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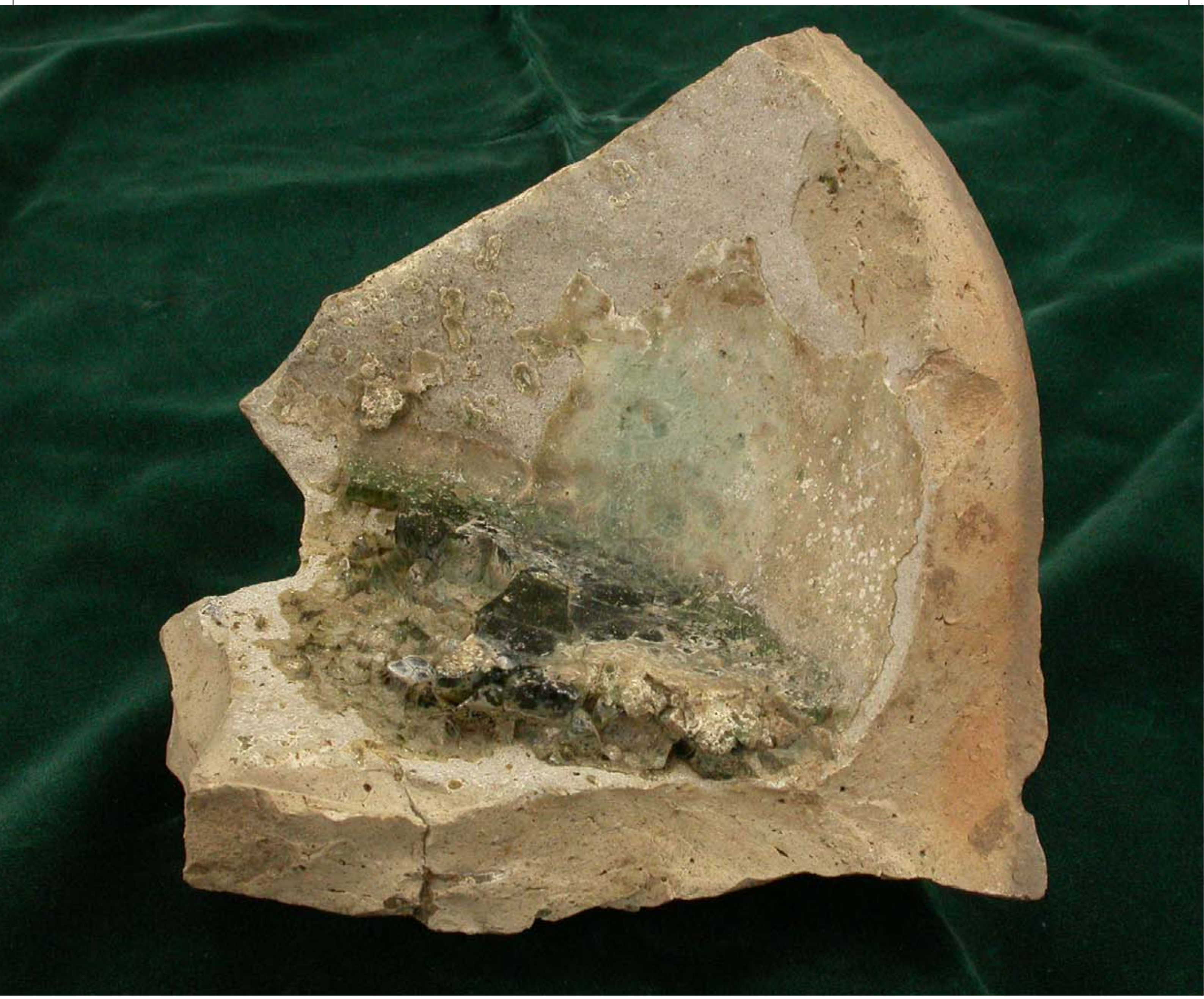
NEWENT GLASSHOUSE, NEWENT, GLOUCESTERSHIRE
EXAMINATION OF GLASS AND GLASSWORKING WASTE

TECHNOLOGY REPORT

David Dungworth



ARCHAEOLOGICAL SCIENCE

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EXAMINATION OF GLASS AND GLASSWORKING WASTE

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SUMMARY
The chemical analysis of an assemblage of glass artefacts and glassworking debris (including crucibles) has provided information on glass manufacturing technology at the beginning of the 17th century. The Glasshouse at Newent was one of the last to have been fuelled with wood. An examination of the chemical composition of the exterior surfaces of the crucibles confirms that they were heated in a wood-fuelled furnace. The glassworking debris indicates the production of a high-lime low-alkali (HLLA) glass of composition similar to that produced both in other forest regions (the Weald and Staffordshire) as well as in early coal-fired furnaces. The compositional similarities between HLLA glass produced in wood- and coal-fuelled furnaces suggest that both employed similar strategies to obtain fluxes for glassmaking. These results cast some doubt on the idea that 'forest' glassmakers used the ash from the wood fuel as a flux.

ACKNOWLEDGEMENTS
I would like to thank Sue Byrne of Gloucester City Museum and Art Gallery and Don Sherratt of Green Croft Farm, Taynton who provided the samples that are reported on here.

ARCHIVE LOCATION
The glass artefacts and working waste are located at Gloucester City Museum, Brunswick Road, Gloucester GL1 1HP.

DATE OF RESEARCH
2004–2009

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INTRODUCTION

The glasshouse at Newent was one of the last of the so-called 'forest' glasshouses. Glass had been produced in some forested regions of England from the 14th century onwards: in particular the Weald and Staffordshire (Godfrey 1975; Kenyon 1967; Linford and Welch 2004; Pape 1934). In the late 16th century the industry developed rapidly with the arrival of glassmakers from continental Europe. The first of these new glassmakers established themselves in the Weald in 1567 but by the 1580s members of this community had begun to spread to other parts of Britain.

Parish records show that French glassmakers (Tysacks, Pilneys, Voydens and Liscourts) had set up a glasshouse at Newent in Gloucestershire by 1599 (Pape 1934; Vince 1977). In 1607 Abraham Liscourt was paying ten pounds rent for the glasshouse. All of the forest glassmakers employed furnaces that used wood as their fuel but the situation changed in 1615 when the use of wood for firing glass furnaces was banned and a patent was granted to Robert Mansell allowing him exclusive rights to the production of glass using coal fuel (Godfrey 1975). Abraham Liscourt was one of the glassmakers who petitioned Parliament in 1621 (Godfrey 1975, 62). In his submission Liscourt claimed to have used coal, but Godfrey shows that these claims were false. There are some suggestions that glassmaking may have continued at Newent following the ban on the use of wood fuel. In his 1634 will, John Bulnoys, 'glassmaker of Newent', bequeathed his moulds and tools to his eldest son (Vince 1977). The marriage of a glassmaker (John Gulney) in Newent is recorded in 1638. In 1640 a Widow Davis rented the site of the glasshouse but the low rent (only one pound) suggests that it was no longer in use (Vince 1977).

THE GLASS AND GLASSWORKING WASTE

The material examined includes both glass and glassworking waste, most of which was collected during fieldwalking in 1968 (Vince 1977). The collected material includes 21 fragments of working waste, such as moils, dribbles and offcuts, as well as 25 fragments of vessels and nine window glass fragments. In addition to the glass and glassworking waste, five fragments of crucible were provided by local farmer, Don Sherratt (see Appendix 1). The glass vessels include plain pedestal beakers and cylindrical beakers with thin-cut trailing and applied rigaree-decorated base-ring. Body fragments are mostly plain but examples with optic-blown wrythen decoration are also present. The types of vessel and their decoration are consistent with manufacture from the late 16th century to early 17th century (Willmott 2002). The window glass comprised small fragments, 2–3mm in thickness, but too small to indicate whether it was crown or broad glass.

METHODS

All of the fragments of glass and glassworking debris were mounted in epoxy resin and ground and polished to a 3-micron finish to expose a cross-section through the glass. The samples were inspected using an optical microscope (brightfield and darkfield illumination) to identify corroded and uncorroded regions. The samples were analysed using two techniques to determine chemical composition: SEM-EDS and EDXRF. The energy dispersive X-ray spectrometer (EDS) attached to a scanning electron microscope (SEM) provided accurate analyses of a range of elements while the EDXRF spectrometer provided improved sensitivity and accuracy for some minor elements. The SEM used was a FEI Inspect F which was operated at 25kV with a beam current of approximately 1.2nA. The X-ray photons generated by the electron beam were detected using an Oxford Instruments X-act SDD detector. The quantification of detected elements was achieved using the Oxford Instruments INCA software. The EDS spectra were calibrated (optimised) using a cobalt standard. Deconvolution of the X-ray spectra and quantification of elements was improved by profile optimisation and element standardisation using pure elements and compounds (MAC standards). The chemical composition of the samples is presented in this report as stoichiometric oxides with oxide weight percent concentrations based on likely valence states (the exception being chlorine which is expressed as element wt%). The accuracy of the quantification of all oxides was checked by analysing a wide range reference materials (Corning, NIST, DGG and Newton/Pilkington). The data have been normalized to 100wt%. Table 1 gives values for the detection limits, accuracy and precision of the reported data (data in Appendices 2–7).

Table 1. Detection limits (MDL) and errors for each element or oxide (wt%)

	SEM-EDS		EDXRF	
	MDL	Error	MDL	Error
Na_2O	0.05	0.1		
MgO	0.05	0.05		
Al_2O_3	0.05	0.2		
SiO_2		0.2		
P_2O_5	0.1	0.02		
SO_3	0.1	0.02		
Cl	0.1	0.01		
K_2O	0.05	0.1		
CaO	0.05	0.3		
TiO_2	0.05	0.02		
MnO	0.05	0.02		
Fe_2O_3	0.05	0.02		
BaO	0.1	0.05		
ZnO			0.02	0.01
SrO			0.01	<0.01
ZrO_2			0.01	<0.01
PbO			0.03	0.01

RESULTS

The glass and glassworking waste

All of the analysed samples are high-lime low-alkali glasses (full details of the composition of the analysed samples can be found in Appendix 2). The 21 fragments of glassworking waste share broadly the same composition (Table 2). This glass on average has a combined alkali content of approximately 10wt% and a lime content of almost 20%. A wide range of other oxides are present which are almost certainly due to the use of plant ashes as the alkali source. The variation in composition probably reflects the varied nature of the raw materials used.

Table 2. Mean composition (with standard deviation) of 21 samples of glassworking waste from Newent

	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	Cl	K_2O	CaO	TiO_2	MnO	Fe_2O_3	ZnO	SrO	ZrO_2
mean	2.0	3.7	4.4	56.8	2.5	0.18	0.51	8.1	19.7	0.23	0.31	1.36	0.03	0.06	0.02
sd	0.6	0.3	0.3	1.4	0.2	0.06	0.19	1.3	1.5	0.03	0.09	0.17	<0.01	0.02	<0.01

The composition of the high-lime low-alkali (HLLA) glass produced at Newent is broadly comparable with HLLA glass produced at other 16th- and 17th-century glasshouses (Table 3). While the first three sites in Table 3 used wood fuel, the last three used coal fuel; there are, however no significant compositional differences between the HLLA glass produced at wood-fired furnaces and at coal-fired furnaces. Therefore it is not possible, simply on the basis of the chemical composition of the HLLA produced at Newent, to suggest whether the Newent furnaces were fired with wood or coal.

