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HORSEBRIDGE, WISBOROUGH GREEN, WEST SUSSEX EXAMINATION OF GLASS AND GLASSWORKING DEBRIS

TECHNOLOGY REPORT

David Dungworth and Colin Clark

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Examination of glass and glassworking debris

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SUMMARY
The chemical analysis of glassworking debris from the site of a Wealden glasshouse provides information on the nature of the glass produced and the refractory materials used. The analysis of the glassworking debris shows that a high-lime low-alkali glass was used to manufacture both vessel and window glass. This glass type was only produced in Britain after the arrival of French glassmakers from 1567. While broadly similar to other late Wealden sites, the glass produced at Horsebridge shows some small but distinct differences compared to available data from other late Wealden glasshouses. The refractory material used comprised two different types of clay. The crucibles were manufactured using a grog-tempered clay which was probably imported from Dorset(?), while the furnace bricks were manufactured using a local, quartz-tempered clay.

ACKNOWLEDGEMENTS
We would like to thank Colin and Alison Jekyll who provided the samples for analysis.

ARCHIVE LOCATION
The samples taken for scientific analysis are held by English Heritage, Fort Cumberland, Portsmouth, PO4 9LD

DATE OF RESEARCH
2005–2010

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INTRODUCTION

Horsebridge is the likely site of a post-medieval furnace used for the manufacture of glass (Kenyon 1967, 188). Winbolt discovered the site on Boxing Day 1930 and reported the recovery of substantial quantities of glass, glassworking debris and 'Rhenish brown speckled ware' from the garden, although no remains of the furnace were identified (Winbolt 1933, 44; Kenyon 1967, 189). The glass from the site has been described as 'unmistakably Late' (Kenyon 1967, 188) and the scatter of Rhenish pottery is consistent . The analysis of the glassworking debris from this site contributes to the Wealden Glass Industry Project, funded by English Heritage (Historic Environment Enabling Programme Project Number 5299) and undertaken by the Surrey County Archaeological Unit.

THE GLASSWORKING DEBRIS

Table 1. Samples selected for analysis

#	Description	Colour
1	Droplet	Green
2	Droplet	Green
3	Droplet	Green
4	Droplet	Green
5	Droplet	Green
6	Droplet	Green
7	Moil	Green
8	Moil	Blue-green
9	Run/pull	Green
10	Vessel fragment	Green
11	Vessel fragment	Blue-green
12	Vessel fragment	Green
13	Window fragment	Blue-green
14	Window fragment	Green
15	Window fragment	Green
16	Window fragment	Blue-green
17	Window fragment	Blue-green
18	Window fragment	Blue-green
19	Window fragment	Blue-green
20	Crucible fragment	
21	Crucible fragment	
22	Crucible fragment	
23	Crucible fragment	
24	Three furnace bricks with 'glazed' surface	
25	Furnace brick with 'glazed' surface	

A selection of glassworking waste (runs, drips and moils), glass artefacts (including vessel and window glass), crucible and furnace bricks (Table 1) were made available for analysis by Colin and Alison Jekyll.

Figure 1. Glass and glassworking debris (with sample numbers)

METHODS

All of the fragments of glass and glassworking debris were mounted in epoxy resin then ground and polished to a 1-micron finish to expose a cross-section. The samples were inspected using an optical microscope (brightfield and darkfield illumination) to identify corroded and uncorroded regions. Where possible, 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 (especially where $Z < 23$) while the energy dispersive X-ray fluorescence spectrometer provided improved sensitivity (ie limits of detection) for many minor elements (especially where $Z > 23$) due to improved peak to background ratios.

The SEM used was a FEI Inspect F which was operated at 25kV with a beam current of approximately 1.2nA. The X-ray spectra 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%).

Table 2. Minimum Detection limits (MDL) and analytical errors for each oxide

	SEM-EDS			EDXRF	
	MDL	Error		MDL	Error
Na_2O	0.1	0.1	V_2O_5	0.02	0.03
MgO	0.1	0.1	Cr_2O_3	0.02	0.03
Al_2O_3	0.1	0.1	MnO	0.02	0.03
SiO_2	0.1	0.2	Fe_2O_3	0.02	0.03
P_2O_5	0.1	0.1	CoO	0.01	0.01
SO_3	0.1	0.1	NiO	0.01	0.01
Cl	0.1	0.1	CuO	0.01	0.01
K_2O	0.1	0.1	ZnO	0.01	0.01
CaO	0.1	0.1	As_2O_3	0.02	0.01
TiO_2	0.1	0.1	SnO_2	0.1	0.05
BaO	0.2	0.1	Sb_2O_5	0.15	0.07
			Rb_2O	0.005	0.005
			SrO	0.005	0.005
			ZrO_2	0.005	0.005
			Bi_2O_3	0.03	0.02
			PbO	0.03	0.02

The EDXRF used was an EDAX Eagle II which was operated at 40kV with a current of 1mA. The Eagle II was fitted with a glass capillary to focus the X-Ray beam on an area approximately 0.3mm in diameter. This meant that it was possible to obtain EDXRF data for the bulk composition of the samples but not for the 'linescans' taken through the vitrified surfaces and/or adhering glass of the crucible samples.

The accuracy of the quantification of all oxides (both SEM-EDS and EDXRF) was checked by analysing a wide range reference materials (Corning, NIST, DGG and Newton/Pilkington). A number of elements were sought but not detected: vanadium, chromium, cobalt, tin, antimony.

RESULTS

Glassworking debris and glass

The glassworking debris from Horsebridge is all rich in calcium with relatively low proportions of alkalis (sodium and potassium). As such this glass is similar to other high-lime low-alkali (HLLA) glass produced in the Weald after the arrival of French glassmakers from 1567. This HLLA glass is quite different to the potassium-rich glass produced at earlier sites such as Blunden's Wood (Dungworth and Paynter 2010). The finished glass artefacts found at Horsebridge share almost identical compositions with the Horsebridge glassworking debris. This includes both vessel and window glass samples suggesting that both types of glass were produced at the one glasshouse. While there are similarities between the HLLA glass produced at Horsebridge and other late Wealden sites, there are small differences in the composition of the glass produced at each site (Figures 2 and 3; Table 3).

