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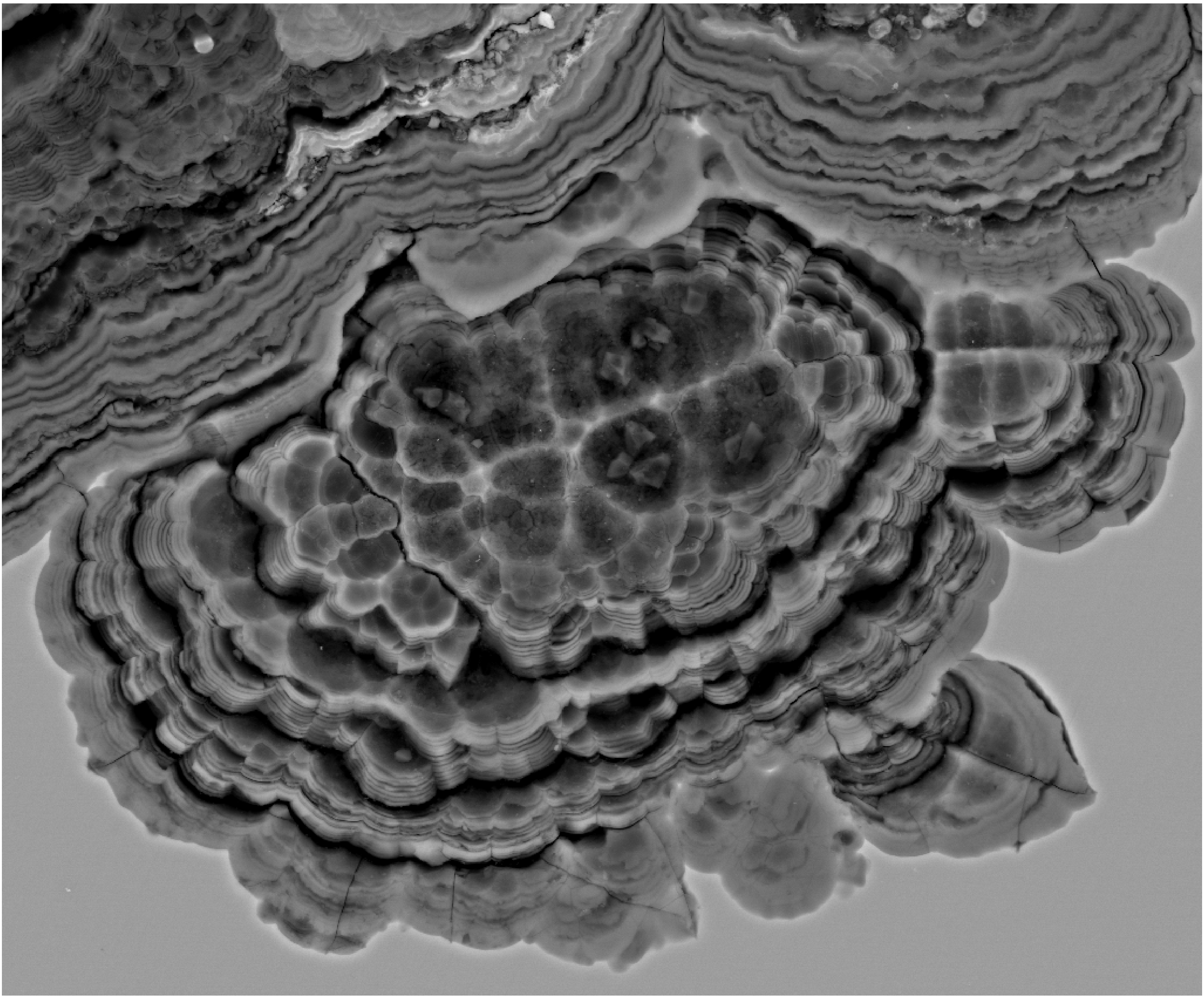
BLUNDEN'S WOOD GLASSHOUSE, HAMBLEDON, SURREY
SCIENTIFIC EXAMINATION OF GLASSWORKING MATERIALS

