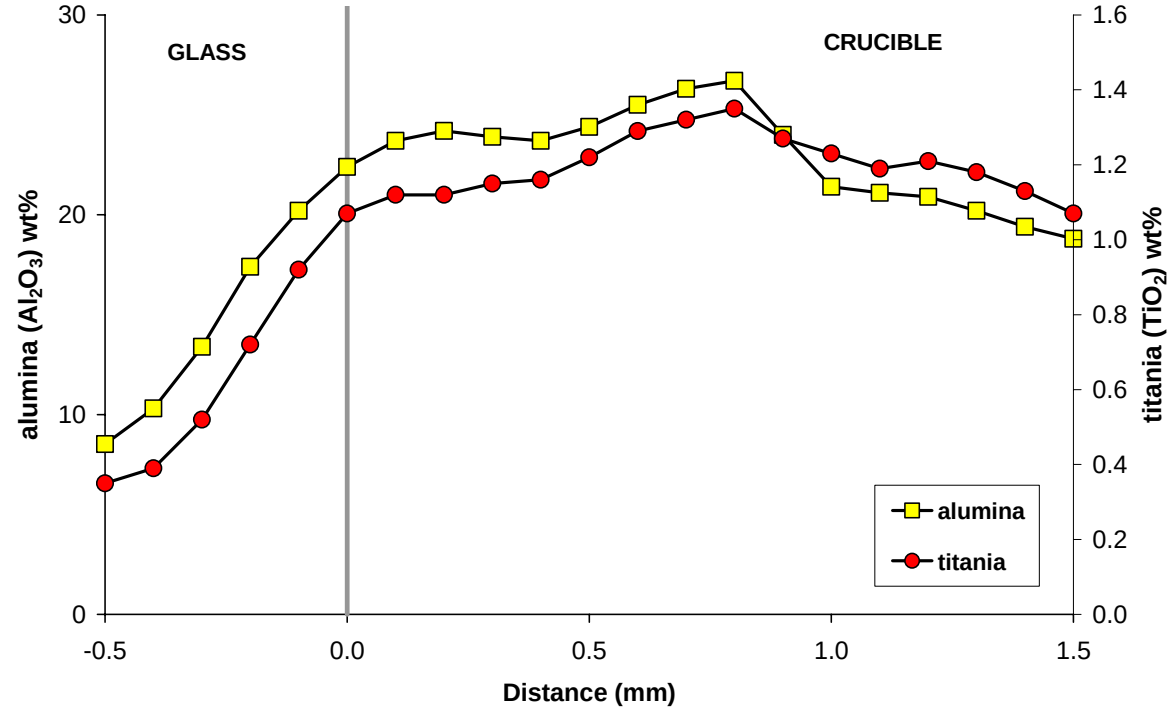

Figure 11. Analysis of the crucibles and adhering glass (alumina and titania). This figure is based on the average results for three samples (18, 19 and 20)

Alumina and titania are most abundant within the ceramic fabric of the crucible and show a decline in the adhering glass (figure 11). The crucible was clearly dissolving into the glass.

The composition of the glass adhering to the inner surface of the crucibles is not uniform but varies with distance from the interface between the glass and the crucible. This variation is due to reactions between the crucible and the glass. The alkalis in the glass have tended to react with the ceramic fabric of the crucible and have penetrated into the crucible (as much as 1mm). Similarly, the crucible has dissolved into the adhering glass and 'contaminated' it. Comparing the composition of the adhering glass (at 0.5mm from the interface) with the mixed alkali glassworking waste (table 4) suggests that the crucibles had been used to melt the mixed alkali glass. If the only the glass adhering to the crucibles had been analysed then a misleading picture of its composition would have been gained.

Table 4. Average composition of the mixed alkali glassworking waste, the composition of the glass adhering to the crucibles (at 0.5mm from the interface)

	Glassworking waste	Glass adhering to crucibles
Na_2O	7.6±0.7	6.9
MgO	5.3±0.5	3.3
Al_2O_3	3.5±1.1	8.5
SiO_2	67.0±1.3	68.5
P_2O_5	1.2±0.2	1.1
K_2O	4.2±0.3	4.9
CaO	9.7±1.2	5.4
TiO_2	0.1±0.1	0.4
Fe_2O_3	1.0±0.3	1.0