Table 3. Mean composition of HLLA glassworking waste from other sites (June Hill = Dungworth 2007b; Tanland = Dungworth and Clark 2004; Sidney Wood = Welham 2001; Silkstone = Dungworth and Cromwell 2006; Vauxhall = Dungworth 2006)

Site	Date	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	Cl	K_2O	CaO	TiO_2	MnO	Fe_2O_3
June Hill	1567–1615	1.2	4.1	2.2	61.1	2.2	0.2	0.4	7.7	18.8	0.3	0.9	0.9
Tanland	1567–1615	1.5	2.8	2.2	61.2	2.2	0.2	0.5	3.8	24.2	0.3	0.7	1.2
Sidney Wood	1567–1615	2.7	2.9	3.9	60.3	1.7	0.1	nr	4.1	22.9	0.3	0.7	1.3
Silkstone	1655–1680	1.1	4.9	4.3	53.5	2.9	0.3	0.3	8.4	21.2	0.3	0.8	2.1
Silkstone	1680–1700	1.6	4.8	3.6	57.2	2.0	0.3	0.3	3.9	23.8	0.2	0.5	1.9
Vauxhall	1663–1704	1.1	2.4	2.4	60.7	2.4	0.2	<0.2	7.4	21.5	0.2	0.2	1.5

A comparison of the composition of the glassworking waste with the glass artefacts (tablewares and window glass) shows few differences between the artefacts and the working waste (Figures 1 and 2). Nevertheless a careful examination of the concentrations of all measured oxides shows that seven (samples 17–21, 37 and 39) out of the nine window glass fragments have compositions which differ sufficiently to indicate that they were not made at Newent. Out of the 25 tableware fragments, only five (samples 15, 23, 27, 28 and 54) have compositions which differ sufficiently to suggest that they were not made at Newent.

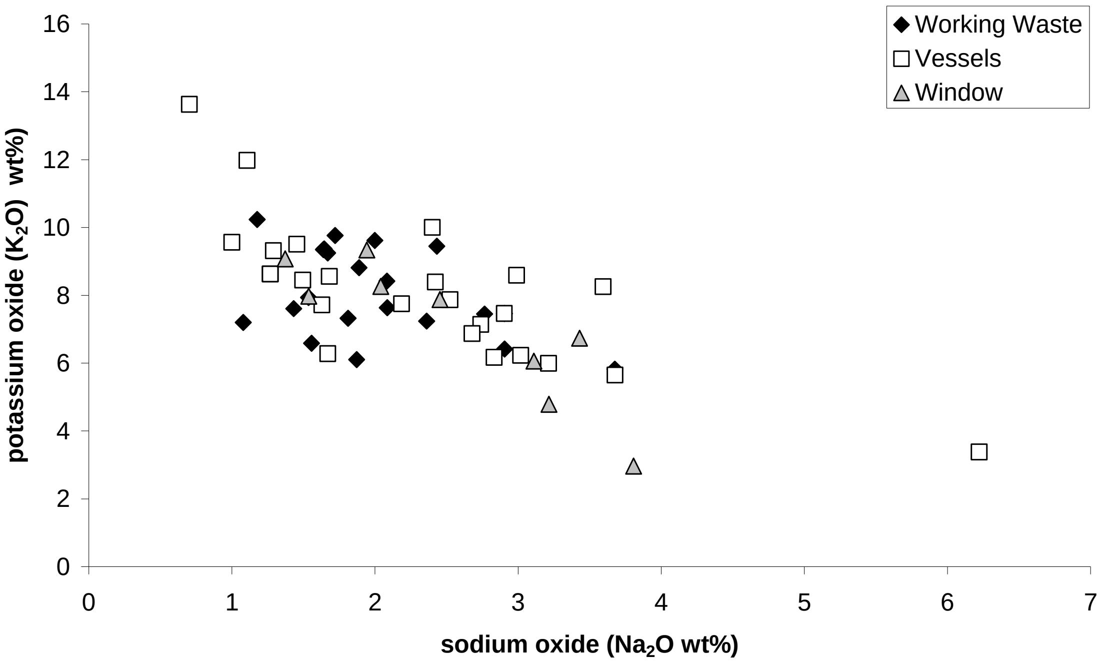

Figure 1. Sodium oxide and potassium oxide content of the glass and glassworking samples

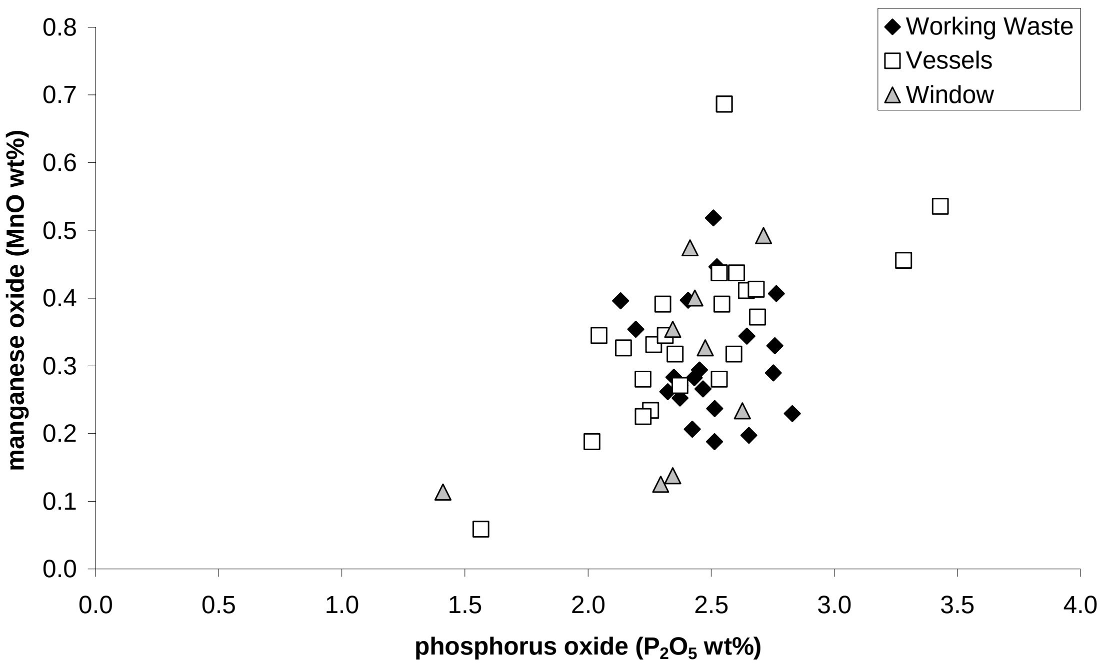

Figure 2. Phosphorus oxide and manganese oxide content of the glass and glassworking samples

The crucibles

Five crucibles fragments were available for study. The largest fragment (sample 57) comprised part of a base with a considerable thickness of glass adhering to the interior surface (Figure 3). The base diameter of this sample was approximately 300mm and it survived to a height of 150mm. The remaining body sherds had diameters of 410mm (sample 59), 310mm (sample 60) and 390mm (sample 61); sample 58 was too small to provide any reliable estimate of its diameter. Wall thickness varied from 17 to 30mm. The size, shape and wall thickness of the Newent crucibles are comparable with the 14th-century examples from Blunden's Wood (Wood 1965) and the 16th-century examples from Knightons (Wood 1982). All of the crucibles showed the presence of a thin glazed or vitrified exterior surface (usually a pale green colour).

Figure 3. Newent crucible (sample 57)

Each sample of crucible was examined and analysed using SEM-EDS to determine microstructure and chemical composition of the ceramic fabric and the adhering glass or glaze (full results in the Appendices 3–7). The crucibles all share similar microstructures: they have abundant small (<0.2mm) silica polymorph inclusions and occasional grog inclusions (Figure 4). The matrix of the crucibles is completely vitrified and shows the precipitation of mullite crystals (Figure 5). The chemical analysis of the ceramic fabric of the crucibles (undertaken on regions away from the glazed surfaces) shows that these are rich in silica and alumina with minor amounts of potassium, iron and titanium oxides

(Table 4). The composition of these crucibles is comparable with other medieval and post-medieval crucibles (Dungworth 2006; 2007a; 2007b; Dungworth and Mortimer 2005).

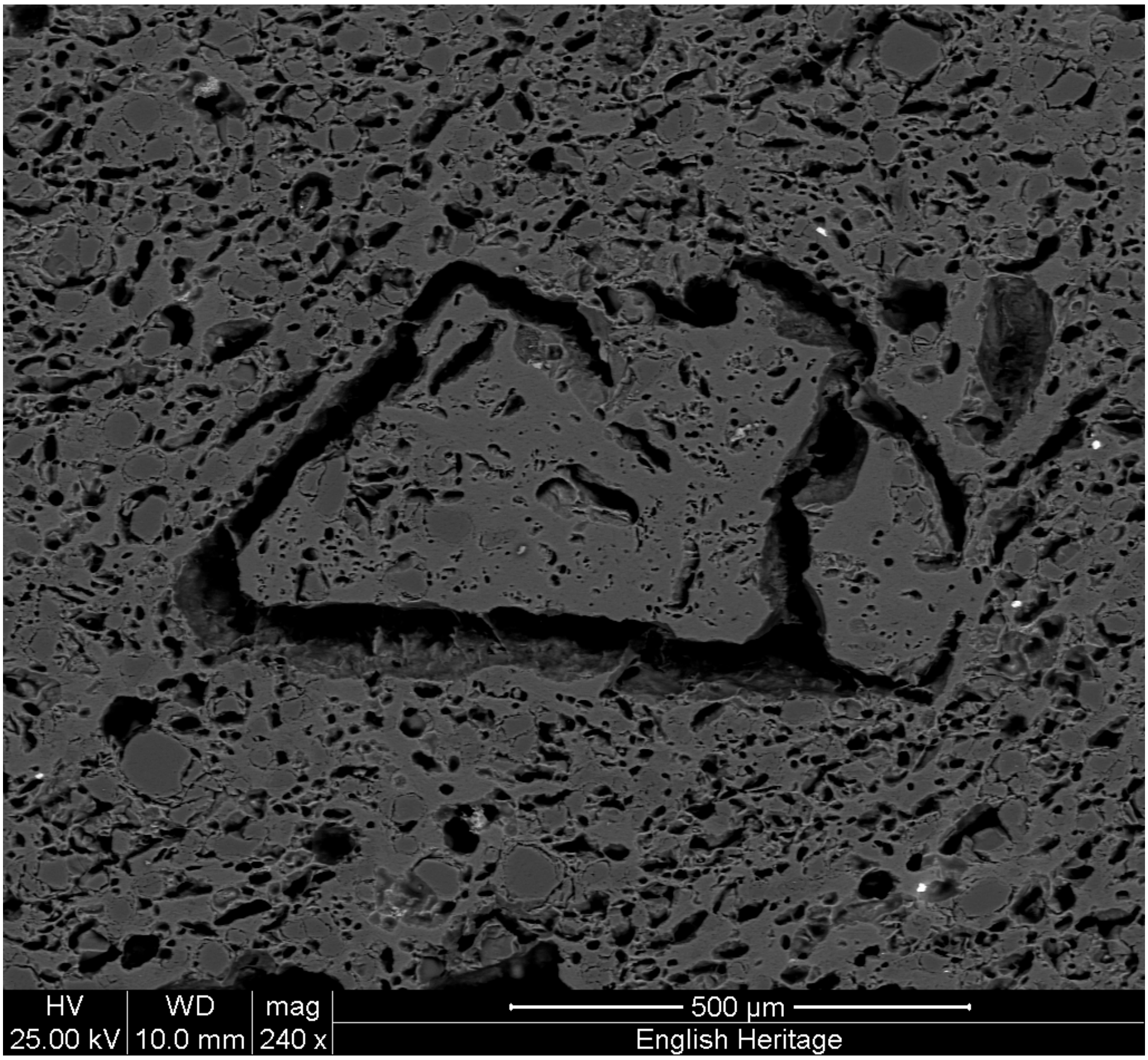

Figure 4. SEM image of crucible 58 showing grog inclusion with characteristic shrinkage gaps

Table 4. Average chemical composition of the ceramic fabric of the Newent crucibles (see Appendices 3–7 for full details)