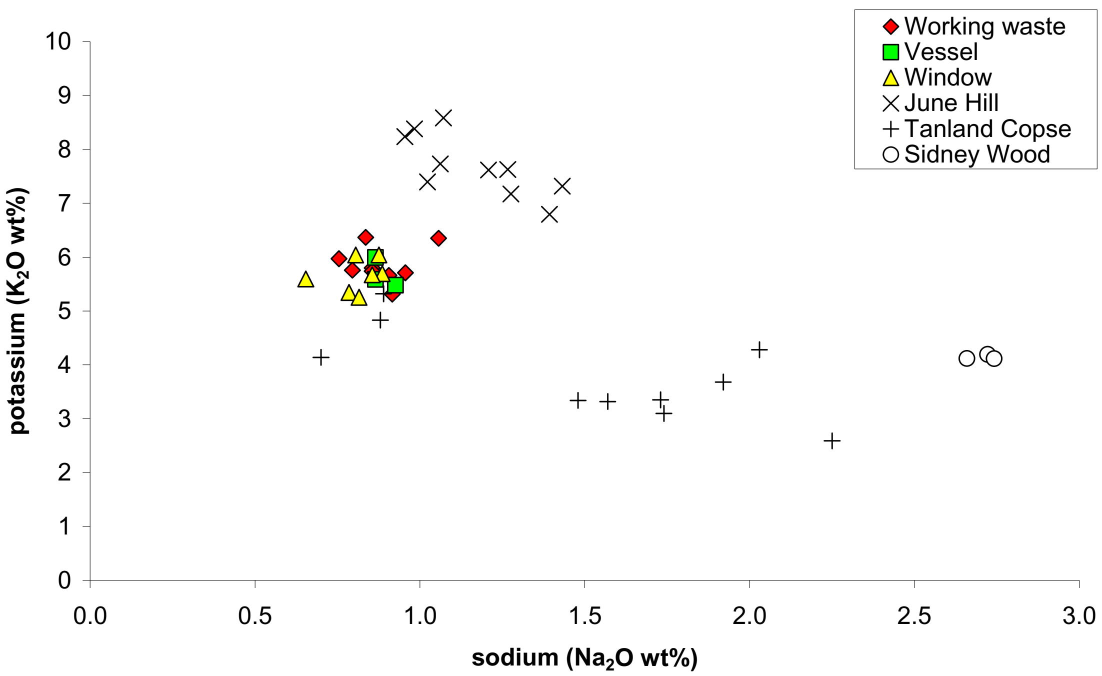

Figure 2. Sodium and potassium content of the Horsebridge glass samples compared with data from other late Wealden sites: Tanland (Dungworth and Clark 2004), June Hill (Dungworth 2007) and Sidney Wood (Welham 2001)

Table 3. Average composition of glass from late Wealden sites

Site	Na_2O	MgO	Al_2O_3	P_2O_5	K_2O	CaO	MnO	Fe_2O_3
Horsebridge	0.9±0.1	3.6±0.5	2.1±0.4	2.1±0.3	5.9±0.3	20.4±1.3	1.7±0.2	1.0±0.2
June Hill	1.2±0.2	4.2±0.3	2.3±0.4	2.3±0.2	7.7±0.6	19.2±1.2	0.9±0.5	0.9±0.3
Tanland Copse	1.5±0.5	2.8±0.2	2.2±0.2	2.2±0.2	3.8±0.8	24.2±1.0	0.7±0.1	1.2±0.1
Sidney Wood	2.7±0.1	2.9±0.1	3.9±0.1	1.7±0.1	4.1±0.1	22.9±0.1	0.7±0.1	1.3±0.1

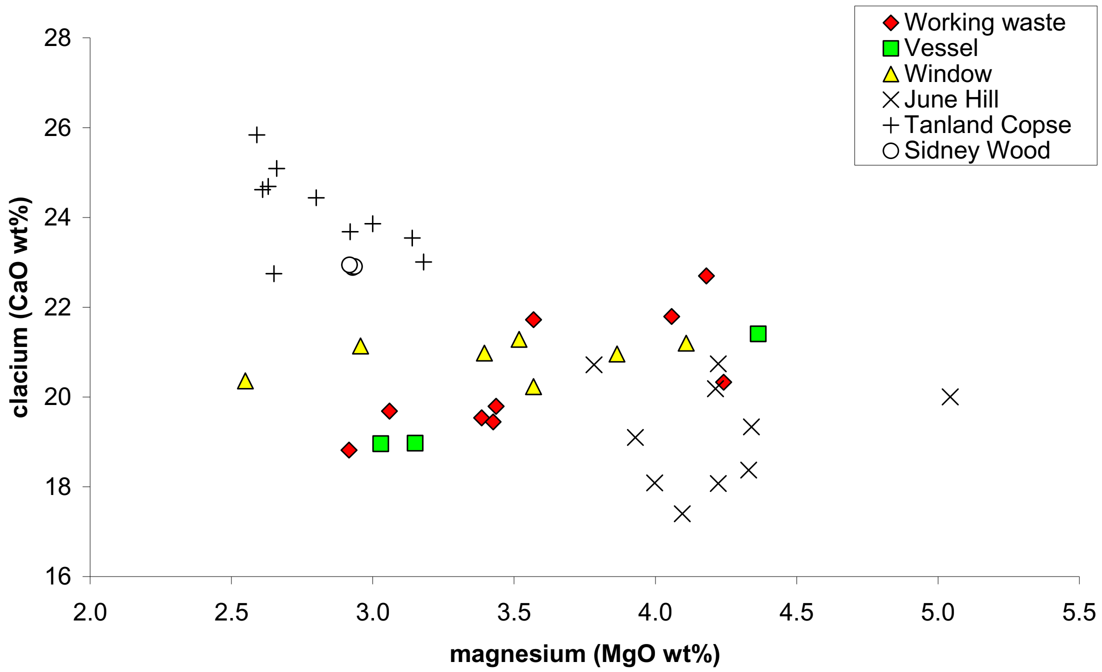

Figure 3. Magnesium and calcium content of the Horsebridge glass samples compared with data from other late Wealden sites: Tanland (Dungworth and Clark 2004), June Hill (Dungworth 2007) and Sidney Wood (Welham 2001)

Crucible and furnace fragments

Four crucible samples were examined; each with interior surfaces with glass adhering. The ceramic fabric of these crucibles comprised a vitrified clay with fine quartz particles. In addition, these crucibles contained grog inclusions (Figure 4). These grog particles are characterised by more extreme vitrification and shrinkage cracks around their circumferences. This fabric contrasts with the fragments of brick from the furnace which do not contain any grog inclusions (Figure 5). The Horsebridge grog-tempered crucible fabric is similar to that of crucible fabric from other late Wealden sites (Paynter forthcoming), while the quartz-tempered brick fabric is similar to that of crucible fabric from early Wealden sites (Paynter forthcoming; Dungworth and Paynter 2010). The difference in fabric seen in the crucible micromorphology can also be detected in the chemical composition of the crucibles and bricks (Figure 6). The late refractories tend to have higher alumina and titanium but lower silica and iron contents (cf Paynter forthcoming). The differences between the clays used for the Horsebridge crucibles and furnace bricks suggests that these clays were obtained from separate sources.