Ceramic fabric of the crucibles

Crucibles used for melting glass would be have to be made from suitable materials which could withstand the high temperatures required. The sources of clays used for the manufacture of glassmaking crucibles in the 17th and 18th centuries are not fully known. For a short period in the early 17th century, Mansell (who held a monopoly in glassmaking) had brought clay from Stourbridge to Newcastle but found it unsuitable. He claimed that glassmakers in Stourbridge had deliberately corrupted the clay and imported clay from France and Germany before eventually securing a local supply (Godfrey 1975: 88). Later in the 17th century, Merrett reports that clay for crucible manufacture was obtained from the Isle of Wight, Nonsuch (Surrey) and Worcester (Cable 2001: 245–246). The ceramic fabrics of the Cheese Lane crucibles were analysed and the results compared with examples from other post-medieval glasshouses.

The crucibles are rich in silica and alumina (figure 12); a composition that would be extremely refractory and well-suited to withstanding the temperatures required to manufacture glass (*c*.1200–1300°C). Such clays are readily available in most Coal Measures deposits, some of which outcrop within a few kilometres of Bristol.

A range of minor oxides, e.g. magnesia, potash, iron oxide and titania (figure 13), are also present in the crucibles. The levels of minor oxides in the Cheese Lane crucibles are broadly similar to those of the Bedminster crucibles (another Bristol glasshouse) but are slightly different to those from northern England (Silkstone, Bickerstaffe and Haughton Green) and London (Vauxhall). While the available data on the chemical composition of glassmaking crucibles of the period is extremely limited, there do

appear to be slight differences for different regions. This suggests that each glassmaking region made use of suitable local clays.

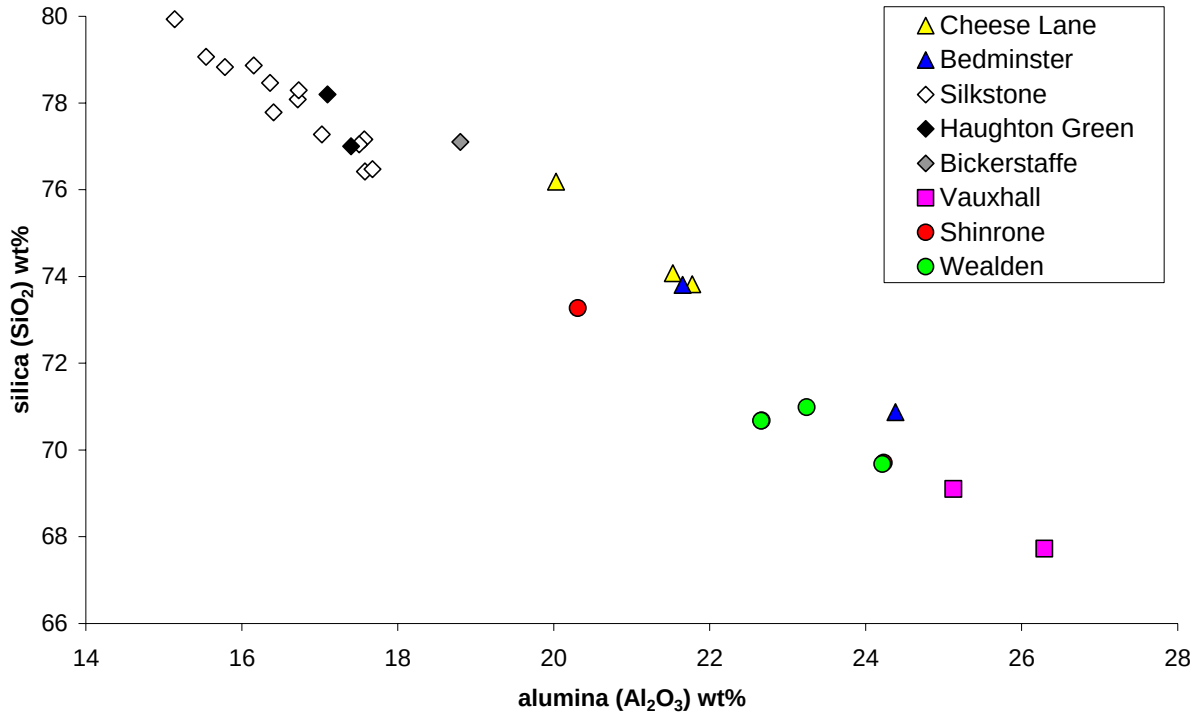

Figure 12. Alumina and silica content of crucibles from Cheese Lane compared to other 17th and 18th century glass houses. (Sources: Bedminster, Bristol [Blakelock et al*. forthcoming]; Silkstone, Yorkshire [Dungworth 2003], Haughton Green, Manchester [Vose 1994]; Bickerstaffe, Lancashire [Vose 1980]; Vauxhall, London [Tyler & Willmott forthcoming]; Shinrone, Ireland [O'Brien* et al*. forthcoming])*