TECHNOLOGY REPORT

David Dungworth and Sarah Paynter



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Scientific examination of glassworking materials

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SUMMARY

Some 400 fragments of glass and glassy waste were recovered from the 14th-century glassworking site at Blunden's Wood. The assemblage included window and vessel glass, both of which were made at the site using a plant ash glass, rich in potassium, magnesium and calcium oxides, typical of the period. Some glass made elsewhere was also identified, which may have been brought to the site as cullet. The composition of the glass made at Blunden's Wood is compared with that made at other English glasshouses of the period as well as glass manufactured in mainland Europe. The data are also used to investigate the possible origins of window glass from English cathedrals.

ACKNOWLEDGEMENTS

We would like to thank Mary Alexander, Curator Guildford Museum for providing access to the materials examined and permission to sample for scientific analysis. We would like to thank Andrew Meek for allowing access to his analytical data for Blunden's Wood.

ARCHIVE LOCATION

The glassworking debris is held by Guildford Museum, Castle Arch, Guildford, Surrey, GU1 3SX. The samples taken for scientific analysis are held by English Heritage, Fort Cumberland, Portsmouth, PO4 9LD

DATE OF RESEARCH

2006–2010

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INTRODUCTION

The medieval glasshouse in Blunden's Wood was discovered in 1959 and excavated in 1960 by Eric Wood (1965). The excavation uncovered the remains of a furnace, approximately 3.5m by 3.1m, comprising a central fire trench with two parallel *sieges* (low sandstone walls on which the crucibles would have sat). The excavation also recovered a considerable assemblage of glass and glassworking waste (including crucibles). Some 400 fragments of glass and glassy waste were recovered; the former included both window and vessel glass. The assemblage of pottery from Blunden's Wood included Cheam ware datable to the second quarter of the 14th century. Archaeomagnetic dating of the furnace suggested that its last firing took place c1330. The site was completely destroyed in 1961 during the extraction of clay for brick making. The fact that the site is the earliest, independently dated, medieval glasshouse in England has ensured that it has been the focus of repeated study. A single analysis of glass from the site was published as part of the excavation report (Wood 1965). Further scientific analysis has been carried out by Merchant (1998), Welham (2001) and Meek (forthcoming). 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

The assemblage of glass and glassworking debris held by Guildford museum includes vessel and window glass, glassworking waste (moils, runs and drips) and crucibles. Samples were taken from eleven fragments of working waste (four moils, four lumps, two drips and one run), six fragments of window glass (two thin, two thick weathered and two thick unweathered), eight fragments of vessel glass (three rim sherds, one lamp base, two with wrythen decoration and two heavily weathered body sherds), and five crucibles (two bucket-shaped and three barrel-shaped).

METHODS

All of the fragments of 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 with brightfield and darkfield illumination to identify corroded and uncorroded regions. All of the Blunden's Wood samples exhibited corroded surfaces (Figure 1). 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 (i.e. limits of detection) for many minor elements, especially where Z > 23, due to improved peak to background ratios.