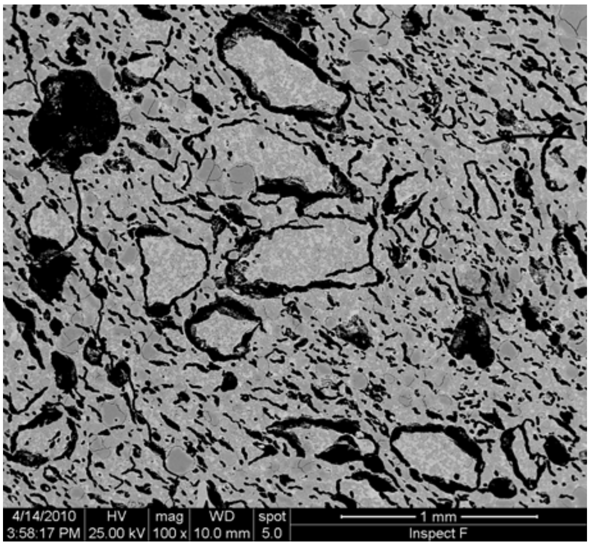

Figure 4. SEM image (back-scattered electron detector) showing the ceramic fabric of crucible 22. This shows the presence of grog inclusions with rather sparse quartz particles

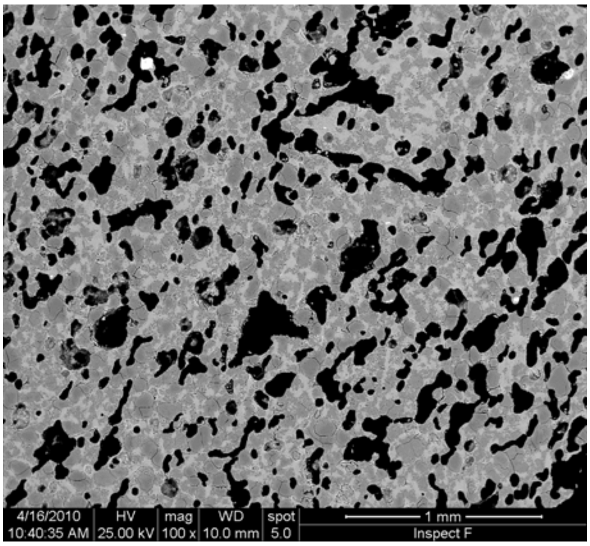

Figure 5. SEM image (back-scattered electron detector) showing the ceramic fabric of brick 25. This shows an absence of grog inclusions but abundant, small quartz particles

The four crucible fragments were analysed to determine the chemical composition of the glass adhering to the interior surfaces and any interaction between this glass and the ceramic fabric of the crucible (cf Dungworth 2008). A series of analyses were taken through the glass adhering to the interior surface and into the underlying ceramic (Figures 7 and 8). Due to the thinness of the adhering glass (<1mm) the glass adhering to the interior surfaces of the crucibles have compositions which do not match the composition of the glassworking debris reported above. The glass adhering to the interior surfaces shows evidence of interaction with the ceramic fabric of the crucibles, in particular, elevated levels of aluminium and titanium. The lowest concentrations of aluminium in the adhering glass were between 6 and 12wt% (Al_2O_3) while the glassworking debris averaged 2.1wt%.

The adhering glass also exhibited elevated levels of potassium (Figure 8); in many cases the potassium concentration in the adhering glass was higher than that of the ceramic fabric of the crucibles and the working waste. The elevation of potassium content was most marked in the glass within a few hundred microns of the glass-ceramic boundary. This phenomenon has been detected in other post-medieval crucibles used to melt HLLA glass (Dungworth 2008) and appears to be related to diffusion-controlled mechanisms within this vitreous layer. The compositional differences between the adhering glass and the glassworking debris may also be due in part to other reactions with the furnace, such as attack by alkali-rich vapour volatilised from fuel ash.

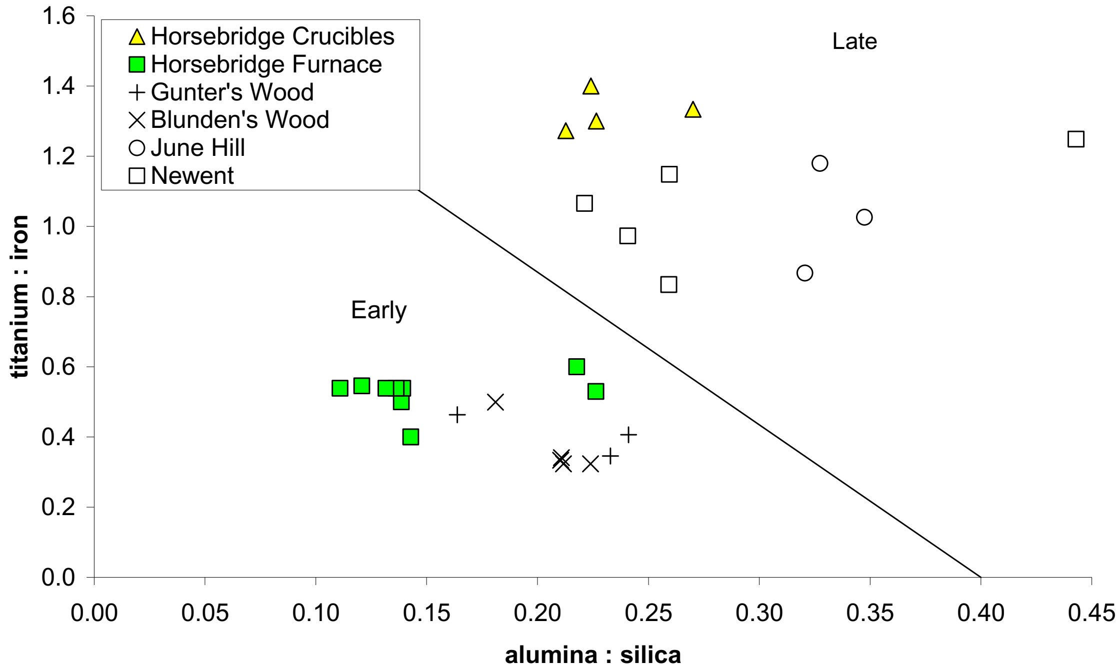

Figure 6. Alumina : silica and titanium : iron ratios of Horsebridge crucibles and bricks compared with refractories from early and late sites: Gunter's Wood (Dungworth 2010a), Blunden's Wood (Dungworth and Paynter 2010), June Hill (Dungworth 2007) and Newent (Dungworth 2010b)

The vitreous surfaces of the two brick samples (24 and 25) were also investigated (Figure 9 and 10). These vitreous surfaces displayed elevated concentrations of alkalis but lower concentrations of other elements characteristic of the glass manufactured at Horsebridge (especially magnesium, phosphorus and calcium). The two brick fragments are assumed to have derived from part of the furnace superstructure, although their exact location within this superstructure is unknown. While the vitreous surfaces of these samples may have formed in part due to the spillage of glass on them, it is likely that attack by alkali-rich vapour volatilised from fuel ash was more significant. The relatively low concentrations of alkali earth elements in these vitreous layers supports the suggestion that they formed primarily through reactions between the bricks and volatile alkalis.