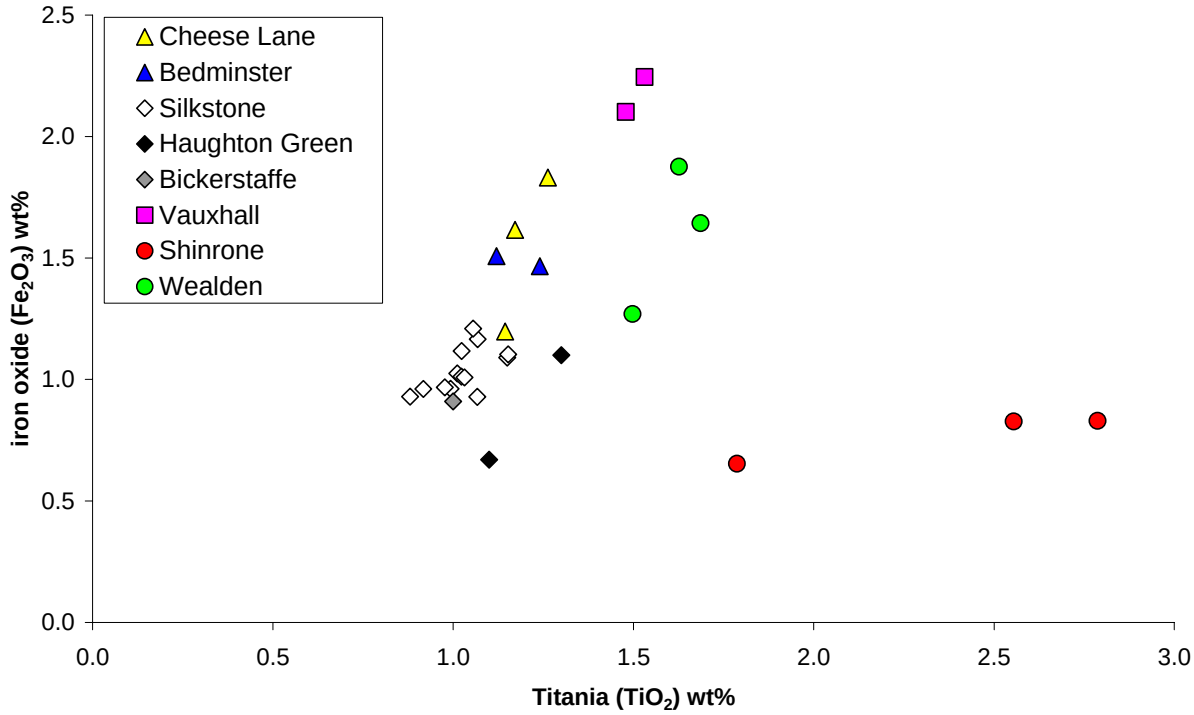

Figure 13. Titania and iron oxide content of crucibles from Cheese Lane compared to other 16th and 17th century glass houses. (Sources: see figure 11)

The most striking difference in crucible composition is between the English crucibles and those from the Shinrone glasshouse in Ireland. It is unfortunate that there are no readily available data on the chemical composition of glassmaking crucibles from continental Europe with which these data could be compared.

Conclusions

The chemical analyses of the glassworking wastes has shown that the most important type of glass manufactured was a mixed alkali glass. This is broadly similar to the mixed alkali glass manufactured at Silkstone, Yorkshire, *c*.1660–1680. Mixed alkali glasses were manufactured with raw materials which contained relatively low levels of iron oxide compared to the high-lime low-alkali glasses used for bottle manufacture. They were probably known by the contemporary terms ‘ordinary’ or ‘white’ glass (the terms ‘flint’ and ‘crystal’ were reserved for soda or lead glasses, made using more expensive ingredients). Mixed alkali glass was used to produce vessel glass such as drinking glasses. At Silkstone the production of mixed alkali glass was abandoned *c*.1680, and replaced with colourless lead glass. The evidence from Cheese Lane appears to show that the invention of colourless lead glass did not lead to the complete abandonment of mixed alkali glass. It is possible that soda-lime and high-lime low-alkali glasses were also produced at Cheese Lane, however, the number of samples with these compositions is very low.