	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	K_2O	CaO	TiO_2	Fe_2O_3
57	0.1	0.6	19.2	74.2	0.1	2.1	0.5	1.3	1.6
58	0.2	0.4	18.3	76.2	0.1	1.5	0.5	1.2	1.2
59	0.2	0.4	17.3	78.2	<0.1	1.3	0.3	1.1	1.0
60	0.3	0.6	28.5	64.3	0.1	2.0	0.6	1.9	1.5
61	0.1	0.4	19.6	75.6	0.1	1.5	0.2	1.2	1.1

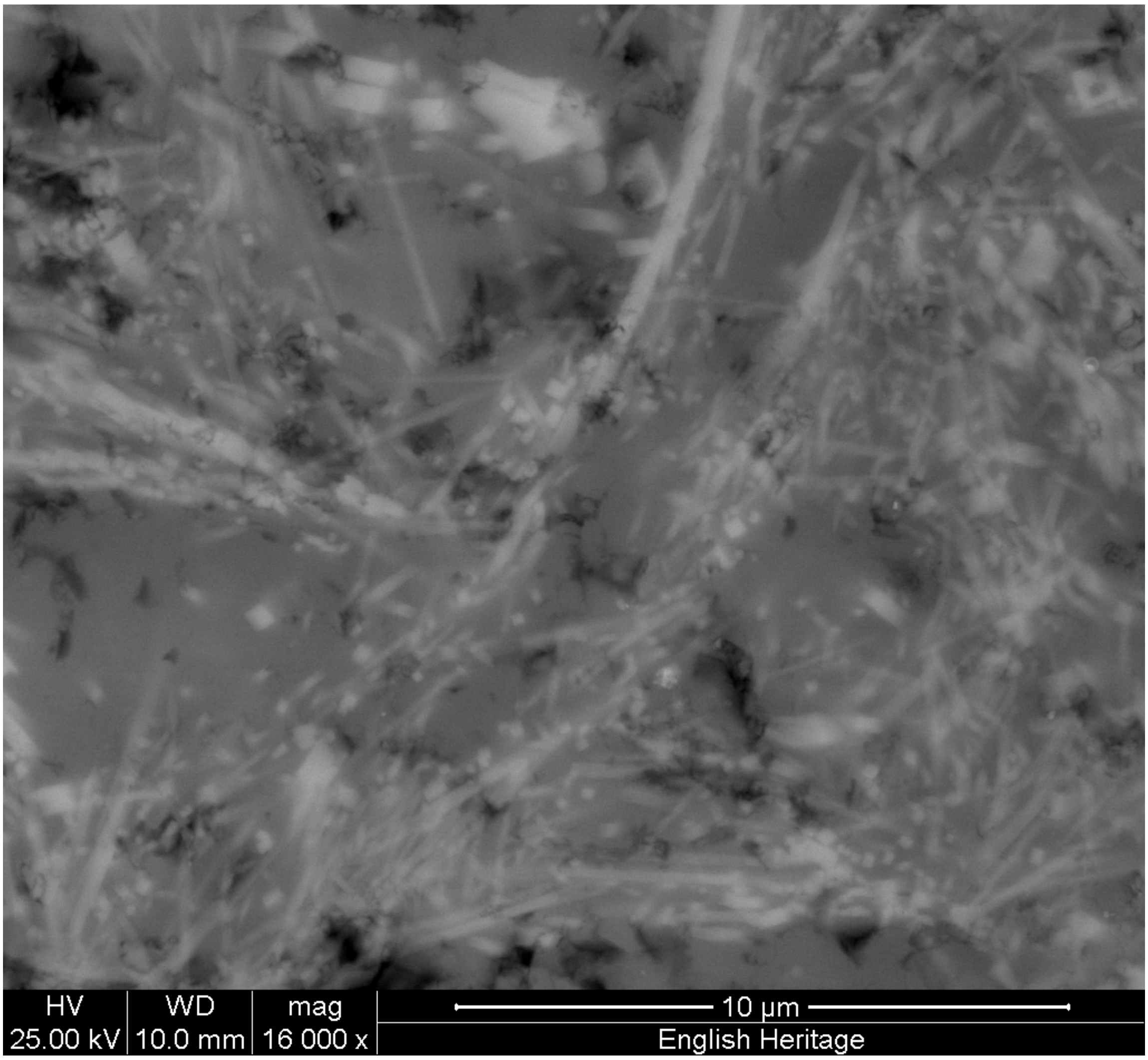

Figure 5. SEM image of crucible 58 showing precipitation of mullite (light grey crystals)

A series of SEM-EDS analyses were undertaken to investigate the adhering glass or glazed surface of each crucible sample (where these survived). The results show many similarities with results previous obtained on post-medieval glassworking crucibles (Dungworth 2008). Compared with the unreacted core of the crucible, the glass adhering to the interior surfaces contains higher concentrations of some of the oxides found in the glassworking waste (Figures 6 and 7; see Appendices 4–7). The changes in the concentrations of different oxides through the adhering glass show a four-fold division (A–D) similar to that observed previously (Dungworth 2008). Zone A comprises a glass which has a composition close to that of the glassworking waste (cf Tables 2 and 5),; the most frequent difference being that zone A often contains higher concentrations of alumina due to diffusion of alumina from the ceramic fabric of the crucible into the adhering glass. Zone B is characterised by a rise in the concentration of alkalis (Na_2O and K_2O) but a drop in the concentration of alkali earths (MgO and CaO). Zone C is characterised by minimum values for alkali earths (Figure 7) and iron oxide. Zone D comprises the ceramic fabric of the crucible with no indications of contamination by adhering glass or leaching of elements (in particular iron) from the crucible.

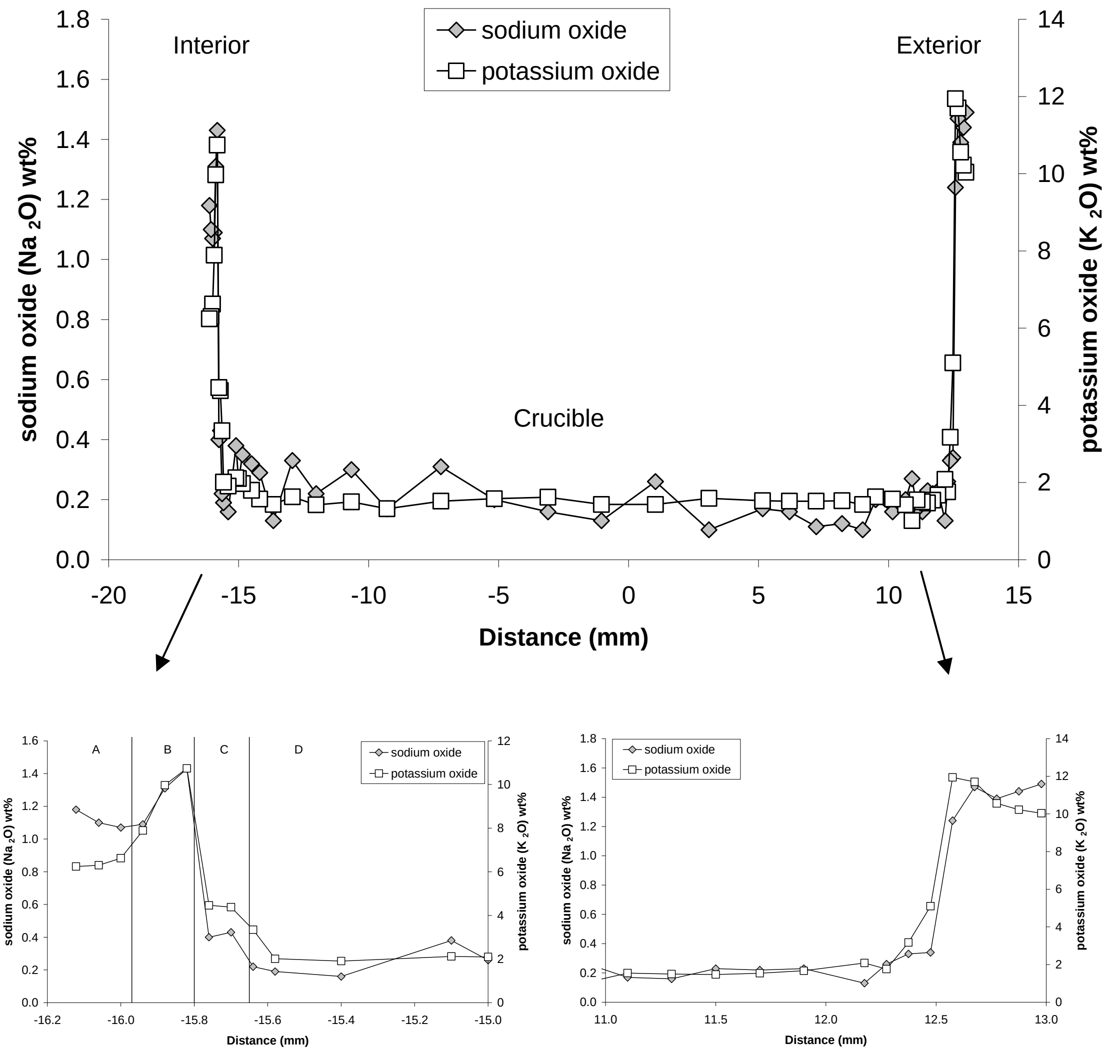

Figure 6. Linescans for sodium and potassium oxide through the entire cross-section of crucible 58. The lower graphs show the interior and exterior surfaces in greater detail (Vertical scales differ)

Table 5. Composition of adhering glass or glaze on the Newent crucibles (A = zone A, see Figures 6 and 7)

	Position	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	Cl	K_2O	CaO	TiO_2	MnO	Fe_2O_3
57	interior (A)	1.1	4.1	3.8	52.8	2.7	0.3	0.2	12.2	21.0	0.2	0.4	1.0
58	interior (A)	1.1	3.0	9.0	61.2	1.3	<0.1	<0.1	6.4	14.7	0.7	0.4	1.9
58	exterior	1.4	1.7	11.9	64.6	0.3	<0.1	<0.1	10.3	7.6	0.7	0.2	1.2
59	interior (A)	1.4	1.4	11.9	66.6	0.2	<0.1	<0.1	10.1	6.8	0.5	0.1	0.9
59	exterior	1.0	0.4	15.0	66.6	<0.1	<0.1	0.6	12.1	2.7	0.9	0.1	0.4
60	interior (A)	4.6	5.3	6.0	57.0	1.5	0.1	<0.1	6.4	16.1	0.5	0.8	1.5
60	exterior	6.5	5.0	9.4	57.8	1.8	<0.1	<0.1	6.8	10.1	0.7	0.4	1.2