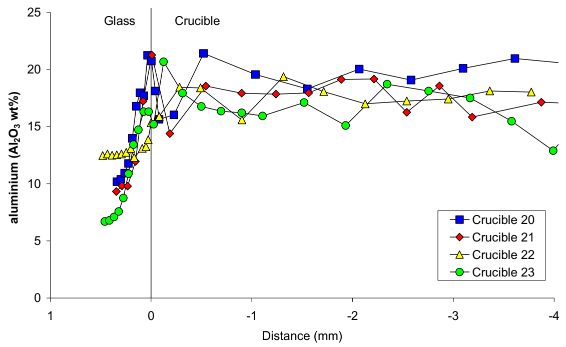

Figure 7. Aluminium concentration of the crucibles and the glass adhering to the interior surfaces

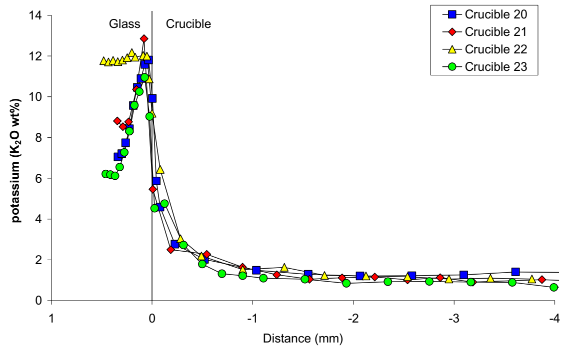

Figure 8. Potassium concentration of the crucibles and the glass adhering to the interior surfaces

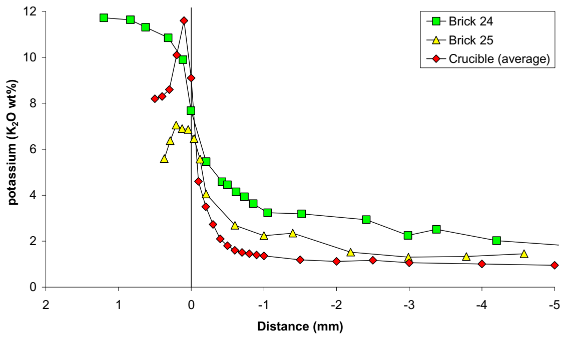

Figure 9. Potassium concentration of the vitreous surfaces of the refractory materials

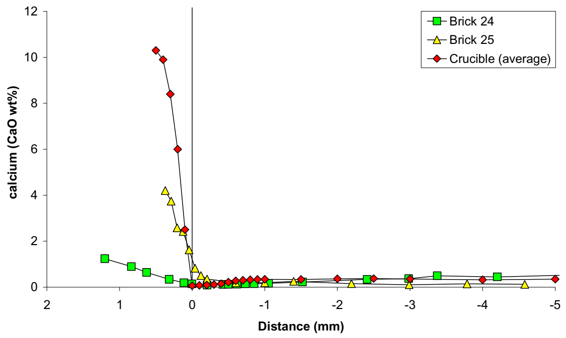

Figure 10. Calcium concentration of the vitreous surfaces of the refractory materials

DISCUSSION

The chemical analysis of the Horsebridge glassworking debris has shown that one type of glass was produced: HLLA glass. This type of glass was produced on Wealden sites after the arrival of French glassmakers from 1567. The chemical analysis therefore confirms the late date for the site suggested by the associated domestic pottery. The compositional similarities between the glassworking debris and the finished glass suggest that the Horsebridge glasshouse produced both window and vessel glass.

A comparison of the composition of glass produced at four late Wealden sites (Horsebridge, June Hill, Tanland Copse and Sidney Wood) suggests that there are small but distinct differences between each site. This raises the possibility that the chemical analysis of extant 16th-century (vessel or window) glass might allow it to be traced back to a single production site. Unfortunately there are perhaps as many as twenty or more late Wealden sites for which no glass composition data is available.

The analysis of glassworking debris from Horsebridge has also included four crucibles and two furnace bricks. While the crucibles are made from a typical late Wealden grog-tempered clay (cf Paynter forthcoming) the furnace bricks are made from a quartz-tempered clay that is typical of refractories produced before the arrival of French glassmakers from 1567. Paynter (forthcoming) has suggested that the late Wealden grog-tempered clays used raw materials obtained from distant sources (eg Dorset?). Transport costs for this clay would perhaps encourage Wealden glassmakers to continue to use local clays for less critical refractories, such as furnace bricks, and reserve the imported clay for crucibles only.

The vitrified surfaces/adhering glass on the interior surfaces of the crucibles do not share the same composition as the glassworking debris due to a variety of factors, especially the interaction between the glass and the ceramic fabric of the crucible. The furnace bricks have vitrified surfaces which are rich in alkalis but contain low concentrations of alkali earth elements (compared to the vitreous surfaces of the crucibles). The vitrified surfaces of the furnace bricks are likely to have formed primarily due to reactions between the ceramic fabric of the bricks and the alkali-rich volatile fraction derived from the fuel ash (cf Paynter *et al* 2005, 14).