The analyses of the crucibles and glass adhering to them shows that such samples indicate the type(s) of glass manufactured but that such samples tend to be contaminated due to the reactions which occurred between the glass and the crucible.

References

Ashurst, D 1970 ‘Excavations at Gawber Glasshouse’ *Post Medieval Archaeology* **4**, 92–140

Ashurst, D 1987 ‘Excavations at 17th–18th century Glasshouse at Bolsterstone and the 18th century Bolsterstone Pothouse, Stockbridge, Yorkshire’ *Post Medieval Archaeology* **21**, 147–226

Berg, T & Berg, P 2001 *R R Angerstein’s Illustrated Travel Diary, 1753–1755*. London: Science Museum

Blakelock, E, Dungworth, D & Paynter, S forthcoming Analysis of glass and glassworking debris from the Bedminster Glue factory site, Bristol. Centre for Archaeology Report. London: English Heritage

Cox, G A & Pollard, A M 1977 ‘X–ray fluorescence analysis of ancient glass: the importance of sample preparation’ *Archaeometry* **19**, 45–54

Dungworth, D B 2003 Scientific examination of glass and glassworking materials from Silkstone, Yorkshire. Centre for Archaeology Report 90/2003

Dungworth, D B & Clark, C 2004 SEM-EDS analysis of Wealden Glass. Centre for Archaeology Report 54/2004. London: English Heritage

Godfrey, E 1975 *The Development of English Glassmaking, 1560–1640*. Chapel Hill: University of North Carolina Press

Gurney, D R 1956 *From Broad-Glass to Cut Crystal*. Lodnon: Leonard Hill

Hatton, G 2004 Scientific examination of glass and glass working materials from Nailsea, Avon. Centre for Archaeology Report. London: English Heritage

Henderson, J 1998 ‘Post-Medieval glass: production, characterisation and value’ in P McCray (Ed) *The Prehistory and History of Glassmaking Technology*. Westerville, Ohio: American Ceramic Society, 33–59

Mortimer, C 1991 Analysis of Medieval and Post Medieval glass from the City of London. Ancient Monuments Laboratory Report 135/1991. London: English Heritage

Mortimer, C 1993a Analysis of Post Medieval glass and glassworking debris from Old Broad Street, City of London. Ancient Monuments Laboratory Report 52/1993. London: English Heritage

Mortimer, C 1993b Analysis of window glass from Chastleton House, Oxfordshire. Ancient Monuments Laboratory Report 117/1993. London: English Heritage

O’Brien, C, Farrelly, J & Paynter, S forthcoming The 17th century glasshouse at Shinrone, Co. Offaly, Ireland. Centre for Archaeology Report. London: English Heritage.

Paynter, S & Doonan, R 2003 ‘Analysis of the window glass’ in A Hardy, A Dodd & G Keevil (Eds) *Aelfric's Abbey: Excavations at Eynsham Abbey, Oxfordshire 1989–92*. Oxford: Oxford Archaeology, 541–547

Tyler, K & Willmott, H forthcoming *Excavations at John Baker's Vauxhall Glasshouse*. London: Museum of London

Vose, R H 1980 *Glass*. London: Collins

Vose, R H 1994 ‘Excavations at the 17th-century glasshouse at Haughton Green, Denton, near Manchester’ *Post-Medieval Archaeology* **28**, 1–71

Welch, C M 1997 ‘Glass-making in Wolseley, Staffordshire’ *Post-Medieval Archaeology* **31**, 1–60