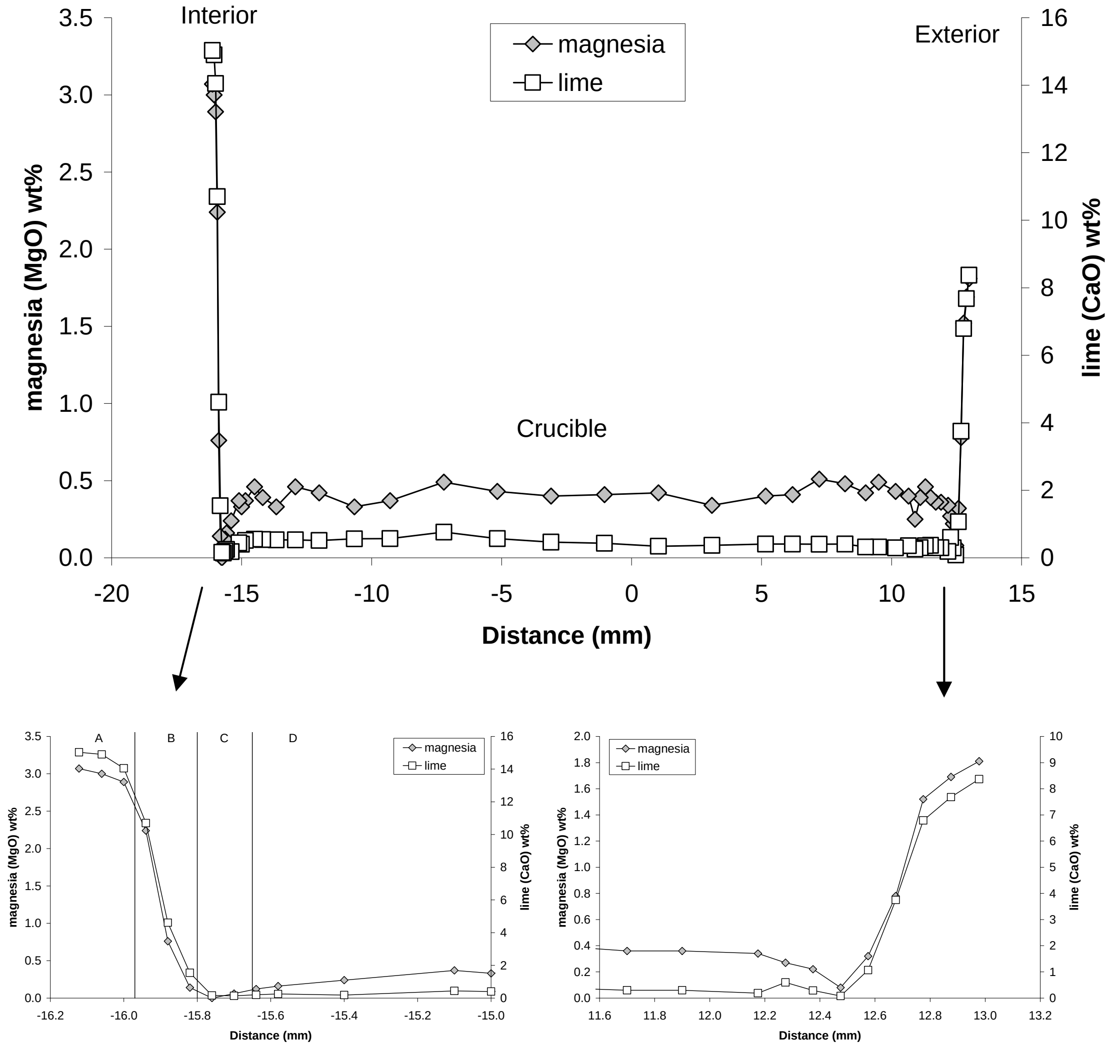

Figure 7. Linescans for magnesia and lime through the entire cross-section of crucible 58. The lower graphs show the interior and exterior surfaces in greater detail (vertical scales differ)

Most of the crucibles also had glazed outer surfaces which, in respect of their chemical composition, resembled the glass adhering to the interior surfaces (Figures 6 and 7). The exterior surfaces, however, usually contain less magnesia and lime (and more alumina) than the interior surfaces (Table 5). The glazing of the outer surfaces may be due to a combination of two factors: firstly, reactions between the ceramic fabric of the crucibles and fuel ash/vapour (cf Paynter *et al* 2005), and secondly deliberately manufactured glass which accidentally dribbled down the exterior surface during glass gathering. Figure 8 compares the iron oxide and potassium oxide concentrations in the outer glazed surfaces of crucibles with their unreacted ceramic fabrics for both Newent and Silkstone crucibles, as well as clinker (coal ash) and wood ash. The exterior surfaces of the Newent crucibles show potassium enrichment but no enrichment of iron, while the exterior surfaces of the Silkstone crucibles show a strong increase in iron as well as a smaller increase in potassium concentration. The slight increase in potassium in the exterior surfaces of the Silkstone crucibles probably represents the contribution of a proportion of manufactured glass spilt during gathering. The Silkstone crucibles were definitely heated in a coal-fired furnace and the exterior surfaces show chemical similarities with coal ash. The exterior surfaces of the Newent crucibles, however show stronger similarities with the composition of wood ash indicating that the Newent crucibles were heated in a wood-fired furnace. The broad similarities in composition between the glass adhering to the interior surfaces of the Newent crucibles and the glazed outer surfaces suggests that wood was used as both a fuel to heat the furnaces and as a source of alkali in glass manufacturing.

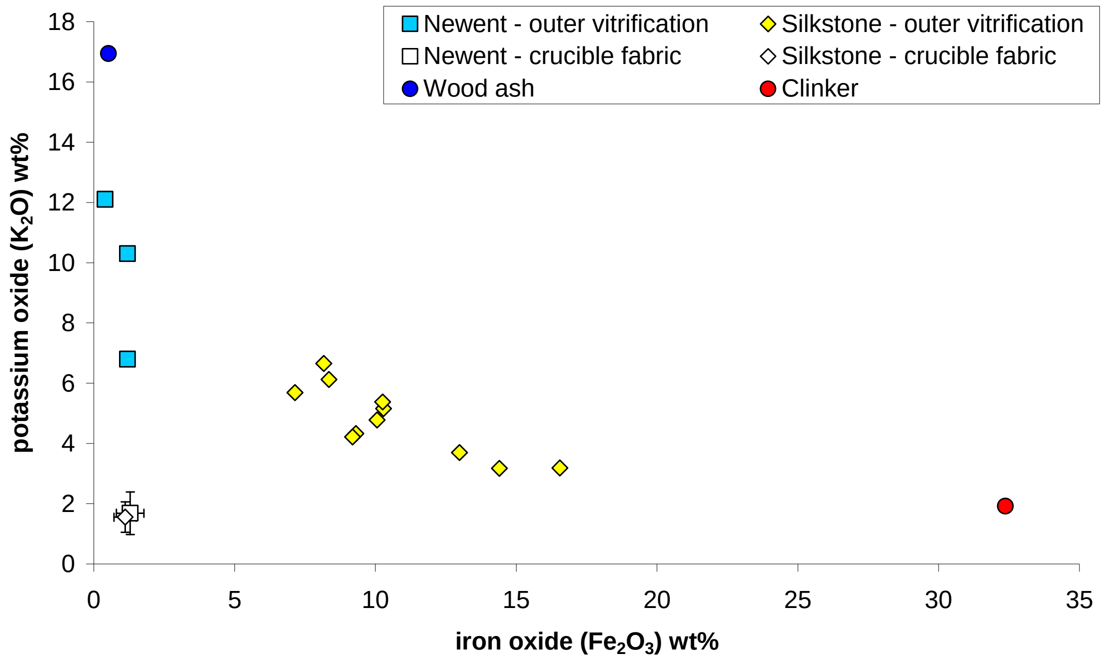

Figure 8. Iron oxide and potassium oxide content of Newent and Silkstone crucibles and their outer glazed surfaces

CONCLUSIONS

The scientific examination of the glass and glassworking waste from Newent provides information on the nature of glass manufacture during the last generation of 'forest' glass. The assemblage of glassworking waste (such as moils, drips and threads) are all composed of high-lime low-alkali glass similar to that manufactured at late Wealden sites and later 17th-century coal-fired furnaces (such as Silkstone). In general the same type of glass was used to manufacture both windows and tablewares but many sites specialised in one or the other product. The Newent glasshouse appears to have specialised in the production of tableware. The window glass found at the site may represent cullet. A close examination of the glassworking debris provides further information on glassmaking fluxes and fuel of the period.

The glasshouse at Newent was established in the last decade of the 16th century by French glassmakers and continued in operation for at least a decade or two. The glasshouse was almost certainly still in operation when Mansell obtained his patent and James I issued his proclamation banning the use of wood as a fuel in glasshouses. One of the Newent glassmakers (Liscourt) claimed to have used coal as a fuel for the furnace but this has been questioned by Godfrey (1975). The examination of a selection of crucible fragments suggests that they were all heated in wood-fired furnaces — there is thus no archaeological evidence for the use of coal fuel at Newent. As Mansell went to considerable lengths to close down wood-fired furnaces in the 1620s, it is not clear whether glass manufacture could have continued at Newent as late as the 1638 marriage of Gulney referred to above.

While the outer vitrified surfaces of Newent and other broadly contemporary crucibles provide clear indications of the nature of the fuel used to heat the furnaces, there are no significant compositional differences in the HLLA glass produced at wood-fired or coal-fired furnaces. This fact is of significance for an understanding of the raw materials used in the manufacture of this sort of glass and the impact that coal had on the use of raw materials. While sand was the main ingredient in glassmaking, this had a very high melting temperature so an alkali-rich flux was added. The wide range of elements present in forest glass indicates that a plant ash of some sort was used. There are several historical references to use of ashes from beech wood (Hawthorne and Smith 1979, 52) and bracken (Welch 1997). It is often assumed that forest glassmakers who used wood-fired furnaces used the ash from heating the furnaces as a raw material in the manufacture of glass. Kenyon suggests that the glassmakers used 'the ash from beech and oak billets with which the furnaces were fired, supplemented by the ash of other inland plants including bracken' (Kenyon 1967, 36). In discussing the source of ashes used as a flux in forest glassmaking, Godfrey suggests that, 'when wood was burned as a fuel, the ashes were taken from the furnaces: they cost nothing at all and the supply normally seems to have been ample' (Godfrey 1975, 196–7). The introduction of coal-fired furnaces, however, is seen as removing this source of plant ash and necessitating the specific purchase of plant ash suitable for glass manufacture (Godfrey 1975, 158, 197). Merrett describes the supply of a wide range of plant ashes to glassmakers in the 1660s, 'for green-glasses in England, they buy all sorts of ashes confused one with another, of persons who go up and down the countrey' (Cable 2001, 322–3).

The suggestion that forest glassmakers made use of ash from the wood burned in their furnaces and that with the switch to coal this source was lost does not find any support in a chemical analysis of finished glass of the period. The chemical composition of HLLA glass produced before and after the switch to coal is essentially the same, which suggests that similar sources of flux were used. While the ashes of burnt wood can be used as a suitable alkali-rich flux, the alkali concentration of such ashes is strongly affected by the temperature at which the wood is burnt (Paynter 2008, 273). In particular, alkalis tend to be volatile at high temperatures and so are not likely to be retained in the ash from fuel used to fire a glass-melting furnace. Wood ashes from a wood-fired glass-melting furnace will tend to have high concentrations of calcium compounds with very low concentrations of alkalis making 'it less suitable for glass production' (Paynter 2008, 290). Such ashes might have been used as a raw material in glassmaking but they would have to be supplemented with plant ashes burnt at much lower temperatures and so with a higher alkali content. It is likely, therefore, that glassmakers in the 16th and 17th centuries, both before and after the ban on the use of wood to fuel their furnaces, obtained at least a proportion of their raw materials from sources other than the ashes from their furnaces.