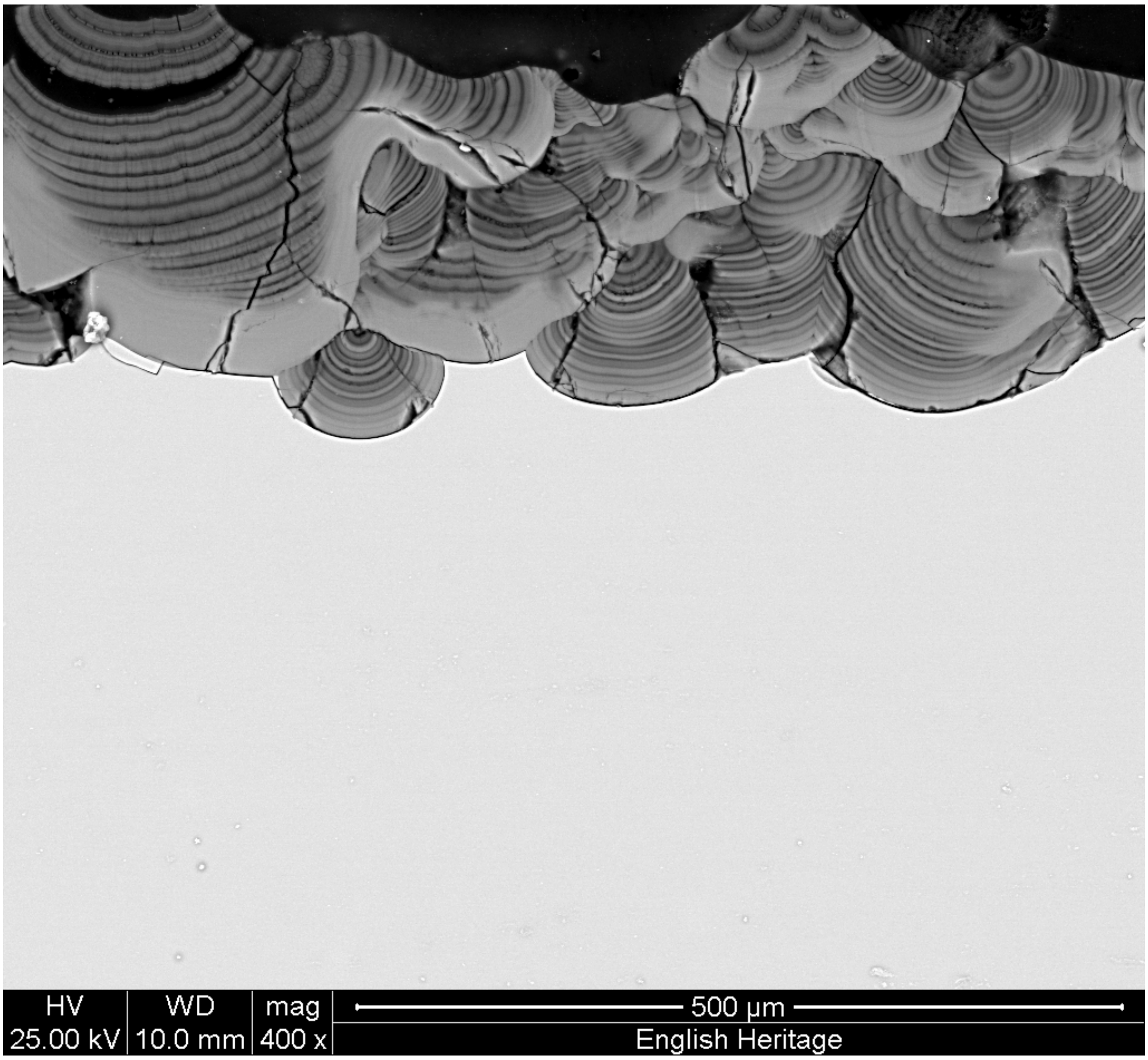

Figure 1. SEM image (back-scattered electron detector) showing, in cross-section, the corroded surface of sample 11 (the corroded layer is at the top of the image)

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 optimised by calibrating using a cobalt standard. Deconvolution of the X-ray spectra and quantification of elements were 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 1. 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	0.02	0.02
SO_3	0.1	0.1	NiO	0.02	0.03
Cl	0.1	0.1	CuO	0.03	0.01
K_2O	0.1	0.1	ZnO	0.02	0.01
CaO	0.1	0.1	As_2O_3	0.02	0.01
TiO_2	0.05	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
			PbO	0.05	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, as these were carried out with the SEM at intervals of less than 0.1mm.