Witt, C, Weeden, C & Schwind, AP 1984 *Bristol Glass*. Bristol Redcliffe Press

Appendix

Chemical composition of glass and glassworking waste from Cheese Lane

ID = sample number

ID	Context	Phase	Description	Colour	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	Cl	K_2O	CaO	TiO_2	MnO	Fe_2O_3	PbO	SrO	Total
1	1597	2C	Fragment	Pale green	8.1	5.9	2.8	67.6	1.2	0.2	0.4	4.3	9.4	nd	nd	0.9	nd	0.38	101.2
2a	1597	2C	Fragment	Pale green	8.2	5.6	2.8	65.8	1.2	0.2	0.3	4.2	10.1	0.2	nd	0.8	nd	0.38	99.8
2b	1597	2C	Fragment	Pale green	8.6	5.9	2.7	65.8	1.1	0.3	0.4	4.2	10.2	0.2	nd	0.8	nd	0.38	100.7
3	1597	2C	Fragment	Pale green	8.0	6.0	2.8	66.0	1.1	0.3	0.3	4.2	9.3	0.1	nd	0.9	nd	0.40	99.4
4	1597	2C	Thread	Green	6.2	6.4	3.0	67.9	1.2	0.3	0.2	3.6	10.2	nd	nd	1.0	nd	0.38	100.0
6	1222	3	Bubbly chunk	Black	5.7	4.0	10.0	64.7	1.1	nd	0.1	4.3	7.4	0.4	nd	2.9	nd	0.25	100.9
7	1222	3	Stretched fragment	Dark green	6.0	3.9	10.6	63.7	1.2	nd	0.2	4.2	7.2	0.4	nd	3.0	nd	0.34	100.8
8	1222	3	Chunk	Green	7.0	5.0	5.1	68.1	1.3	nd	0.3	4.1	8.1	0.2	nd	1.4	nd	0.40	100.8
9	1471	2C	Fragment	Pale green	7.9	4.8	3.0	68.1	1.0	nd	0.3	4.4	9.9	nd	0.1	0.9	nd	0.44	100.9
10	1223	3	Chunk	Blue green	5.9	3.9	10.3	64.9	1.0	nd	0.2	4.1	7.4	0.3	nd	2.9	nd	0.44	101.4
11	1223	3	Chunk	Dark green	7.1	4.9	2.6	69.0	0.9	0.2	0.4	3.9	10.9	nd	nd	0.7	nd	0.42	101.0
12a	1223	3	Thread	Green	6.9	5.0	4.7	67.8	1.3	0.2	0.4	4.1	8.4	0.3	nd	1.2	nd	0.41	100.7
12b	1223	3	Thread	Green	5.8	5.0	6.1	67.5	1.2	nd	0.2	4.3	8.3	0.3	nd	1.8	nd	0.41	101.0
12c	1223	3	Thread	Green	6.3	4.8	6.7	66.2	1.1	0.2	0.2	4.0	8.6	0.3	nd	1.8	nd	0.41	100.8
13	1223	3	Chunk	Dark green	6.3	3.7	11.3	62.6	1.1	nd	0.1	4.6	7.7	0.5	nd	3.0	nd	0.29	101.2
14	1223	3	Chunk	Pale green	6.6	4.7	5.1	67.2	1.4	nd	0.3	4.0	8.4	0.2	nd	1.4	nd	0.40	99.7
15	1223	3	Chunk	Green	7.0	5.2	4.6	68.3	1.4	nd	0.3	4.1	8.1	0.1	nd	1.2	nd	0.40	100.7
17	1223	3	Chunk	Pale green	7.7	5.5	2.5	68.9	1.4	0.3	0.4	4.1	9.1	nd	nd	0.8	nd	0.45	101.2
22	1268	2B	Fragment	Colourless	12.2	1.8	1.1	69.3	0.4	0.4	0.6	8.7	4.9	0.2	0.1	0.3	nd	0.06	99.9
23	1112	3	Fragment	Pale green	7.1	4.8	3.9	68.1	0.8	0.2	0.4	3.8	11.1	0.2	nd	0.8	nd	0.39	101.4
24	1112	3	Fragment	Pale green	7.0	4.6	5.1	67.7	1.2	nd	0.2	4.3	8.0	nd	nd	1.6	nd	0.39	100.1
25	1112	3	Fragment	Pale green	7.4	4.8	2.5	67.9	1.1	0.2	0.4	4.1	10.8	0.1	nd	0.7	nd	0.44	100.4
26	1112	3	Fragment	Pale green	7.4	4.7	2.5	67.5	1.3	0.3	0.3	4.1	11.0	nd	nd	0.7	nd	0.44	100.3
27	1112	3	Fragment	Pale green	8.2	5.0	3.4	67.2	1.0	0.3	0.4	3.9	10.6	nd	0.1	0.8	nd	0.43	101.2
28	1112	3	Fragment	Green	7.7	5.0	3.1	67.1	1.2	0.2	0.3	4.6	10.6	nd	nd	0.8	nd	0.46	101.1
29	1112	3	Moil	Pale green	7.2	5.1	4.5	68.7	1.2	nd	0.4	4.1	8.5	0.2	nd	1.2	nd	0.19	101.1
30	1112	3	Bottle fragment	Dark green	2.3	3.5	5.1	60.8	1.2	nd	0.3	2.7	22.2	0.2	nd	2.5	nd	0.13	100.8
31	1112	3	Fragment	Colourless	16.6	nd	1.0	73.8	nd	0.3	nd	0.3	8.4	nd	nd	0.1	nd	nd	100.5
32a	1360	2C	Thread	Pale green	7.8	5.1	3.3	65.1	1.2	0.2	0.3	4.4	11.1	nd	nd	0.5	nd	0.44	100.0
32b	1360	2C	Thread	Pale green	7.4	4.9	2.9	67.3	1.0	0.2	0.3	4.2	10.3	nd	nd	0.8	nd	0.44	99.7