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APPENDIX 1: SAMPLE LIST

No.	Mus Ref	Description	Vince Figure
1	A24524	Moil	
2	A24524	Droplet/dribble	
3	A24519	Offcut	
4	A24519	Offcut	
5	A24519	Offcut	
6	A24524	Lump	
7	A24524	Droplet/dribble	
8	A24524	Droplet/dribble	
9	A24524	Droplet/dribble	
10	A24524	Droplet/dribble	
11	A24482	Drinking vessel – inturned base	
12	A24482	Drinking vessel – folded foot	
13	A24482	Drinking vessel – folded foot	
14	A24482	Drinking vessel – folded foot	
15	A24482	Drinking vessel – inturned base	
16	A24524	Offcut	
17	A24520	Window	
18	A24520	Window	
19	A24520	Window	
20	A24520	Window	
21	A24520	Window	
22	A24519	Offcut	
23	A22489	Drinking vessel	13
24	A24508-15	Tube, tapering and curved	32-8
25	A24508-15	Tube, tapering and curved	32-8
26	A24526	Drinking vessel – mould blown ribbing	
27	A24492	Drinking vessel – mould blown ribbing	16
28	A24493	Bottle neck (waster)	17
29	A24494	Merse ?	18
30	A24495	Prunt ?	19
31	A24496	Drinking vessel – mould blown ribbing	20
32	A24497	Drinking vessel – mould blown ribbing	21
33	A24524	Lump	
34	A24524	Moil	

No.	Mus Ref	Description	Vince Figure
35	A24527	Drinking vessel - plain, rim (diameter ~80mm)	
36	A24524	Ceramic with vitrified surface	
37	A24521	Window	
38	A24521	Window	
39	A24521	Window	
40	A24521	Window	
41	A24522	Moil ("bottle")	
42	A24522	Moil ("bottle")	
43	A24522	Moil ("bottle")	
44	A24522	Possible bottle neck	
45	A24525	Drinking vessel - mould blown ribbing (waster)	
46	A24525	Drinking vessel - mould blown ribbing	
47	A24525	Drinking vessel - mould blown ribbing	
48	A24525	Drinking vessel - folded foot	
49	A24523	Moil ("bottle")	
50	A24523	Moil ("bottle")	
51	A24523	Moil ("bottle")	
52	A24523	Thick-walled vessel ("bottle") possibly the kick of a bottle	
53	A24523	Thick-walled vessel ("bottle")	
54	A24523	Thick-walled vessel ("bottle")	
55	A24523	Thick-walled vessel ("bottle")	
56	Sherratt	Moil	
57	Sherratt	Crucible	
58	Sherratt	Crucible	
59	Sherratt	Crucible	
60	Sherratt	Crucible	
61	Sherratt	Crucible	

APPENDIX 2: CHEMICAL COMPOSITION OF THE GLASS AND GLASSWORKING WASTE

No.	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	Cl	K_2O	CaO	TiO_2	MnO	Fe_2O_3	ZnO	SrO	ZrO_2	BaO	PbO
1	2.36	3.46	3.93	59.9	2.45	0.12	0.69	7.24	17.45	0.27	0.29	1.50	0.03	0.054	0.028	0.11	<0.04
2	1.08	3.78	4.79	55.1	2.51	0.26	0.14	7.20	22.34	0.28	0.52	1.42	0.03	0.058	0.025	0.17	0.06
3	2.76	3.60	4.25	57.0	2.41	0.10	0.76	7.45	19.36	0.21	0.40	1.25	0.03	0.052	0.024	0.12	0.08
4	1.87	3.60	4.25	56.5	2.47	0.19	0.39	6.10	22.47	0.24	0.27	1.34	0.03	0.073	0.026	<0.1	<0.04
5	2.08	3.43	4.14	58.0	2.35	0.15	0.56	8.42	18.66	0.20	0.28	1.26	0.03	0.055	0.035	0.15	0.11
6	1.89	3.86	4.38	56.5	2.51	0.25	0.40	8.82	19.20	0.23	0.24	1.36	0.03	0.054	0.023	<0.1	<0.04
7	1.67	3.66	4.44	55.7	2.76	0.15	0.54	9.25	19.04	0.25	0.41	1.68	0.02	0.048	0.021	0.12	<0.04
8	2.91	3.97	4.08	57.8	2.43	0.35	0.64	6.42	19.28	0.23	0.28	1.32	0.03	0.101	0.026	<0.1	<0.04
9	2.09	3.11	4.42	57.4	2.13	0.18	0.51	7.64	20.13	0.23	0.40	1.33	0.02	0.060	0.026	0.15	<0.04
10	1.64	3.63	4.51	55.9	2.64	0.21	0.39	9.37	19.18	0.22	0.34	1.50	0.02	0.047	0.015	0.16	<0.04
11	2.99	3.89	4.31	57.5	2.27	0.32	0.55	8.59	17.45	0.18	0.33	1.19	0.03	0.108	0.028	0.23	<0.04
12	1.50	3.10	4.60	58.8	2.04	0.24	0.27	8.45	18.63	0.25	0.34	1.28	0.03	0.056	0.020	0.13	<0.04
13	1.00	3.88	4.04	57.3	2.69	0.18	0.26	9.56	18.83	0.17	0.37	1.15	0.03	0.051	0.018	0.19	<0.04
14	1.29	3.55	4.46	58.1	2.02	0.27	0.32	9.32	18.53	0.21	0.19	1.36	0.02	0.038	0.023	<0.1	<0.04
15	2.74	3.37	2.70	58.8	2.64	0.14	0.74	7.14	19.60	0.25	0.41	1.20	0.02	0.055	0.018	<0.1	<0.04
16	1.43	4.37	4.66	57.4	2.83	0.18	0.43	7.61	18.43	0.28	0.23	1.74	0.03	0.050	0.024	0.10	<0.04
17	3.43	3.39	5.44	54.3	2.34	<0.1	0.83	6.74	20.84	0.25	0.14	1.98	0.04	0.069	0.022	<0.1	<0.04
18	3.81	3.55	3.36	60.8	1.41	0.35	0.43	2.96	21.67	0.16	0.11	1.29	0.02	0.185	0.012	<0.1	<0.04
19	2.45	3.58	4.57	56.4	2.48	0.05	0.77	7.88	19.55	0.24	0.33	1.42	0.02	0.061	0.021	0.14	<0.04
20	1.94	3.55	4.87	53.7	2.63	0.21	0.85	9.34	20.27	0.22	0.23	1.93	0.03	0.064	0.024	0.13	<0.04
21	3.22	2.50	5.14	57.2	2.30	0.04	0.95	4.79	21.54	0.32	0.13	1.95	0.04	0.069	0.026	<0.1	<0.04
22	1.81	3.89	4.20	55.8	2.76	0.13	0.45	7.32	21.28	0.21	0.33	1.38	0.02	0.048	0.025	0.14	<0.04
23	6.22	5.03	5.37	52.6	3.43	<0.1	1.64	3.38	20.08	0.21	0.54	1.51	0.03	0.058	0.023	0.14	0.15
24	2.68	3.62	4.75	59.0	2.14	0.13	0.65	6.87	17.77	0.26	0.33	1.54	0.02	0.065	0.037	<0.1	0.08
25	3.02	3.56	4.23	58.8	2.31	<0.1	0.93	6.23	18.79	0.21	0.34	1.25	0.02	0.052	0.025	0.13	0.12
26	2.83	3.90	4.76	57.6	2.53	0.19	0.70	6.17	18.87	0.22	0.44	1.33	0.03	0.052	0.029	0.20	0.05
27	1.67	2.18	3.71	61.2	1.57	0.35	0.31	6.28	20.14	0.23	0.06	2.13	0.03	0.061	0.010	<0.1	<0.04
28	0.70	4.00	3.06	55.1	3.28	0.26	0.39	13.63	17.33	0.24	0.46	1.04	0.03	0.043	0.031	0.12	<0.04
29	1.63	3.87	4.70	58.9	2.30	0.33	0.17	7.72	17.99	0.23	0.39	1.31	0.03	0.062	0.029	0.18	<0.04
30	3.59	4.54	3.68	55.6	2.53	0.24	0.53	8.25	18.95	0.17	0.44	1.03	0.03	0.106	0.015	0.20	<0.04
31	2.42	3.36	4.08	57.6	2.53	<0.1	0.83	8.39	18.81	0.18	0.28	1.20	0.02	0.055	0.017	0.15	0.06
32	1.68	3.81	4.60	56.9	2.59	0.16	0.32	8.56	19.21	0.25	0.32	1.25	0.03	0.074	0.023	<0.1	<0.04
33	1.72	3.43	4.27	55.5	2.32	0.19	0.49	9.76	20.26	0.22	0.26	1.25	0.02	0.059	0.020	0.11	<0.04
34	2.00	2.91	4.99	56.4	2.42	0.10	0.57	9.61	18.86	0.23	0.21	1.47	0.02	0.057	0.019	<0.1	<0.04
35	1.45	3.42	4.19	58.3	2.25	0.13	0.28	9.51	18.34	0.26	0.23	1.20	0.03	0.056	0.024	0.11	<0.04
36	2.73	1.43	11.61	67.5	0.20	<0.1	<0.1	8.83	1.32	0.64	0.12	5.53	<0.01	0.011	0.106	<0.1	<0.04
37	2.04	3.79	4.84	55.6	2.43	0.07	0.54	8.26	19.88	0.28	0.40	1.37	0.03	0.053	0.021	0.17	<0.04
38	1.37	3.55	4.39	55.2	2.41	0.22	0.36	9.07	20.88	0.21	0.47	1.33	0.03	0.059	0.021	0.20	0.04
39	3.11	4.18	4.44	56.6	2.71	<0.1	0.89	6.06	19.65	0.22	0.49	1.43	0.03	0.049	0.027	0.12	<0.04

No.	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	Cl	K_2O	CaO	TiO_2	MnO	Fe_2O_3	ZnO	SrO	ZrO_2	BaO	PbO
40	1.54	3.65	4.25	56.8	2.34	0.14	0.41	7.98	20.46	0.21	0.35	1.40	0.03	0.064	0.020	0.17	<0.03
41	3.68	3.98	4.44	57.3	2.52	0.12	0.99	5.83	18.78	0.24	0.45	1.38	0.03	0.065	0.027	<0.1	<0.03
42	1.56	3.62	4.35	56.7	2.37	0.19	0.36	6.58	22.09	0.28	0.25	1.36	0.03	0.055	0.026	<0.1	0.06
43	1.18	3.83	3.95	53.7	2.75	0.21	0.18	10.23	22.02	0.21	0.29	1.00	0.02	0.056	0.021	<0.1	<0.03
44	3.68	4.01	4.33	57.8	2.60	<0.1	1.00	5.65	18.56	0.22	0.44	1.19	0.02	0.057	0.024	0.15	0.14
45	2.19	3.58	4.34	57.1	2.54	0.13	0.61	7.75	19.38	0.23	0.39	1.38	0.03	0.045	0.010	0.15	<0.03
46	3.21	3.10	4.41	60.0	2.22	0.11	0.94	5.99	17.95	0.23	0.28	1.27	0.03	0.065	0.007	0.11	<0.03
47	2.52	3.20	4.39	59.1	2.22	0.14	0.80	7.87	17.69	0.22	0.22	1.23	0.02	0.054	0.028	<0.1	0.19
48	2.40	3.33	4.75	53.7	2.35	0.23	0.70	10.00	20.17	0.23	0.32	1.44	0.02	0.034	0.009	0.15	<0.03
49	1.54	3.78	4.56	58.5	2.19	0.21	0.36	7.94	18.44	0.27	0.35	1.35	0.03	0.063	0.028	0.16	0.04
50	1.64	3.79	4.44	56.4	2.65	0.17	0.49	9.35	19.12	0.21	0.20	1.20	0.02	0.075	0.017	<0.1	0.20
51	2.43	3.20	4.33	56.3	2.51	0.20	0.68	9.45	18.97	0.20	0.19	1.14	0.03	0.070	0.025	<0.1	<0.03
52	1.27	3.60	3.92	55.6	2.55	0.16	0.38	8.63	21.19	0.20	0.69	1.17	0.03	0.065	0.026	0.26	<0.03
53	2.90	3.95	4.00	58.4	2.37	0.13	0.67	7.46	18.12	0.19	0.27	1.25	0.03	0.060	0.019	<0.1	<0.03
54	1.11	3.94	3.76	52.9	2.68	0.24	0.23	11.98	20.98	0.18	0.41	1.07	0.02	0.064	0.016	0.19	<0.03
55	1.27	3.60	3.92	55.6	2.55	0.16	0.38	8.63	21.19	0.20	0.69	1.17	0.03	0.05	0.03	0.26	<0.03
56	2.90	3.95	4.00	58.4	2.37	0.13	0.67	7.46	18.12	0.19	0.27	1.25	0.02	0.11	0.03	<0.1	<0.03