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

RESULTS

Glassworking waste

The 11 fragments of glassworking waste all share similar chemical compositions: they are potassium-rich glasses which contain a wide range of minor elements (Figure 2 and 3). The range of elements present, especially phosphorus, indicates that this glass was made using a plant ash as the source of alkali. The composition of this glass is similar to medieval forest glass made in England and northern Europe (see discussion below).

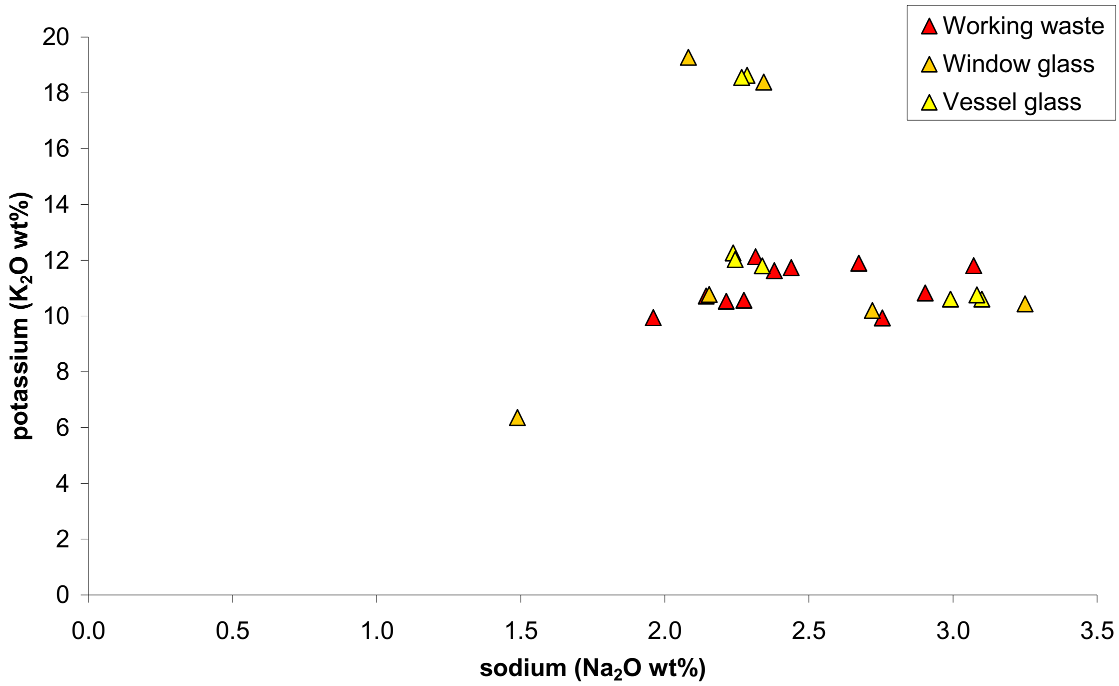

Figure 2. Sodium and potassium oxide contents of the glass and glassworking waste from Blunden's Wood