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APPENDIX I

Bulk analysis: major and minor elements

sample	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	K_2O	CaO	TiO_2	MnO	Fe_2O_3
#01	0.91	3.39	2.28	62.6	2.08	0.25	5.66	19.54	0.31	1.61	1.25
#02	0.86	3.06	2.05	63.7	1.88	0.37	5.80	19.69	0.27	1.36	0.87
#03	0.92	2.92	2.37	64.6	1.56	0.29	5.31	18.82	0.35	1.73	1.13
#04	0.84	3.57	1.62	60.6	2.14	0.40	6.37	21.72	0.24	1.51	0.79
#05	0.80	4.24	2.25	60.8	1.99	0.30	5.76	20.33	0.32	2.17	1.00
#06	0.76	3.44	1.61	63.1	2.16	0.38	5.97	19.79	0.25	1.64	0.74
#07	1.06	4.06	2.57	57.8	2.53	0.26	6.35	21.79	0.38	1.66	1.42
#08	0.86	3.43	1.70	63.8	1.94	0.36	5.74	19.45	0.23	1.49	0.77
#09	0.96	4.18	2.19	58.3	2.20	0.32	5.71	22.70	0.33	1.91	1.02
#10	0.93	3.15	2.60	63.0	2.27	0.32	5.48	18.97	0.35	1.28	1.55
#11	0.87	4.36	2.13	59.2	2.21	0.25	5.99	21.41	0.31	2.15	0.95
#12	0.87	3.03	2.28	63.8	1.52	0.32	5.58	18.96	0.38	2.02	1.15
#13	0.65	3.86	1.35	63.0	1.71	0.25	5.59	20.96	0.23	1.78	0.57
#14	0.81	4.11	2.31	59.8	2.20	0.23	6.04	21.20	0.33	1.87	0.97
#15	0.89	3.57	2.32	61.8	1.88	0.29	5.69	20.23	0.30	1.83	1.10
#16	0.88	3.52	1.93	61.1	2.13	0.21	6.04	21.29	0.30	1.64	0.89
#17	0.86	2.96	2.12	62.3	1.99	0.23	5.67	21.14	0.29	1.33	0.94
#18	0.79	3.40	2.09	62.3	1.83	0.41	5.34	20.98	0.31	1.58	0.90
#19	0.82	2.55	1.92	64.7	1.73	0.32	5.26	20.36	0.25	1.13	0.95
#20	0.32	0.24	20.08	74.4	0.11	<0.1	1.28	0.45	1.57	<0.02	1.22
#21	0.08	0.21	17.52	78.1	0.13	<0.1	1.03	0.25	1.38	<0.02	1.04
#22	0.17	0.19	17.60	77.7	<0.1	<0.1	1.25	0.27	1.34	0.03	1.05
#23	0.32	0.16	16.67	78.5	0.18	<0.1	0.85	0.35	1.44	0.05	1.07
#24B1	0.11	0.49	10.26	85.3	0.11	<0.1	1.61	0.28	0.65	0.02	1.10
#24B2	0.11	0.54	11.38	83.7	0.12	<0.1	1.69	0.31	0.75	<0.02	1.33
#24B3	<0.1	0.45	11.13	84.3	0.11	<0.1	1.47	0.26	0.66	<0.02	1.26
#24M1	0.19	0.76	16.50	75.8	0.11	<0.1	3.64	0.39	0.90	0.09	1.54
#24M2	0.12	0.71	17.16	76.0	0.12	<0.1	2.16	0.95	0.89	0.12	1.65
#25	0.23	0.43	11.83	82.6	<0.1	<0.1	1.40	0.13	0.78	0.12	1.95

Sample 24 has been divided into five components: three bricks (B) and two mortar (M)

Bulk analysis: minor and trace elements

sample	Cl	BaO	NiO	CuO	ZnO	As_2O_3	Rb_2O	SrO	ZrO_2	PbO	Bi_2O_3
#01	<0.1	0.31	0.01	0.01	0.03	0.03	0.010	0.125	0.043	<0.03	0.04
#02	0.12	0.23	0.01	<0.01	0.03	0.02	0.009	0.111	0.048	<0.03	<0.03
#03	<0.1	0.22	<0.01	<0.01	0.01	0.02	0.009	0.126	0.045	<0.03	<0.03
#04	<0.1	0.28	0.01	0.01	0.02	0.03	0.010	0.128	0.042	0.03	0.04
#05	<0.1	0.30	0.01	<0.01	0.02	0.04	0.012	0.142	0.040	0.03	0.04
#06	<0.1	0.28	<0.01	<0.01	0.02	0.03	0.011	0.123	0.046	<0.03	0.05
#07	<0.1	0.23	0.01	<0.01	0.03	0.04	0.011	0.126	0.039	0.03	0.05
#08	<0.1	0.29	0.01	<0.01	0.03	0.03	0.010	0.121	0.047	<0.03	0.04
#09	<0.1	0.28	<0.01	0.01	0.02	0.02	0.010	0.135	0.039	<0.03	<0.03
#10	0.11	0.24	0.01	<0.01	0.03	0.04	0.011	0.106	0.048	0.03	0.05
#11	<0.1	0.31	0.01	<0.01	0.01	0.05	0.011	0.140	0.041	0.04	0.05
#12	<0.1	0.23	0.01	<0.01	0.02	0.03	0.010	0.134	0.046	<0.03	<0.03
#13	<0.1	0.22	<0.01	<0.01	<0.01	<0.02	0.009	0.123	0.040	<0.03	<0.03
#14	<0.1	0.29	0.01	<0.01	0.02	0.03	0.011	0.128	0.042	<0.03	0.04
#15	<0.1	0.26	0.01	<0.01	0.02	0.02	0.011	0.129	0.044	<0.03	<0.03
#16	<0.1	0.24	0.01	<0.01	0.03	0.04	0.009	0.139	0.048	0.03	0.04
#17	<0.1	0.23	0.02	0.01	0.03	0.03	0.009	0.126	0.050	0.06	0.03
#18	<0.1	0.23	0.02	0.01	0.03	0.06	0.011	0.128	0.044	0.04	0.07
#19	<0.1	0.25	<0.01	<0.01	0.02	0.04	0.009	0.112	0.048	0.06	0.06
#20	<0.1	<0.2	<0.01	<0.01	<0.01	<0.02	0.010	0.017	0.077	0.03	<0.03
#21	<0.1	<0.2	<0.01	<0.01	<0.01	<0.02	0.006	0.027	0.074	<0.03	<0.03
#22	<0.1	<0.2	<0.01	<0.01	<0.01	<0.02	0.010	0.027	0.116	<0.03	<0.03
#23	<0.1	<0.2	<0.01	<0.01	<0.01	<0.02	0.008	0.022	0.097	<0.03	<0.03
#24B1	<0.1	<0.2	<0.01	<0.01	<0.01	<0.02	0.011	0.055	0.085	0.03	<0.03
#24B2	<0.1	<0.2	<0.01	<0.01	<0.01	<0.02	0.016	0.053	0.084	<0.03	<0.03
#24B3	<0.1	<0.2	<0.01	<0.01	<0.01	<0.02	0.011	0.055	0.051	<0.03	<0.03
#24M1	<0.1	<0.2	<0.01	<0.01	<0.01	<0.02	0.014	0.039	0.058	<0.03	<0.03
#24M2	<0.1	<0.2	<0.01	<0.01	<0.01	<0.02	0.017	0.054	0.064	0.04	<0.03
#25	<0.1	<0.2	<0.01	<0.01	0.02	<0.02	0.017	0.013	0.044	0.04	<0.03

Sample 24 has been divided into five components: three bricks (B) and two mortar (M)