ID	Context	Phase	Description	Colour	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	Cl	K_2O	CaO	TiO_2	MnO	Fe_2O_3	PbO	SrO	Total
33	1360	2C	Moil	Pale green	7.7	5.5	3.0	65.9	1.1	0.3	0.4	4.4	11.9	0.1	nd	0.9	nd	0.46	101.5
34	1360	2C	Chunk	Pale green	7.6	4.9	2.4	65.1	1.2	0.3	0.4	5.1	11.6	0.1	nd	0.5	nd	0.45	100.2
35	1360	2C	Chunk	Pale green	8.5	6.5	2.5	65.4	1.5	0.5	0.3	4.2	9.5	0.1	nd	0.7	nd	0.38	100.1
36	1360	2C	Chunk	Pale green	8.6	5.8	2.6	66.1	1.3	0.3	0.3	4.6	8.7	0.1	nd	0.9	nd	0.40	100.2
37	1514	2C	Moil	Pale green	8.2	5.8	2.7	65.5	1.2	0.3	0.4	4.1	10.5	nd	nd	0.8	nd	0.39	99.9
38	1514	2C	Chunk	Dark green	3.1	4.7	6.2	58.0	1.1	0.3	0.2	3.4	21.1	0.3	0.4	2.8	nd	0.13	101.8
39	1093	2B	Chunk	Pale green	7.1	5.1	2.3	67.6	1.2	0.2	0.3	4.4	11.7	0.2	0.1	0.7	nd	0.46	101.4
40	1093	2B	Chunk	Pale green	8.9	6.0	3.0	64.4	1.5	0.2	0.4	5.1	8.5	0.2	nd	0.8	nd	0.46	99.4
41	1529	2B	Off-cut	Green	8.4	5.5	3.0	68.5	1.1	0.2	0.3	4.2	8.2	0.2	nd	0.9	nd	0.36	100.8
42	1529	2B	Off-cut	Green	8.3	5.6	2.8	67.9	1.0	nd	0.3	4.2	8.2	0.2	nd	0.9	nd	0.37	99.8
43	1529	2B	Fragment	Green	7.5	5.9	2.8	68.2	1.2	nd	0.4	3.8	8.9	nd	0.1	0.8	nd	0.35	99.9
44	1529	2B	Off-cut	Green	7.6	5.9	2.8	69.6	1.3	0.2	0.4	3.9	8.9	0.2	nd	0.8	nd	0.35	101.7
45	1514	2C	Folded fragment	Pale green	9.1	5.8	2.9	65.2	1.4	0.3	0.3	4.4	10.1	nd	nd	0.8	nd	0.41	101.2
46	1514	2C	Chunk	Pale green	8.0	6.1	2.7	65.7	1.3	0.2	0.4	4.1	10.3	0.1	nd	0.7	nd	0.38	100.0
47	1514	2C	Thread (bubbly)	Pale green	7.6	5.2	4.1	65.7	1.2	nd	0.2	4.0	10.0	0.2	nd	1.0	nd	0.46	99.7
48	1514	2C	Thread (handle?)	Dark green	2.2	4.3	6.5	57.4	1.0	0.2	0.3	3.4	20.7	0.3	0.2	2.7	nd	0.12	99.4
49	1065	3	Fragment	Blue-green	8.4	5.4	3.4	67.2	1.2	0.2	0.3	3.8	9.0	0.2	nd	1.0	nd	0.36	100.4
50	1118	3	Bubbly chunk	Pale green	7.2	4.8	4.2	67.2	1.1	nd	0.4	4.0	10.8	0.2	nd	0.9	nd	0.40	101.3
51	1118	3	Bubbly chunk	Pale green	7.8	4.5	3.5	66.1	1.0	0.3	0.3	4.1	9.9	nd	nd	1.1	nd	0.39	99.0
52	1497	3	Chunk	Black	5.1	2.1	17.7	61.5	0.7	nd	nd	5.8	3.8	0.8	nd	3.3	nd	0.21	100.9
53	1245	3	Bubbly chunk	Green	7.2	4.7	6.1	67.4	1.3	nd	0.3	4.3	7.7	0.2	nd	1.8	nd	0.38	101.2
54	1245	3	Thread	Pale green	7.7	6.0	2.4	66.0	1.3	0.3	0.3	4.2	9.5	0.1	nd	0.6	nd	0.40	99.5
55	1237	3	Chunk	Pale green	8.4	5.1	3.5	64.4	1.4	nd	0.4	4.9	7.5	0.3	nd	1.1	2.3	0.29	100.2
56	1112	3	Chunk	Green	7.1	4.6	6.1	65.8	1.1	nd	0.2	4.0	9.9	0.2	nd	1.3	nd	0.39	100.7
57	1112	3	Chunk	Pale green	7.3	5.1	2.5	67.3	1.1	0.2	0.3	4.2	11.6	nd	nd	0.6	nd	0.45	100.7
58	1112	3	Bubbly chunk	Pale green	6.9	4.9	3.6	67.2	0.9	nd	0.3	4.1	10.7	nd	nd	0.9	nd	0.39	100.0
59	1112	3	Folded fragment	Pale green	7.6	5.1	3.4	67.6	1.0	nd	0.4	4.3	10.6	nd	nd	0.7	nd	0.43	101.1