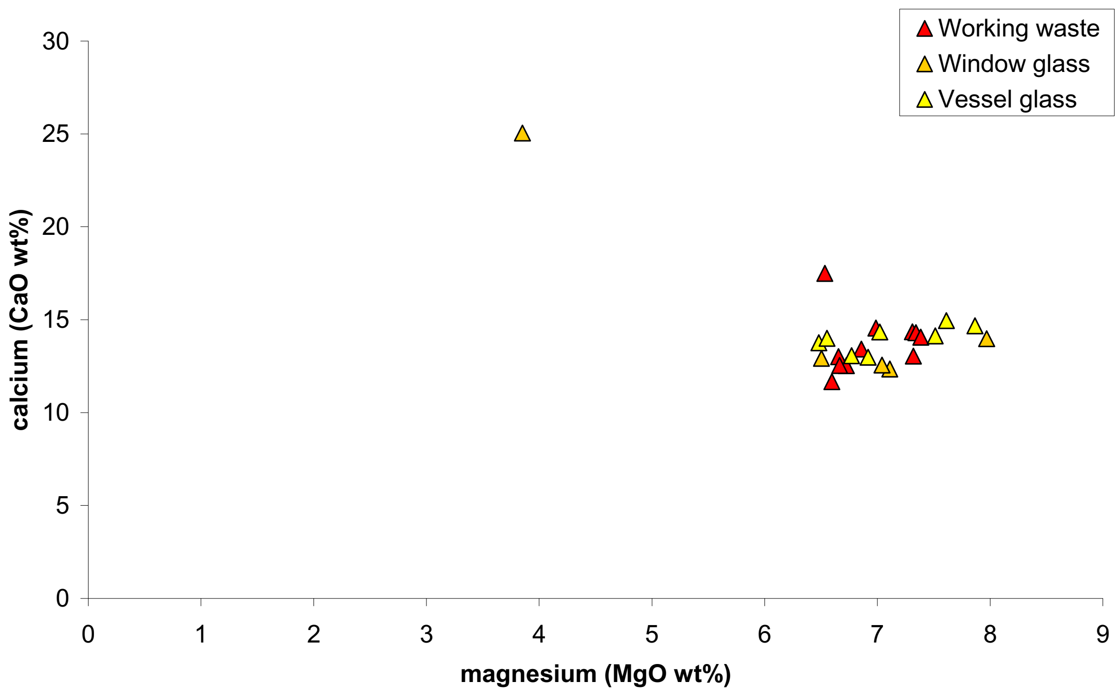

Figure 3. Magnesium and calcium oxide contents of the glass and glassworking waste from Blunden's Wood

Window and Vessel Glass

Most examples of window and vessel glass from Blunden's Wood have compositions which are within the limits provided by the working waste, confirming that the glasshouse produced both types of glass. Wood (1965, 66) noted that wrythen vessel glass was rarely found at Blunden's Wood and suggested that the excavated examples might have been cullet. The current analysis, however, shows that wrythen vessel glass was produced at Blunden's Wood.