APPENDIX 2

Linescan through crucible 20

(distance in millimetres, positive = glass, negative = ceramic)

distance	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	K_2O	CaO	TiO_2	MnO	Fe_2O_3
0.338	0.84	2.36	10.17	64.01	0.76	7.05	11.60	0.85	0.96	1.17
0.300	0.79	2.34	10.38	64.34	0.65	7.21	11.06	0.89	0.92	1.23
0.262	0.82	2.03	10.92	65.08	0.51	7.74	9.93	0.79	0.84	1.22
0.224	0.92	1.66	11.77	66.04	0.45	8.43	8.16	0.73	0.64	1.06
0.186	1.00	1.00	13.97	65.81	0.32	9.57	6.03	0.81	0.44	0.83
0.147	1.06	0.66	16.77	63.47	0.16	10.46	5.23	1.06	0.27	0.64
0.110	1.13	0.52	17.96	62.45	0.09	10.89	4.68	1.21	0.29	0.58
0.072	1.11	0.35	17.69	63.96	0.15	11.58	3.08	1.22	0.10	0.41
0.034	1.28	0.18	21.23	60.31	0.12	11.8	2.85	1.60	<0.1	0.26
-0.004	0.98	0.10	20.72	64.68	0.10	9.92	1.34	1.71	<0.1	0.20
-0.042	0.43	0.02	18.11	73.51	0.14	5.87	0.08	1.52	<0.1	0.18
-0.080	0.34	0.01	15.63	77.60	<0.1	4.59	0.05	1.39	<0.1	0.20
-0.227	0.24	0.10	16.02	78.49	0.19	2.77	0.09	1.39	<0.1	0.65
-0.521	0.25	0.23	21.40	72.57	0.20	2.02	0.25	1.72	<0.1	1.15
-1.036	0.31	0.22	19.55	74.65	<0.1	1.49	0.72	1.54	<0.1	1.13
-1.551	0.22	0.25	18.29	76.77	0.13	1.29	0.30	1.40	<0.1	1.04
-2.066	0.37	0.20	20.03	74.71	0.15	1.21	0.34	1.52	<0.1	1.10
-2.581	0.32	0.25	19.07	75.48	0.20	1.22	0.51	1.52	<0.1	1.23
-3.096	0.26	0.24	20.09	74.42	<0.1	1.26	0.40	1.61	<0.1	1.32
-3.611	0.34	0.25	20.95	72.89	0.15	1.41	0.46	1.74	<0.1	1.36
-4.131	0.34	0.23	20.52	73.63	0.12	1.38	0.43	1.60	<0.1	1.27
-4.668	0.39	0.24	22.17	72.68	<0.1	0.98	0.44	1.62	<0.1	1.31

APPENDIX 3

Linescan through crucible 21

(distance in millimetres, positive = glass, negative = ceramic)

distance	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	K_2O	CaO	TiO_2	MnO	Fe_2O_3
0.345	0.93	2.16	9.32	65.03	0.22	8.81	10.30	0.81	1.08	1.30
0.289	0.92	2.13	9.81	66.05	0.17	8.53	9.39	0.77	1.01	1.05
0.233	0.89	2.04	9.79	66.11	0.26	8.77	9.17	0.80	0.96	1.07
0.155	0.83	1.05	11.95	67.95	0.21	10.36	5.41	0.78	0.57	0.81
0.079	1.09	0.12	17.22	65.02	0.07	12.85	1.66	1.46	<0.1	0.19
-0.007	0.30	<0.1	21.26	70.79	0.13	5.46	0.06	1.91	<0.1	0.07
-0.186	0.16	<0.1	14.39	81.10	<0.1	2.50	0.07	1.32	<0.1	0.36
-0.544	0.12	0.21	18.54	76.38	<0.1	2.27	0.18	1.53	<0.1	0.66
-0.899	0.15	0.21	17.92	77.47	0.10	1.64	0.26	1.40	<0.1	0.77
-1.239	0.10	0.19	17.83	78.02	0.10	1.27	0.20	1.37	<0.1	0.81
-1.564	0.12	0.18	17.95	78.06	<0.1	1.05	0.22	1.33	<0.1	0.86
-1.888	<0.1	0.23	19.12	76.55	0.17	1.12	0.24	1.43	<0.1	1.00
-2.213	0.13	0.20	19.16	76.08	0.10	1.16	0.24	1.45	<0.1	1.15
-2.537	<0.1	0.21	16.25	79.63	0.11	1.02	0.21	1.40	<0.1	1.00
-2.862	<0.1	0.21	18.56	76.71	0.10	1.13	0.26	1.45	<0.1	1.10
-3.187	<0.1	0.18	15.83	80.09	0.19	0.91	0.23	1.30	<0.1	1.06
-3.873	0.10	0.18	17.13	78.44	0.15	1.03	0.27	1.35	<0.1	1.02
-4.559	<0.1	0.23	16.88	78.79	0.14	0.89	0.26	1.37	<0.1	1.00
-5.247	0.13	0.21	17.25	78.48	0.16	0.97	0.27	1.37	<0.1	1.08
-5.933	0.11	0.23	17.07	78.59	0.10	0.97	0.25	1.34	<0.1	1.09

APPENDIX 4

Linescan through crucible 22

(distance in millimetres, positive = glass, negative = ceramic)

distance	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	K_2O	CaO	TiO_2	MnO	Fe_2O_3
0.480	1.19	1.45	12.46	63.51	0.09	11.77	6.54	0.92	0.80	1.04
0.433	1.17	1.50	12.61	63.43	0.15	11.71	6.58	0.85	0.73	1.13
0.387	1.12	1.46	12.50	63.37	0.11	11.79	6.58	0.90	0.79	1.15
0.340	1.19	1.47	12.53	63.63	0.12	11.72	6.50	0.99	0.77	1.07
0.294	1.19	1.40	12.60	63.85	<0.1	11.80	6.23	0.91	0.79	0.99
0.247	1.28	1.21	12.75	64.41	0.13	11.92	5.49	0.94	0.70	0.95
0.201	1.06	1.09	13.08	65.58	0.13	12.17	4.40	0.94	0.54	0.85
0.168	1.08	1.00	12.29	67.49	<0.1	11.94	3.63	0.86	0.49	0.97
0.088	0.90	0.53	13.09	69.31	0.11	12.03	1.98	0.92	0.25	0.79
0.051	0.77	0.31	13.24	70.26	<0.1	12.00	1.28	1.03	0.16	0.75
0.029	1.20	0.15	13.85	71.42	<0.1	10.88	0.75	1.09	<0.1	0.49
0.000	1.11	<0.1	15.33	72.59	0.10	9.19	0.17	1.38	<0.1	0.15
-0.081	0.28	<0.1	15.88	75.67	0.13	6.44	<0.1	1.26	<0.1	0.23
-0.283	0.14	0.16	18.44	76.01	0.17	3.04	<0.1	1.31	<0.1	0.63
-0.490	0.12	0.16	18.38	76.68	0.17	2.19	0.14	1.25	<0.1	0.68
-0.901	0.12	0.19	15.58	80.14	0.11	1.52	0.18	1.15	<0.1	0.79
-1.314	0.17	0.20	19.37	75.36	0.18	1.63	0.27	1.44	<0.1	1.01
-1.713	0.11	0.19	18.06	77.50	0.10	1.24	0.28	1.27	<0.1	0.96
-2.125	0.49	0.17	16.99	77.87	<0.1	1.21	0.29	1.33	<0.1	1.02
-2.537	0.13	0.17	17.24	77.99	<0.1	1.17	0.27	1.39	<0.1	1.06
-2.949	0.20	0.20	17.41	77.98	<0.1	1.06	0.30	1.33	<0.1	1.20
-3.361	0.12	0.18	18.12	77.38	0.12	1.10	0.26	1.34	<0.1	1.17
-3.773	<0.1	0.21	18.02	77.53	<0.1	1.06	0.28	1.45	<0.1	1.15