Chemical analysis of crucibles and adhering glass from Cheese Lane

ID	Context	Phase	Description	Na2O	MgO	Al2O3	SiO2	P2O5	SO3	Cl	K2O	CaO	TiO2	MnO	Fe2O3	PbO	SrO	Total
16	1223	3	Crucible outer surface	3.7	1.4	17.4	63.9	0.3	nd	nd	4.9	3.2	0.7	nd	4.0	nd	0.16	99.8

ID	Context	Phase	Description	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	Cl	K_2O	CaO	TiO_2	MnO	Fe_2O_3	PbO	Total
18	1225	3	0–300µ	6.0	5.6	4.6	69.8	1.3	0.3	0.1	3.5	8.7	0.3	nd	1.0	nd	101.0
18	1225	3	300–600µ	6.5	2.6	9.8	70.2	0.9	nd	0.2	5.0	4.1	0.3	nd	0.7	nd	100.6
18	1225	3	600–900µ	7.1	nd	19.4	59.5	0.2	nd	0.2	6.2	0.2	0.9	nd	0.2	nd	94.0
18	1225	3	900–1200µ	0.6	nd	25.2	58.6	0.3	nd	nd	1.7	nd	1.1	nd	0.8	nd	88.3
18	1225	3	1200–1500µ	0.6	0.3	21.6	65.2	0.2	nd	nd	1.2	nd	1.1	nd	1.3	nd	91.6
18	1225	3	1500–1800µ	nd	0.3	17.3	46.7	nd	nd	nd	0.6	0.1	0.8	nd	0.9	nd	66.8
18	1225	3	1800–2100µ	nd	0.3	20.5	73.1	0.2	nd	nd	0.7	0.1	1.0	nd	1.2	nd	97.1
18	1225	3	2100–2400µ	nd	nd	12.2	52.7	nd	nd	nd	0.4	0.1	0.8	nd	0.8	nd	67.2
18	1225	3	2400–2700µ	nd	nd	10.4	78.9	0.2	nd	nd	0.3	nd	0.9	nd	0.8	nd	91.6