APPENDIX 3: CHEMICAL COMPOSITION OF CRUCIBLE 57

	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	Cl	K_2O	CaO	TiO_2	MnO	Fe_2O_3
Crucible	0.16	0.57	19.35	74.3	<0.1	<0.1	<0.1	2.00	0.48	1.40	<0.1	1.54
Crucible	0.11	0.58	18.99	74.5	0.18	<0.1	<0.1	2.17	0.50	1.25	<0.1	1.62
Crucible	0.15	0.67	19.95	73.0	0.14	<0.1	0.21	2.19	0.57	1.36	<0.1	1.57
Crucible	0.16	0.56	18.68	75.1	<0.1	<0.1	<0.1	2.05	0.56	1.17	<0.1	1.48
Glass	1.54	3.96	3.95	53.4	2.67	0.31	0.44	12.01	20.04	0.21	0.40	0.92
Glass	0.96	3.94	3.49	53.0	2.71	0.30	0.19	12.29	21.31	0.23	0.46	1.00
Glass	0.96	3.94	3.56	53.0	2.63	0.38	0.15	12.38	21.09	0.18	0.43	1.00
Glass	1.00	4.18	3.92	52.4	2.74	0.26	0.19	12.22	21.14	0.18	0.43	1.10
Glass	0.95	4.25	3.86	52.3	2.65	0.27	0.18	12.22	21.25	0.21	0.50	1.13

These analysis where not taken through the whole crucible

APPENDIX 4: CHEMICAL COMPOSITION OF CRUCIBLE 58

Distance (mm)	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	Cl	K_2O	CaO	TiO_2	MnO	Fe_2O_3
12.980	1.49	1.81	11.57	64.0	0.29	<0.1	<0.1	10.04	8.37	0.66	0.27	1.28
12.880	1.44	1.69	11.89	64.7	0.22	<0.1	<0.1	10.22	7.68	0.64	0.21	1.20
12.780	1.39	1.52	12.20	65.0	0.25	<0.1	<0.1	10.56	6.79	0.70	0.20	1.19
12.680	1.47	0.78	14.21	66.2	0.15	<0.1	<0.1	11.70	3.75	0.78	0.13	0.80
12.580	1.24	0.32	16.85	67.1	0.10	<0.1	<0.1	11.94	1.07	0.71	<0.05	0.54
12.480	0.34	0.08	16.59	76.0	<0.1	0.13	<0.1	5.10	0.08	1.55	<0.05	0.39
12.375	0.33	0.22	17.80	76.2	<0.1	0.12	<0.1	3.17	0.29	0.88	<0.05	0.87
12.275	0.26	0.27	13.30	81.8	0.13	0.27	<0.1	1.76	0.60	0.62	<0.05	0.78
12.175	0.13	0.34	19.19	75.8	<0.1	<0.1	<0.1	2.08	0.19	0.97	<0.05	1.18
11.900	0.23	0.36	17.60	77.4	0.10	<0.1	<0.1	1.67	0.30	1.06	<0.05	1.15
11.700	0.22	0.36	18.89	76.1	0.13	<0.1	<0.1	1.54	0.30	1.09	<0.05	1.24
11.500	0.23	0.39	19.09	76.0	<0.1	0.11	0.10	1.47	0.37	1.11	<0.05	1.23
11.300	0.16	0.46	18.40	76.7	<0.1	<0.1	<0.1	1.50	0.36	0.93	<0.05	1.12
11.100	0.17	0.39	18.41	76.6	<0.1	0.11	<0.1	1.55	0.30	1.06	<0.05	1.21
10.900	0.27	0.25	15.77	80.5	<0.1	<0.1	<0.1	1.01	0.26	0.80	<0.05	0.91
10.650	0.20	0.40	16.92	77.3	<0.1	<0.1	<0.1	1.42	0.36	1.87	<0.05	1.28
10.150	0.16	0.43	19.04	75.1	0.12	0.10	<0.1	1.57	0.29	1.84	<0.05	1.36
9.500	0.20	0.49	19.82	74.6	0.12	<0.1	<0.1	1.63	0.32	1.46	<0.05	1.38
9.000	0.10	0.42	18.02	77.0	0.17	<0.1	<0.1	1.43	0.32	1.20	<0.05	1.17
8.212	0.12	0.48	18.40	76.1	0.15	<0.1	<0.1	1.53	0.41	1.36	0.09	1.21
7.216	0.11	0.51	18.54	76.0	0.15	<0.1	<0.1	1.52	0.40	1.37	0.05	1.28
6.186	0.16	0.41	18.94	75.6	<0.1	<0.1	<0.1	1.52	0.41	1.27	<0.05	1.32
5.155	0.17	0.40	18.89	75.9	0.11	0.11	<0.1	1.53	0.41	1.28	<0.05	1.22
3.094	0.10	0.34	18.52	76.2	<0.1	<0.1	<0.1	1.59	0.37	1.29	<0.05	1.28
1.033	0.26	0.42	18.18	76.7	<0.1	0.13	0.11	1.43	0.34	1.19	<0.05	1.21
-1.041	0.13	0.41	18.19	76.6	0.14	0.11	0.10	1.43	0.43	1.26	<0.05	1.19
-3.102	0.16	0.40	18.50	76.1	0.14	0.10	<0.1	1.62	0.46	1.23	<0.05	1.25
-5.162	0.20	0.43	18.47	75.7	0.17	0.16	<0.1	1.58	0.57	1.07	<0.05	1.31
-7.223	0.31	0.49	18.51	75.3	0.10	0.24	0.10	1.52	0.76	1.23	<0.05	1.30
-9.291	0.17	0.37	17.35	77.5	0.19	0.10	<0.1	1.32	0.57	1.04	0.05	1.18
-10.664	0.30	0.33	18.19	76.1	<0.1	0.18	0.10	1.50	0.56	1.14	<0.05	1.31
-12.014	0.22	0.42	17.49	77.2	<0.1	0.12	<0.1	1.42	0.51	1.18	<0.05	1.18
-12.934	0.33	0.46	18.98	74.9	0.15	0.15	<0.1	1.63	0.53	1.11	<0.05	1.32
-13.669	0.13	0.33	17.23	77.8	0.16	0.11	0.11	1.43	0.53	1.01	<0.05	1.16
-14.186	0.29	0.39	17.87	76.1	0.33	0.16	<0.1	1.57	0.54	1.39	<0.05	1.29
-14.502	0.32	0.46	18.75	74.1	0.11	0.21	0.12	1.80	0.55	1.79	0.05	1.52
-14.850	0.35	0.37	17.64	76.3	<0.1	0.13	<0.1	1.97	0.51	1.16	<0.05	1.28
-15.000	0.26	0.33	17.72	76.5	<0.1	<0.1	<0.1	2.10	0.40	1.03	<0.05	1.18
-15.100	0.38	0.37	16.39	78.0	<0.1	<0.1	<0.1	2.12	0.44	0.85	<0.05	1.11
-15.400	0.16	0.24	13.99	81.8	<0.1	<0.1	<0.1	1.91	0.18	0.63	<0.05	0.92
-15.580	0.19	0.16	14.77	81.1	0.12	<0.1	0.10	2.01	0.25	0.35	<0.05	0.87

Distance (mm)	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	Cl	K_2O	CaO	TiO_2	MnO	Fe_2O_3
-15.640	0.22	0.12	18.29	75.8	<0.1	<0.1	0.10	3.34	0.20	0.67	<0.05	0.89
-15.700	0.43	0.06	21.05	72.1	<0.1	<0.1	<0.1	4.38	0.14	0.98	<0.05	0.70
-15.760	0.40	<0.05	13.01	81.1	<0.1	0.13	<0.1	4.46	0.16	0.40	<0.05	0.08
-15.820	1.43	0.14	17.19	67.6	0.12	<0.1	<0.1	10.74	1.54	0.68	<0.05	0.55
-15.880	1.31	0.76	13.72	67.2	0.25	<0.1	<0.1	9.97	4.61	0.65	0.16	1.16
-15.940	1.09	2.24	10.90	63.5	0.90	<0.1	<0.1	7.89	10.70	0.65	0.22	1.69
-16.000	1.07	2.89	9.27	61.6	1.36	<0.1	<0.1	6.62	14.05	0.67	0.38	1.83
-16.060	1.10	3.00	9.05	60.9	1.22	<0.1	<0.1	6.30	14.90	0.65	0.44	1.90
-16.122	1.18	3.07	8.81	61.0	1.36	<0.1	<0.1	6.24	15.03	0.71	0.40	1.97

The distance (mm) represents the SEM stage y-coordinate at each analysis point.

APPENDIX 5: CHEMICAL COMPOSITION OF CRUCIBLE 59

Distance (mm)	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	Cl	K_2O	CaO	TiO_2	MnO	Fe_2O_3
-17.460	1.05	0.73	13.73	66.0	<0.1	0.11	0.79	11.73	4.48	0.73	0.14	0.56
-17.360	1.00	0.40	15.26	66.7	<0.1	<0.1	0.59	12.25	2.51	0.79	0.08	0.41
-17.259	1.02	0.21	16.13	67.1	<0.1	0.10	0.46	12.46	1.05	1.12	0.07	0.32
-17.160	0.54	<0.05	17.30	72.4	<0.1	<0.1	<0.1	8.31	0.20	1.14	<0.05	0.11
-17.060	0.20	<0.05	18.09	76.0	<0.1	<0.1	<0.1	4.16	0.08	1.13	<0.05	0.10
-16.960	0.21	0.10	16.82	77.9	<0.1	<0.1	<0.1	3.52	0.07	1.06	<0.05	0.22
-16.860	0.22	0.11	16.54	78.4	<0.1	<0.1	<0.1	3.06	0.10	1.07	<0.05	0.30
-16.760	0.20	0.21	18.50	76.3	<0.1	<0.1	<0.1	2.92	0.12	1.07	<0.05	0.49
-16.669	0.26	0.34	18.81	75.6	<0.1	<0.1	<0.1	2.73	0.09	1.26	<0.05	0.72
-16.570	0.13	0.23	19.93	75.5	0.12	<0.1	<0.1	2.21	0.10	1.16	<0.05	0.65
-16.470	0.10	0.27	18.12	77.2	0.10	<0.1	<0.1	2.20	0.12	1.07	<0.05	0.73
-16.370	0.19	0.32	17.26	77.8	<0.1	<0.1	<0.1	2.22	0.11	1.15	-0.02	0.88
-16.270	0.15	0.24	16.50	79.5	<0.1	<0.1	<0.1	1.63	0.12	0.95	<0.05	0.70
-16.170	0.10	0.29	17.12	78.7	0.12	<0.1	<0.1	1.63	0.23	1.01	<0.05	0.78
-16.112	0.15	0.37	19.51	75.4	<0.1	<0.1	<0.1	1.90	0.17	1.20	<0.05	1.01
-16.010	0.12	0.33	17.62	78.1	<0.1	<0.1	<0.1	1.70	0.14	1.07	<0.05	0.85
-15.910	0.14	0.36	18.10	77.5	<0.1	<0.1	<0.1	1.62	0.15	1.09	<0.05	0.89
-15.810	0.19	0.36	18.52	76.8	<0.1	<0.1	0.10	1.69	0.20	1.10	<0.05	0.93
-15.710	0.17	0.37	18.24	76.7	<0.1	<0.1	<0.1	1.82	0.26	1.15	<0.05	1.04
-15.610	0.14	0.32	15.98	79.9	<0.1	<0.1	<0.1	1.40	0.15	1.00	<0.05	0.88
-15.480	0.08	0.37	18.20	77.3	<0.1	<0.1	<0.1	1.54	0.22	1.12	<0.05	0.99
-15.380	0.13	0.35	16.14	79.3	<0.1	<0.1	<0.1	1.62	0.16	1.06	<0.05	0.96
-15.280	0.13	0.30	14.90	81.1	<0.1	<0.1	0.13	1.34	0.19	1.05	<0.05	0.88
-15.180	0.21	0.33	16.21	79.3	<0.1	<0.1	0.14	1.39	0.19	1.01	<0.05	0.98
-15.030	0.12	0.36	16.93	78.9	<0.1	<0.1	<0.1	1.31	0.22	0.97	<0.05	0.91
-14.722	0.15	0.36	17.69	77.7	<0.1	<0.1	0.11	1.47	0.20	1.10	<0.05	0.99
-14.520	0.15	0.32	17.28	78.3	0.11	0.11	<0.1	1.41	0.21	1.16	<0.05	0.94
-14.320	0.15	0.37	16.43	79.3	<0.1	<0.1	0.10	1.30	0.18	1.09	<0.05	0.93
-13.970	0.13	0.35	17.28	78.2	<0.1	<0.1	0.13	1.37	0.20	1.10	<0.05	0.98
-13.700	0.16	0.32	15.81	80.1	<0.1	<0.1	0.11	1.17	0.19	0.99	<0.05	0.88
-13.250	0.15	0.32	17.25	78.5	0.12	<0.1	0.11	1.29	0.23	1.14	<0.05	1.02
-13.048	0.12	0.27	16.92	78.8	0.19	<0.1	0.15	1.26	0.23	1.10	<0.05	0.91
-12.150	0.12	0.30	17.98	77.6	<0.1	<0.1	0.21	1.31	0.21	1.13	<0.05	1.00
-11.371	0.15	0.34	17.34	78.2	<0.1	<0.1	0.17	1.30	0.20	1.20	<0.05	1.06
-10.360	0.09	0.35	17.15	78.6	<0.1	<0.1	<0.1	1.22	0.24	1.07	<0.05	1.00
-9.360	0.17	0.37	18.26	77.0	<0.1	0.11	0.12	1.36	0.26	1.25	<0.05	1.12
-8.360	0.07	0.31	17.35	78.2	<0.1	0.12	0.14	1.32	0.22	1.11	<0.05	1.02
-7.360	0.17	0.34	17.89	77.7	0.12	<0.1	0.17	1.28	0.22	1.13	<0.05	1.01
-6.190	0.17	0.32	16.33	79.4	<0.1	<0.1	0.16	1.21	0.33	1.03	<0.05	0.96
-5.190	0.06	0.38	17.39	78.2	<0.1	<0.1	<0.1	1.36	0.27	1.12	0.05	1.03
-4.190	0.25	0.40	16.52	78.9	0.19	<0.1	0.11	1.22	0.24	1.07	<0.05	1.14