APPENDIX 5

Linescan through crucible 23

(distance in millimetres, positive = glass, negative = ceramic)

distance	Na_2O	MgO	Al_2O_3	SiO2	P_2O_5	K_2O	CaO	TiO_2	MnO	Fe_2O_3
0.460	0.93	2.47	6.69	67.45	0.55	6.21	11.50	0.67	1.75	1.37
0.413	0.78	2.43	6.79	68.38	0.69	6.18	11.12	0.68	1.58	1.25
0.367	0.69	2.42	7.09	68.62	0.61	6.12	10.93	0.66	1.63	1.09
0.321	0.62	2.17	7.57	69.09	0.57	6.55	10.09	0.65	1.44	0.98
0.275	0.67	1.74	8.75	69.67	0.54	7.27	8.39	0.69	1.24	0.78
0.224	0.71	1.18	10.87	70.44	0.20	8.31	6.09	0.57	0.80	0.56
0.174	0.88	0.69	13.42	68.97	0.22	9.58	4.28	0.79	0.48	0.42
0.125	1.01	0.37	14.72	68.83	0.14	10.25	2.92	1.06	0.20	0.34
0.074	1.13	0.11	16.31	67.94	0.12	10.95	1.74	1.21	<0.1	0.26
0.024	0.89	<0.1	16.30	71.02	0.10	9.03	1.08	1.09	<0.1	0.15
-0.026	0.38	<0.1	15.20	78.31	0.11	4.53	0.10	1.07	<0.1	0.11
-0.124	0.50	0.11	20.67	71.27	0.19	4.76	0.18	1.68	<0.1	0.48
-0.312	0.43	0.13	17.92	75.08	0.26	2.73	0.33	1.41	<0.1	1.13
-0.499	0.35	0.18	16.76	76.99	0.27	1.79	0.29	1.38	<0.1	1.33
-0.694	0.28	0.17	16.35	79.06	0.16	1.32	0.24	1.31	<0.1	0.80
-0.900	0.25	0.18	16.20	78.75	0.23	1.22	0.39	1.64	<0.1	0.84
-1.107	0.33	0.13	15.92	78.84	0.27	1.10	0.34	1.72	<0.1	0.94
-1.519	0.31	0.15	17.10	77.83	0.12	1.05	0.27	1.49	<0.1	1.03
-1.931	0.43	0.13	15.09	79.94	0.12	0.85	0.37	1.28	<0.1	1.04
-2.343	0.32	0.19	18.71	76.27	0.26	0.93	0.34	1.47	<0.1	1.22
-2.755	0.37	0.19	18.11	76.38	0.13	0.94	0.37	1.57	<0.1	1.21
-3.167	0.38	0.17	17.50	77.38	0.27	0.91	0.40	1.52	<0.1	1.02
-3.579	0.27	0.17	15.47	79.72	0.11	0.89	0.32	1.52	<0.1	1.06
-3.992	0.23	0.15	12.89	83.31	0.13	0.65	0.30	1.26	<0.1	0.76
-4.404	0.23	0.16	17.25	78.26	0.21	0.75	0.31	1.32	<0.1	0.97
-4.817	0.31	0.12	18.33	76.56	0.21	0.90	0.41	1.57	<0.1	1.24

APPENDIX 6

Linescan through brick 24B1

(distance in millimetres, positive = glassy surface, negative = ceramic)

distance	Na_2O	MgO	Al_2O_3	SiO2	P_2O_5	K_2O	CaO	TiO_2	MnO	Fe_2O_3
1.250	1.24	0.59	11.77	73.62	<0.1	9.68	1.29	0.49	0.27	1.10
1.011	1.01	0.72	11.22	73.15	0.14	10.02	1.26	0.60	0.37	1.49
0.839	0.89	0.78	10.95	73.73	<0.1	9.88	1.09	0.56	0.39	1.59
0.710	0.94	0.71	11.18	73.90	0.16	9.78	0.92	0.58	0.26	1.42
0.499	0.91	0.34	12.26	74.94	0.11	9.65	0.37	0.52	<0.1	0.84
0.282	0.83	0.19	12.16	76.65	<0.1	8.98	0.14	0.57	<0.1	0.44
0.087	0.71	<0.1	16.47	73.38	0.24	8.22	0.13	0.58	<0.1	0.24
-0.088	0.43	<0.1	12.54	80.48	0.16	5.34	0.10	0.58	<0.1	0.23
-0.288	0.26	0.11	11.55	82.54	0.11	4.41	<0.1	0.59	<0.1	0.41
-0.521	0.19	0.21	11.27	82.98	0.13	3.63	0.10	0.71	<0.1	0.71
-0.769	0.30	0.50	16.64	76.41	0.14	4.09	0.11	0.80	<0.1	1.00
-1.067	0.20	0.28	10.04	85.27	<0.1	2.56	0.13	0.58	<0.1	0.75
-1.591	0.16	0.46	11.22	83.73	0.13	2.40	0.23	0.63	<0.1	0.96
-2.665	0.13	0.46	10.77	84.36	0.10	2.08	0.24	0.66	<0.1	1.02
-3.304	0.14	0.54	12.00	82.89	0.14	2.00	0.30	0.62	<0.1	1.13
-4.611	0.15	0.51	11.38	83.99	0.18	1.61	0.26	0.64	<0.1	1.05
-5.919	0.14	0.47	11.90	83.48	0.11	1.34	0.31	0.64	<0.1	1.11
-7.231	0.10	0.49	11.21	84.01	0.27	1.32	0.34	0.55	<0.1	1.26

Linescan through brick 24B2

(distance in millimetres, positive = glassy surface, negative = ceramic)