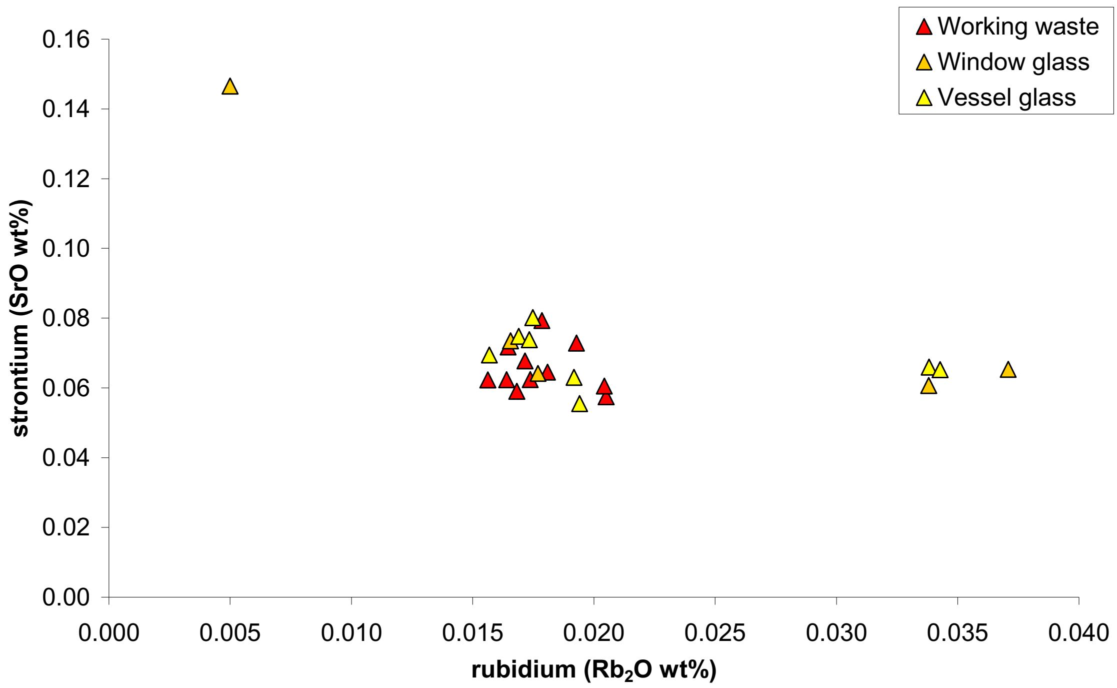

Figure 4. Rubidium and strontium oxide contents of the glass and glassworking waste from Blunden's Wood

Wood (1965, 66) noted the presence of painted glass from Blunden's Wood which suggests that a proportion of the glass found represents cullet. Only five samples have compositions which are sufficiently different to be certain that they were not made at Blunden's Wood. These comprise the four heavily weathered glass fragments (two vessels [#03 and #04] and two windows [#09 and #10]) and one of the thin (unweathered) window glass fragments (#19). These samples must represent material manufactured elsewhere but brought to Blunden's Wood as cullet. The compositional differences between the imported cullet and the glass manufactured at Blunden's Wood exist among major (Figures 2 and 3) and minor elements (Figure 4). The heavily weathered samples of vessel and window glass share almost identical compositions to each other and were probably made at the same site. These samples contain more potassium than any analysed medieval glass produced in England (Figure 2). The fifth cullet sample (#19) has a high-lime low-alkali glass composition (Figure 3). There is no evidence for the manufacture of this type of glass in England prior to the arrival of French glassworkers in the late 16th century (Dungworth and Clark 2004). The possible origins of the cullet are discussed below.