Distance (mm)	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	Cl	K_2O	CaO	TiO_2	MnO	Fe_2O_3
-3.190	0.17	0.35	16.51	79.0	0.10	0.11	0.11	1.23	0.32	0.96	<0.05	1.04
-2.190	0.14	0.34	17.43	78.0	0.14	0.11	<0.1	1.28	0.33	1.12	<0.05	1.07
-1.190	0.16	0.36	16.36	79.2	0.10	0.14	0.10	1.21	0.31	1.07	<0.05	1.00
-0.190	0.20	0.32	16.03	79.6	<0.1	0.21	0.15	1.18	0.18	1.13	<0.05	0.96
0.370	0.20	0.35	17.06	78.2	0.19	0.16	0.14	1.25	0.26	1.11	<0.05	0.94
0.810	0.24	0.32	17.41	77.9	<0.1	0.11	0.16	1.35	0.27	1.18	<0.05	1.11
1.370	0.23	0.36	17.56	77.8	<0.1	<0.1	0.14	1.33	0.26	1.08	<0.05	1.13
2.020	0.19	0.33	17.78	77.8	<0.1	0.10	0.19	1.27	0.26	1.15	<0.05	1.12
3.020	0.21	0.40	17.31	77.9	<0.1	0.12	<0.1	1.37	0.26	1.15	<0.05	1.00
3.890	0.17	0.41	18.69	76.5	0.12	<0.1	<0.1	1.46	0.28	1.12	<0.05	1.13
4.241	0.15	0.37	17.59	77.9	0.17	0.11	<0.1	1.20	0.24	1.11	<0.05	1.03
4.580	0.18	0.34	17.39	78.1	<0.1	0.13	0.13	1.37	0.22	1.08	<0.05	1.07
4.980	0.22	0.32	16.28	79.5	<0.1	0.13	0.11	1.21	0.20	1.15	<0.05	0.95
5.379	0.22	0.32	17.41	77.9	<0.1	0.21	0.21	1.34	0.28	1.05	<0.05	1.06
6.260	0.18	0.37	18.73	76.5	<0.1	0.17	<0.1	1.41	0.23	1.15	<0.05	1.06
6.660	0.19	0.32	17.92	77.3	<0.1	0.14	0.14	1.40	0.21	1.10	<0.05	1.01
7.058	0.19	0.32	15.93	79.6	<0.1	0.16	0.19	1.41	0.22	1.11	<0.05	0.86
7.540	0.23	0.33	16.41	78.9	<0.1	0.15	0.29	1.46	0.16	1.13	<0.05	0.93
7.920	0.28	0.18	16.95	78.4	<0.1	0.13	0.11	2.42	0.08	0.91	<0.05	0.66
7.940	0.15	0.30	18.20	77.0	0.11	<0.1	0.14	1.67	0.19	1.15	<0.05	0.92
8.120	0.17	0.22	15.67	79.9	<0.1	<0.1	0.11	1.79	0.15	1.04	<0.05	0.86
8.140	0.14	0.33	15.97	79.7	<0.1	<0.1	0.11	1.68	0.16	1.04	<0.05	0.86
8.293	0.21	0.28	17.55	77.6	<0.1	<0.1	0.10	2.04	0.16	1.07	<0.05	0.86
8.320	0.21	0.26	16.93	78.4	<0.1	<0.1	0.12	2.00	0.07	1.13	<0.05	0.75
8.520	0.20	0.20	17.21	78.3	<0.1	<0.1	<0.1	2.11	0.10	0.98	<0.05	0.71
8.724	0.20	0.18	17.25	78.0	<0.1	0.10	0.12	2.51	0.08	0.95	<0.05	0.65
8.870	0.19	0.20	18.65	76.4	<0.1	<0.1	0.32	2.49	0.08	0.86	<0.05	0.72
8.970	0.18	0.08	15.84	80.0	0.11	<0.1	0.17	2.22	0.08	0.70	<0.05	0.41
9.070	0.25	0.08	15.45	79.6	0.12	0.10	<0.1	2.99	0.05	0.89	<0.05	0.32
9.170	0.28	0.06	15.86	78.8	<0.1	<0.1	0.14	3.44	0.10	0.90	<0.05	0.18
9.270	0.34	<0.05	18.11	75.6	<0.1	<0.1	0.19	4.40	0.05	1.06	<0.05	0.13
9.320	0.32	<0.05	16.52	77.0	0.14	<0.1	0.22	4.62	<0.05	0.98	<0.05	0.06
9.370	0.30	<0.05	15.11	78.4	<0.1	<0.1	0.31	4.82	<0.05	0.85	<0.05	0.08
9.420	0.88	<0.05	15.05	75.0	<0.1	<0.1	0.19	7.66	0.20	0.77	<0.05	0.09
9.469	3.91	0.14	19.03	64.0	0.42	0.11	0.21	9.60	1.36	0.95	<0.05	0.18
9.520	1.38	0.39	15.68	66.4	<0.1	<0.1	<0.1	12.08	2.73	0.77	<0.05	0.38
9.570	1.31	0.69	13.94	67.2	<0.1	<0.1	<0.1	11.27	4.04	0.63	<0.05	0.61
9.620	1.43	1.08	12.69	66.9	0.15	<0.1	<0.1	10.59	5.66	0.48	0.13	0.78
9.670	1.35	1.39	11.83	66.7	0.19	<0.1	<0.1	10.13	6.77	0.52	0.13	0.96
9.720	1.32	1.60	11.22	66.2	0.21	<0.1	<0.1	9.66	7.92	0.52	0.13	0.99

APPENDIX 6: CHEMICAL COMPOSITION OF CRUCIBLE 60

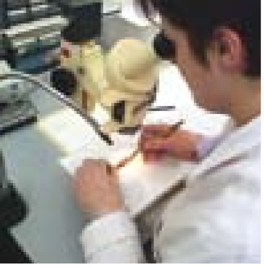
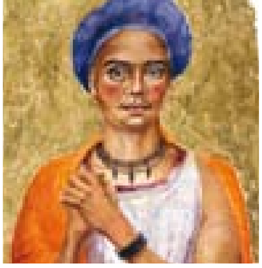
Distance (mm)	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	Cl	K_2O	CaO	TiO_2	MnO	Fe_2O_3
-10.301	4.58	5.32	5.98	57.0	1.50	0.10	<0.1	6.36	16.11	0.54	0.76	1.48
-10.250	4.58	4.21	6.95	61.7	0.91	0.10	<0.1	7.83	11.02	0.53	0.60	1.31
-10.200	4.47	3.55	8.73	63.4	0.88	<0.1	<0.1	8.97	7.67	0.44	0.35	1.27
-10.150	4.34	2.80	11.36	63.0	0.61	<0.1	<0.1	9.68	5.94	0.48	0.33	1.13
-10.100	4.75	1.91	14.72	61.8	0.36	<0.1	<0.1	10.31	4.27	0.59	0.22	0.84
-10.027	1.30	<0.05	22.42	55.8	<0.1	<0.1	<0.1	18.57	0.25	1.15	<0.05	0.28
-10.002	3.91	<0.05	22.39	57.4	0.17	<0.1	<0.1	13.80	0.25	1.63	<0.05	0.27
-9.938	4.41	0.21	21.08	61.9	<0.1	<0.1	<0.1	9.99	0.17	1.91	<0.05	0.24
-9.876	2.11	<0.05	24.94	61.7	<0.1	<0.1	<0.1	8.91	0.14	2.08	<0.05	0.08
-9.829	1.24	<0.05	24.90	64.9	<0.1	<0.1	<0.1	6.92	0.09	2.11	<0.05	0.03
-9.751	1.61	0.10	27.76	60.7	<0.1	<0.1	<0.1	7.54	0.13	1.65	<0.05	0.18
-9.694	1.11	0.05	27.96	62.7	<0.1	<0.1	<0.1	6.16	0.09	1.81	<0.05	0.18
-9.651	0.96	0.10	25.81	65.2	0.10	<0.1	<0.1	5.58	0.11	1.87	<0.05	0.29
-9.582	0.86	0.12	29.79	61.8	0.18	<0.1	<0.1	4.75	0.07	1.75	<0.05	0.53
-9.532	0.67	0.20	26.27	64.8	0.13	<0.1	<0.1	4.82	0.11	2.01	<0.05	0.64
-9.469	0.73	0.22	27.90	63.5	0.21	<0.1	<0.1	4.42	0.11	1.98	<0.05	0.85
-9.419	0.67	0.35	28.23	63.3	0.11	<0.1	<0.1	4.21	0.13	2.00	<0.05	0.98
-9.347	0.70	0.32	25.96	65.2	0.14	<0.1	<0.1	4.41	0.11	2.03	<0.05	1.01
-9.314	0.62	0.31	31.37	60.5	0.12	<0.1	<0.1	3.77	0.17	1.93	<0.05	1.09
-9.272	0.57	0.32	30.61	61.4	0.18	<0.1	<0.1	3.74	0.14	1.98	<0.05	1.09
-9.210	0.68	0.42	24.99	66.3	0.14	<0.1	<0.1	4.10	0.17	2.07	<0.05	1.09
-9.154	0.59	0.43	28.76	63.1	0.19	<0.1	<0.1	3.67	0.16	1.91	<0.05	1.17
-9.103	0.63	0.43	25.60	66.1	0.11	<0.1	<0.1	3.89	0.18	1.87	<0.05	1.08
-9.045	0.61	0.48	25.46	66.2	0.16	<0.1	<0.1	3.86	0.20	1.86	<0.05	1.11
-8.992	0.55	0.46	26.95	64.9	0.13	0.11	<0.1	3.56	0.23	1.90	<0.05	1.14
-8.902	0.54	0.48	29.72	62.6	<0.1	<0.1	<0.1	3.17	0.28	1.81	<0.05	1.22
-8.847	0.50	0.41	33.24	59.4	0.14	<0.1	<0.1	2.94	0.23	1.71	<0.05	1.26
-8.790	0.49	0.46	30.92	61.3	0.14	<0.1	<0.1	3.09	0.27	1.74	<0.05	1.34
-8.725	0.61	0.54	25.10	66.7	0.10	<0.1	<0.1	3.46	0.37	1.79	<0.05	1.23
-8.668	0.56	0.45	28.26	64.0	0.15	<0.1	<0.1	3.18	0.29	1.75	0.06	1.27
-8.612	0.44	0.54	31.03	61.3	0.15	<0.1	<0.1	3.00	0.29	1.99	<0.05	1.36
-8.559	0.38	0.49	34.23	58.4	0.16	<0.1	<0.1	2.64	0.31	1.92	<0.05	1.42
-8.506	0.49	0.51	33.72	58.8	0.13	<0.1	<0.1	2.68	0.31	1.92	<0.05	1.40
-8.439	0.52	0.56	27.25	64.8	0.19	<0.1	<0.1	3.13	0.38	1.88	<0.05	1.24
-8.379	0.44	0.67	26.86	65.3	<0.1	<0.1	<0.1	3.18	0.41	1.87	<0.05	1.22
-8.313	0.51	0.61	28.14	63.8	0.13	<0.1	<0.1	2.97	0.39	1.95	0.05	1.32
-8.253	0.49	0.50	31.11	61.2	0.12	<0.1	<0.1	2.73	0.36	2.09	0.05	1.30
-8.172	0.46	0.50	31.04	61.6	0.20	<0.1	<0.1	2.66	0.36	1.83	<0.05	1.27
-8.114	0.41	0.56	30.07	62.5	<0.1	<0.1	<0.1	2.72	0.39	1.94	<0.05	1.23
-8.061	0.36	0.55	33.14	59.5	0.19	<0.1	<0.1	2.50	0.37	2.02	<0.05	1.38
-8.000	0.36	0.59	28.69	63.7	<0.1	<0.1	<0.1	2.73	0.49	1.96	<0.05	1.29