distance	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	K_2O	CaO	TiO_2	MnO	Fe_2O_3
1.445	1.48	0.82	10.36	69.82	<0.1	12.69	1.91	0.62	0.74	1.19
1.358	1.34	0.77	10.80	70.10	<0.1	12.80	1.66	0.56	0.67	1.10
1.271	1.48	0.68	10.66	70.19	0.12	12.85	1.50	0.64	0.71	1.15
1.183	1.33	0.77	10.79	70.25	0.17	12.79	1.47	0.57	0.66	1.07
1.096	1.24	0.69	10.99	70.89	<0.1	12.69	1.32	0.67	0.49	1.06
1.010	1.27	0.66	10.84	71.26	0.18	12.52	1.18	0.59	0.48	1.02
0.923	1.17	0.60	10.97	71.74	0.11	12.43	0.97	0.57	0.33	1.03
0.836	1.10	0.44	11.16	72.34	0.15	12.22	0.80	0.56	0.25	0.92
0.749	1.08	0.39	11.30	72.63	<0.1	12.02	0.71	0.59	0.21	0.87
0.662	1.00	0.38	11.53	72.80	0.11	11.88	0.62	0.61	0.11	0.88
0.575	0.84	0.41	12.03	72.37	0.14	11.99	0.59	0.60	0.13	0.89
0.489	0.80	0.48	11.82	72.92	0.23	11.49	0.58	0.61	<0.1	0.93
0.487	0.84	0.44	11.77	73.20	0.13	11.47	0.53	0.67	0.11	0.86
0.359	0.87	0.45	12.72	72.76	0.18	11.06	0.31	0.72	<0.1	0.83
0.231	0.69	0.58	12.28	73.77	0.11	10.44	0.28	0.74	<0.1	1.13
0.104	0.56	0.50	12.44	74.44	0.12	9.82	0.17	0.85	<0.1	0.96
-0.074	0.37	0.26	11.54	80.56	0.19	5.87	0.12	0.68	<0.1	0.33
-0.264	0.25	0.38	10.12	82.41	0.19	5.28	0.17	0.64	<0.1	0.49
-0.591	0.25	0.46	12.51	79.74	0.15	5.12	0.18	0.64	<0.1	0.75
-1.101	0.24	0.52	10.37	82.49	0.18	4.40	0.20	0.57	<0.1	1.08
-1.897	0.17	0.51	12.13	80.86	0.13	4.10	0.30	0.56	<0.1	1.11
-2.575	0.18	0.64	12.95	79.63	0.13	3.51	0.52	0.74	0.10	1.43
-3.223	0.21	0.63	11.07	81.92	0.14	3.00	0.58	0.70	<0.1	1.45
-3.598	0.16	0.69	14.28	79.18	0.15	2.55	0.60	0.69	<0.1	1.53
-4.738	0.11	0.68	12.20	81.03	0.15	2.51	0.75	0.76	0.11	1.52
-5.286	0.10	0.55	10.23	84.72	<0.1	1.70	0.66	0.64	<0.1	1.16
-5.791	<0.1	0.52	13.52	81.06	<0.1	1.77	0.63	0.66	<0.1	1.35
-6.595	0.11	0.71	10.42	83.40	0.12	2.24	0.80	0.76	0.10	1.30
-7.595	0.19	0.59	11.08	82.82	0.10	2.00	0.73	0.72	<0.1	1.25
-9.234	0.11	0.72	11.30	82.58	<0.1	1.99	0.80	0.65	<0.1	1.45
-11.199	0.12	0.77	12.01	80.89	0.19	2.31	1.16	0.76	0.13	1.50
-12.608	<0.1	0.62	11.62	82.83	<0.1	1.80	0.72	0.71	<0.1	1.35

Linescan through brick 24B3

(distance in millimetres, positive = glassy surface, negative = ceramic)

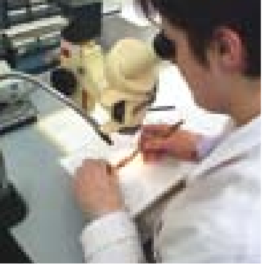
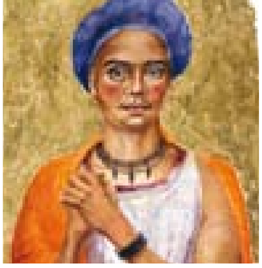
distance	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	K_2O	CaO	TiO_2	MnO	Fe_2O_3
0.406	1.32	0.51	9.80	73.80	<0.1	11.68	0.51	0.53	0.37	1.17
0.354	1.32	0.54	9.71	74.24	0.14	11.53	0.47	0.57	0.28	1.19
0.266	1.12	0.47	10.01	74.56	0.10	11.43	0.33	0.62	0.17	1.06
0.177	0.94	0.44	9.41	76.49	<0.1	10.58	0.27	0.49	0.11	1.02
0.088	0.94	0.42	10.61	74.96	0.15	10.99	0.19	0.56	<0.1	1.08
-0.001	0.61	0.46	7.79	80.82	0.16	7.98	0.16	0.51	<0.1	1.44
-0.090	0.47	0.38	7.79	82.40	0.16	6.94	<0.1	0.58	<0.1	1.22
-0.297	0.30	0.22	11.41	81.18	0.16	5.32	<0.1	0.79	<0.1	0.52
-0.586	0.27	0.41	9.70	83.92	0.18	3.75	0.12	0.71	<0.1	0.90
-0.987	0.17	0.41	10.14	84.27	<0.1	2.76	0.16	0.72	<0.1	1.12
-1.487	0.11	0.36	8.70	86.78	<0.1	1.84	0.16	0.61	<0.1	1.09
-2.500	0.15	0.53	8.83	85.47	<0.1	2.05	0.28	0.71	<0.1	1.42
-3.061	<0.1	0.46	9.14	85.98	0.10	1.67	0.28	0.76	<0.1	1.22
-4.761	<0.1	0.47	9.79	85.44	<0.1	1.43	0.31	0.60	<0.1	1.25
-5.382	0.10	0.57	10.11	84.65	<0.1	1.71	0.33	0.76	<0.1	1.38
-5.891	<0.1	0.50	9.07	86.43	0.12	1.51	0.34	0.55	<0.1	1.26

APPENDIX 7

Linescan through brick 25

(distance in millimetres, positive = glassy surface, negative = ceramic)

distance	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	K_2O	CaO	TiO_2	MnO	Fe_2O_3
0.371	0.52	1.91	22.76	60.78	0.13	5.59	4.20	0.75	0.52	2.61
0.289	0.57	1.64	19.22	64.62	0.20	6.37	3.74	0.69	0.47	2.27
0.207	0.53	1.09	16.38	69.20	0.25	7.05	2.58	0.68	0.30	1.81
0.125	0.64	0.98	17.23	68.81	0.15	6.90	2.42	0.66	0.29	1.80
0.042	0.45	0.66	15.85	71.98	0.23	6.86	1.62	0.61	0.15	1.45
-0.040	0.47	0.32	12.12	77.63	0.26	6.46	0.82	0.67	<0.1	1.15
-0.121	0.33	0.24	14.04	76.91	0.18	5.57	0.50	0.67	0.10	1.29
-0.204	0.26	0.23	11.92	81.12	0.18	4.05	0.35	0.65	<0.1	1.16
-0.602	0.14	0.39	10.83	83.25	0.19	2.69	0.19	0.73	0.12	1.38
-1.000	0.20	0.42	10.06	84.42	0.12	2.24	0.19	0.68	<0.1	1.52
-1.398	0.17	0.51	12.54	80.81	0.13	2.35	0.25	0.88	0.20	2.12
-2.194	0.51	0.47	12.16	81.58	<0.1	1.52	0.15	0.86	0.18	1.95
-2.989	0.13	0.43	11.33	83.71	<0.1	1.30	0.10	0.68	0.11	1.93
-3.786	0.12	0.45	11.58	83.17	0.12	1.33	0.14	0.77	<0.1	1.84
-4.581	0.15	0.38	12.25	82.10	0.10	1.45	0.12	0.81	<0.1	2.06



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