Crucibles

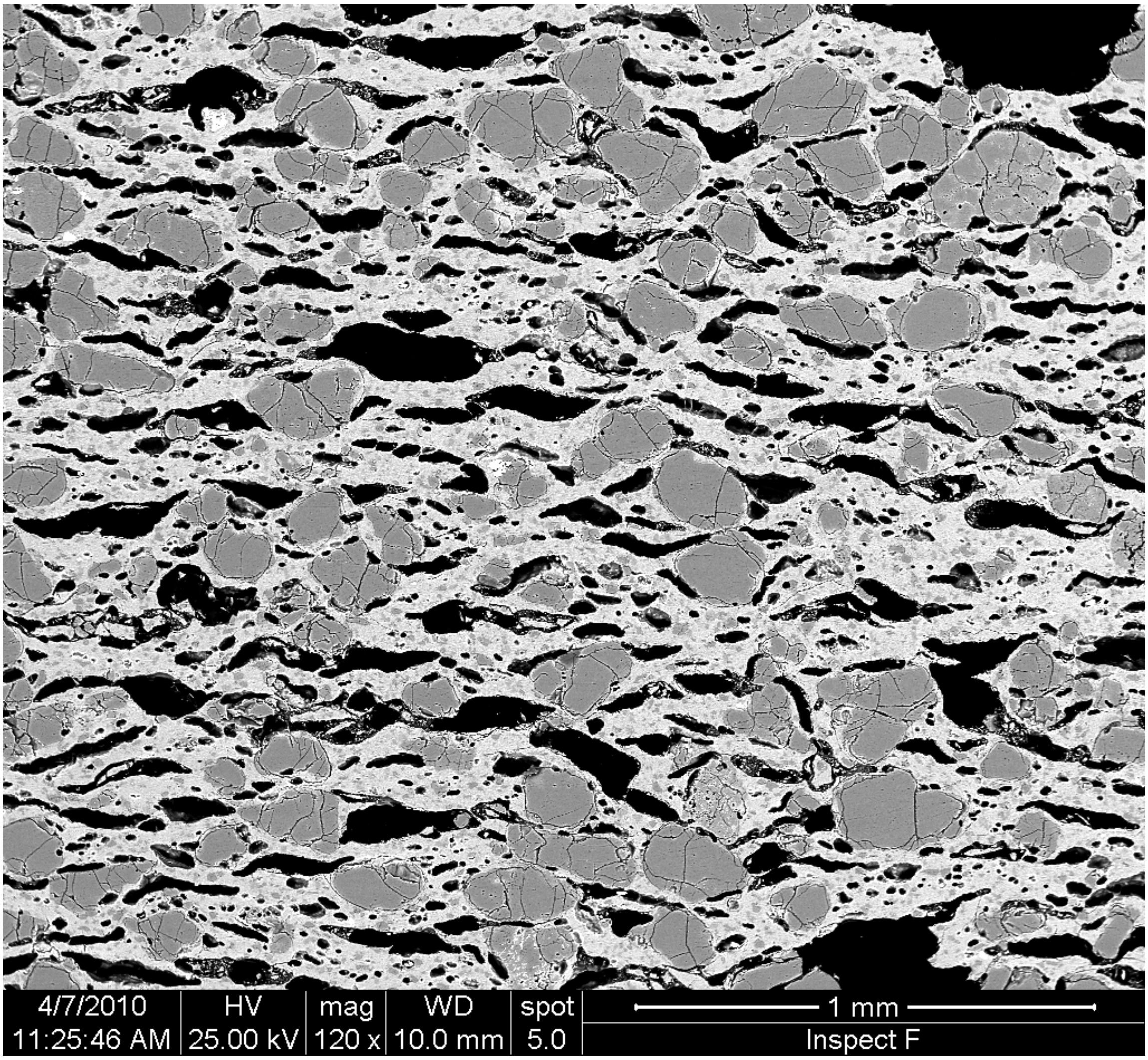

Figure 5. SEM image (back-scattered electron detector) showing, in cross-section, the microstructure of the ceramic fabric of sample 28. The black areas are voids or porosity in the ceramic, the mid grey inclusions are silica polymorphs and the light grey regions are the vitrified ceramic

The five crucibles examined were analysed to identify the temper used, determine the chemical composition of the ceramic fabric and investigate any adhering glass and/or surface vitrification. The ceramic fabric of the crucible comprises abundant silica polymorph grains (typically 0.2mm in diameter) in a porous vitrified matrix (Figure 5). The vitrified matrix contains very small needle-like crystals of mullite. All five crucibles share the same microstructure and chemical composition. These crucibles have low alumina to silica and titanium to iron ratios which are comparable to those in the Gunter's Wood crucibles (Dungworth 2010a) but lower than those of late Wealden sites.

The examination of the Blunden's Wood crucibles makes a significant contribution to the thesis that medieval glass-melting crucibles were quartz-tempered but that at some point in the 16th century glassmakers switched to grog-tempered clays (Paynter forthcoming). The refractory properties of the early and late Wealden crucible are likely to have been similar; while the higher alumina content of the late crucibles would give a higher melting temperature, both the early and late crucibles would suffer significant deterioration of mechanical strength at c1600°C (Levin *et al* 1956, Fig 117). However the grog-tempered crucibles may have been preferred to quartz-tempered crucibles for other characteristics, such as improved resistance to erosion by molten glass (Paynter forthcoming).