ID	Context	Phase	Description	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	Cl	K_2O	CaO	TiO_2	MnO	Fe_2O_3	PbO	Total
19	1225	3	0–200µ	7.2	4.0	7.5	63.1	1.2	nd	0.1	4.8	5.8	0.4	nd	1.2	nd	95.2
19	1225	3	200–400µ	7.3	3.2	9.5	63.0	0.9	nd	0.1	5.3	4.6	0.4	nd	1.0	nd	95.2
19	1225	3	400–600µ	7.1	0.7	17.2	59.1	0.4	nd	0.1	6.9	0.9	0.7	nd	0.6	nd	93.7
19	1225	3	600–800µ	3.0	nd	15.0	66.8	0.2	nd	nd	4.9	nd	0.9	nd	0.2	nd	91.0
19	1225	3	800–1000µ	nd	nd	11.2	65.3	0.2	0.5	nd	1.4	0.3	0.6	nd	0.3	nd	79.8
19	1225	3	1000–1200µ	nd	nd	16.4	75.2	0.2	nd	nd	0.9	0.7	0.9	nd	0.9	nd	95.2
19	1225	3	1200–1400µ	nd	0.4	22.9	61.5	0.4	nd	nd	0.7	0.2	1.2	nd	1.4	nd	88.6
19	1225	3	1400–1600µ	nd	0.3	24.1	60.7	0.2	nd	nd	0.9	0.2	1.4	nd	1.6	nd	89.6
19	1225	3	1600–1800µ	nd	0.3	18.9	66.4	0.3	nd	nd	0.5	0.2	1.2	nd	1.4	nd	89.1
19	1225	3	1800–2000µ	nd	0.8	23.6	66.9	0.3	nd	nd	0.3	0.3	1.4	nd	3.1	nd	96.6
19	1225	3	2000–2200µ	nd	nd	14.5	73.6	0.4	nd	nd	0.2	0.2	0.9	nd	1.0	nd	90.6
19	1225	3	2200–2400µ	nd	nd	16.1	74.7	0.3	nd	nd	0.2	0.3	0.9	nd	1.2	nd	93.7
19	1225	3	2400–2600µ	nd	0.4	25.6	54.8	0.3	nd	nd	0.4	0.3	1.4	nd	1.8	nd	84.9

ID	Context	Phase	Description	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	Cl	K_2O	CaO	TiO_2	MnO	Fe_2O_3	PbO	Total
20	1225	3	0–200µ	6.7	2.8	9.1	68.9	1.0	nd	0.2	4.6	5.1	0.3	nd	1.0	nd	99.7
20	1225	3	200–300µ	6.6	2.1	11.7	68.2	0.9	nd	0.2	5.1	3.7	0.4	nd	1.1	nd	100.0
20	1225	3	300–400µ	6.6	nd	18.6	66.4	nd	nd	0.1	6.0	0.5	0.8	nd	0.6	nd	99.6
20	1225	3	400–600µ	4.8	nd	26.1	62.2	nd	nd	0.1	5.6	nd	1.1	nd	0.3	nd	100.2
20	1225	3	600–800µ	1.4	nd	29.9	60.0	0.4	nd	nd	3.5	nd	1.3	nd	0.8	nd	97.4
20	1225	3	800–1000µ	1.1	nd	29.4	63.7	0.2	nd	nd	2.7	nd	1.3	nd	1.3	nd	99.6
20	1225	3	1000–1200µ	nd	nd	24.4	65.4	0.2	nd	nd	1.4	nd	1.2	nd	1.4	nd	94.1
20	1225	3	1200–1400µ	nd	0.4	28.3	68.2	0.3	nd	nd	1.0	0.1	1.3	nd	1.8	nd	101.5
20	1225	3	1400–1600µ	nd	0.3	20.2	72.6	0.3	nd	nd	0.5	0.2	1.1	nd	1.3	nd	96.7
20	1225	3	1600–1800µ	nd	0.3	18.3	75.1	0.4	nd	nd	0.5	0.2	1.1	nd	1.3	nd	97.2
20	1225	3	1800–2000µ	nd	0.9	23.3	63.4	0.2	nd	nd	0.9	0.3	1.2	nd	1.9	nd	92.1
20	1225	3	2000–2200µ	nd	0.3	24.3	71.2	0.3	nd	nd	0.5	0.2	1.0	nd	1.7	nd	99.5
20	1225	3	2200–2400µ	nd	0.3	18.6	78.6	0.3	nd	nd	0.3	0.1	1.0	nd	1.3	nd	100.7
20	1225	3	2400–2600µ	nd	0.4	20.6	71.5	0.3	nd	nd	0.9	0.3	1.4	nd	1.8	nd	97.1