Distance (mm)	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	Cl	K_2O	CaO	TiO_2	MnO	Fe_2O_3
-7.997	0.46	0.52	27.93	64.6	<0.1	<0.1	<0.1	2.72	0.37	1.90	<0.05	1.27
-7.951	0.46	0.59	25.05	66.9	0.19	<0.1	<0.1	3.04	0.38	2.07	<0.05	1.28
-7.898	0.35	0.46	30.81	61.8	0.10	<0.1	<0.1	2.62	0.38	2.09	<0.05	1.35
-7.848	0.39	0.53	29.30	63.2	<0.1	<0.1	<0.1	2.62	0.40	2.05	<0.05	1.32
-7.800	0.37	0.53	31.33	61.3	0.14	<0.1	<0.1	2.49	0.42	2.12	<0.05	1.33
-7.745	0.40	0.45	30.19	62.3	0.17	<0.1	<0.1	2.57	0.44	2.17	<0.05	1.38
-7.689	0.44	0.58	31.22	61.0	0.14	0.11	<0.1	2.42	0.60	1.95	<0.05	1.50
-7.635	0.36	0.55	28.91	63.4	0.19	<0.1	<0.1	2.53	0.49	1.99	<0.05	1.46
-7.634	0.44	0.50	28.97	63.5	<0.1	<0.1	<0.1	2.59	0.43	2.02	<0.05	1.35
-7.583	0.42	0.54	29.90	62.8	0.12	<0.1	<0.1	2.53	0.43	1.95	<0.05	1.25
-7.553	0.41	0.60	29.04	63.2	0.16	<0.1	<0.1	2.43	0.48	1.99	0.05	1.46
-7.527	0.32	0.55	29.89	62.7	0.11	<0.1	<0.1	2.42	0.50	1.91	<0.05	1.36
-7.500	0.37	0.54	28.55	63.9	0.15	0.11	<0.1	2.36	0.48	2.02	<0.05	1.44
-7.492	0.44	0.52	30.11	61.9	<0.1	0.17	<0.1	2.35	0.70	1.94	<0.05	1.58
-7.458	0.36	0.60	31.71	61.0	0.11	<0.1	<0.1	2.41	0.42	1.99	<0.05	1.41
-7.409	0.30	0.55	27.66	65.1	0.20	<0.1	<0.1	2.33	0.52	1.91	<0.05	1.40
-7.407	0.38	0.57	27.79	64.5	0.14	<0.1	<0.1	2.68	0.45	2.10	<0.05	1.32
-7.346	0.39	0.53	29.32	63.1	0.13	<0.1	<0.1	2.60	0.46	2.08	0.05	1.38
-7.295	0.30	0.50	30.79	62.0	0.15	<0.1	<0.1	2.48	0.47	2.05	<0.05	1.37
-7.249	0.29	0.52	29.47	63.2	<0.1	<0.1	<0.1	2.57	0.49	2.02	<0.05	1.36
-7.005	0.35	0.53	28.01	64.8	0.14	<0.1	<0.1	2.19	0.53	1.86	<0.05	1.44
-6.492	0.39	0.62	30.03	62.2	0.19	0.12	<0.1	2.10	0.70	2.02	<0.05	1.66
-5.492	0.26	0.50	27.92	65.0	0.21	<0.1	<0.1	1.96	0.64	1.88	<0.05	1.52
-4.531	0.28	0.55	28.95	63.5	0.11	<0.1	<0.1	2.22	0.64	2.05	<0.05	1.61
-3.532	0.26	0.54	27.78	65.2	0.12	<0.1	<0.1	1.97	0.56	2.01	<0.05	1.51
-2.532	0.28	0.51	27.23	66.0	0.13	<0.1	<0.1	1.93	0.55	1.86	<0.05	1.50
-1.533	0.32	0.61	29.69	62.8	0.18	<0.1	<0.1	2.11	0.70	1.95	<0.05	1.59
-0.532	0.35	0.54	28.90	63.8	0.14	0.11	<0.1	2.07	0.64	1.96	<0.05	1.56
0.546	0.28	0.52	26.66	66.8	<0.1	0.12	<0.1	1.77	0.60	1.71	<0.05	1.40
1.547	0.33	0.51	28.84	64.1	0.12	<0.1	<0.1	1.93	0.63	1.91	<0.05	1.50
2.546	0.43	0.62	29.36	63.3	0.12	<0.1	<0.1	1.89	0.65	1.87	0.06	1.60
3.546	0.42	0.56	28.28	64.6	<0.1	<0.1	<0.1	1.83	0.61	1.94	0.05	1.41
4.280	0.51	0.56	27.04	65.7	0.15	<0.1	<0.1	1.83	0.60	1.91	<0.05	1.42
4.780	0.55	0.60	29.48	62.8	0.13	<0.1	<0.1	2.05	0.58	1.96	<0.05	1.57
4.952	0.50	0.55	28.46	64.1	<0.1	<0.1	<0.1	2.08	0.56	2.00	<0.05	1.37
5.064	0.48	0.50	26.43	66.8	0.15	<0.1	<0.1	1.95	0.46	1.94	<0.05	1.34
5.165	0.58	0.55	28.50	63.8	0.11	<0.1	<0.1	2.21	0.56	1.97	<0.05	1.49
5.268	0.71	0.52	29.25	62.6	0.21	<0.1	<0.1	2.30	0.53	2.10	<0.05	1.58
5.368	0.42	0.43	23.24	71.3	0.11	<0.1	<0.1	1.42	0.45	1.47	<0.05	1.00
5.466	0.41	0.32	20.57	74.3	0.17	<0.1	<0.1	1.37	0.39	1.35	<0.05	0.99
5.565	0.66	0.56	31.05	60.5	0.13	<0.1	<0.1	2.58	0.63	2.15	<0.05	1.55
5.662	0.48	0.39	23.68	70.3	0.15	<0.1	<0.1	1.79	0.32	1.66	0.06	1.14

Distance (mm)	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	Cl	K_2O	CaO	TiO_2	MnO	Fe_2O_3
5.776	0.68	0.51	29.40	62.5	0.11	<0.1	<0.1	2.78	0.32	2.12	<0.05	1.46
5.897	0.73	0.44	30.04	62.2	<0.1	<0.1	<0.1	2.73	0.29	2.05	<0.05	1.39
5.993	0.75	0.38	27.91	64.1	0.17	<0.1	<0.1	2.70	0.32	2.05	<0.05	1.41
6.095	0.92	0.31	31.59	60.5	0.17	<0.1	<0.1	3.10	0.19	1.87	<0.05	1.24
6.190	1.81	0.22	28.63	60.5	0.15	<0.1	<0.1	5.99	0.14	1.83	<0.05	0.79
6.291	2.97	0.51	29.15	56.4	0.16	<0.1	<0.1	7.44	0.15	1.79	<0.05	1.35
6.377	1.49	0.06	32.28	58.5	<0.1	<0.1	<0.1	5.19	0.09	1.86	<0.05	0.43
6.422	2.85	0.12	29.55	58.2	0.12	<0.1	<0.1	6.78	0.13	1.83	<0.05	0.35
6.538	1.56	0.21	23.60	53.5	0.18	<0.1	<0.1	18.78	0.62	0.94	<0.05	0.48
6.601	1.30	0.28	22.61	53.7	0.27	<0.1	<0.1	18.88	1.17	1.02	<0.05	0.63
6.707	4.96	1.51	19.28	54.9	0.56	<0.1	<0.1	12.30	3.93	1.22	0.18	0.89
6.799	6.88	2.76	15.51	57.1	0.88	<0.1	<0.1	8.34	6.15	0.96	0.23	0.99
6.895	6.52	4.98	9.41	57.8	1.83	<0.1	<0.1	6.82	10.10	0.68	0.37	1.18

APPENDIX 7: CHEMICAL COMPOSITION OF CRUCIBLE 61

Distance (mm)	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	Cl	K_2O	CaO	TiO_2	MnO	Fe_2O_3
7.352	0.19	0.40	18.91	76.6	<0.1	<0.1	<0.1	1.43	0.12	1.07	<0.05	1.00
5.672	0.16	0.42	19.73	75.7	<0.1	<0.1	<0.1	1.52	0.2	1.19	<0.05	1.02
4.109	0.16	0.54	20.41	74.3	0.16	<0.1	<0.1	1.58	0.19	1.24	<0.05	1.20
2.190	0.17	0.37	19.99	75.2	0.15	<0.1	<0.1	1.42	0.19	1.13	<0.05	1.21
0.391	0.14	0.39	19.72	75.2	0.11	<0.1	<0.1	1.60	0.13	1.46	<0.05	1.03
-0.703	0.16	0.38	19.60	75.9	<0.1	<0.1	<0.1	1.42	0.16	1.14	<0.05	1.02
-1.727	0.10	0.39	20.08	75.2	0.11	<0.1	<0.1	1.52	0.16	1.23	<0.05	1.07
-2.616	0.15	0.43	19.05	76.1	<0.1	0.14	<0.1	1.53	0.15	1.25	<0.05	1.07
-3.632	0.14	0.41	19.37	75.8	<0.1	0.13	<0.1	1.54	0.16	1.37	<0.05	1.01
-4.358	0.10	0.40	19.32	75.9	0.15	<0.1	<0.1	1.52	0.15	1.25	<0.05	1.11



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