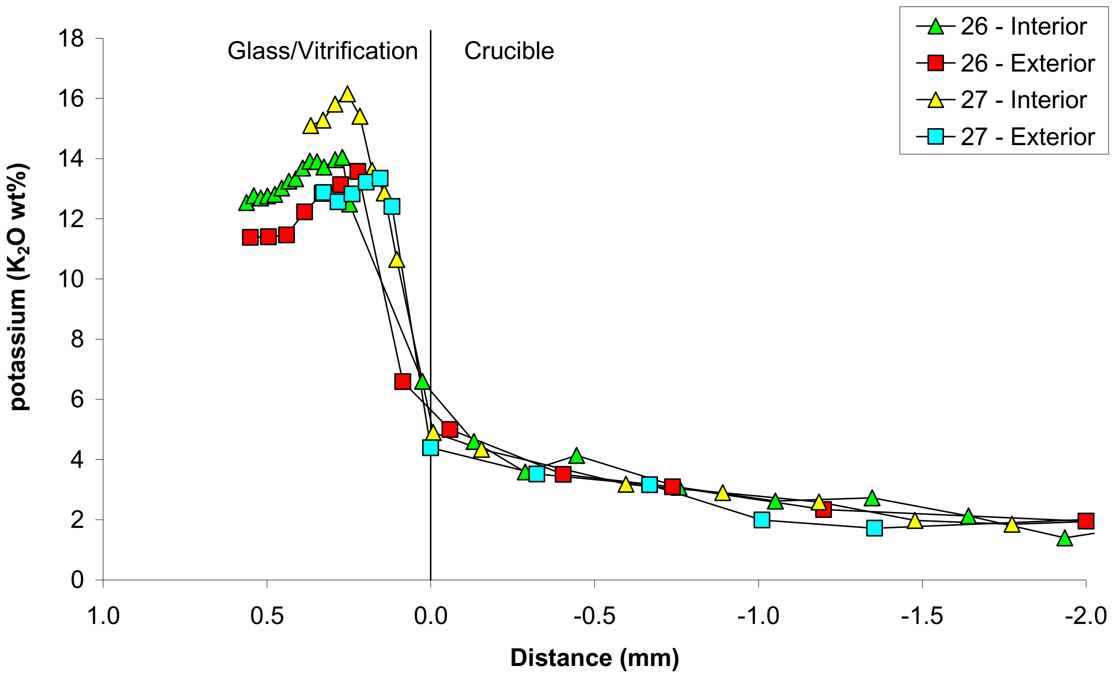

Figure 6. Potassium oxide content of the adhering glass or surface vitrification on two Blunden's Wood crucibles

Two of the Blunden's wood crucibles (#26 and #27) had adhering glass/vitrification on the interior and exterior surfaces. A series of analyses were carried out across these surfaces from the glass/vitrified zone into the unaltered ceramic core of the crucible (cf Dungworth 2008). These analyses (see Figures 6 and 7 and the Appendix) show that both interior and exterior vitrification/adhering glass layers have similar compositions to each other (Figure 6). These layers do not share identical compositions with the other glassworking waste analysed. Aluminium, potassium, titanium and iron are enriched in these layers while magnesium, phosphorus, calcium and manganese are depleted. The elements that are enriched are those that are generally found in higher concentrations in the ceramic fabric of the crucible and presumably derive from the erosion of the crucible by molten glass. The chemical composition of the adhering glass/vitrification is sufficiently different to the other types of glassworking waste to be of little use in determining the nature of the glass manufactured at Blunden's Wood. The examination of later crucibles (Dungworth 2008) has demonstrated that glass adhering to a crucible rarely has a chemical composition that matches associated glassworking residues unless that layer is at least 1mm thick, in which case some unaltered glass may survive. The layers of surface vitrification and adhering glass on the Blunden's Wood crucibles are generally 0.4–0.6mm thick and so are too heavily contaminated by reactions with the ceramic fabric of the crucible.

The chemical similarities between the interior and exterior surfaces of the Blunden's Wood crucibles can be paralleled among other glass-melting crucibles from wood-fired furnaces (Dungworth 2010a; 2010b). The reactions between crucibles and other materials (solid, liquid and gaseous) inside a glass-melting furnace are undoubtedly complex and involve too many variables to allow any robust modelling.

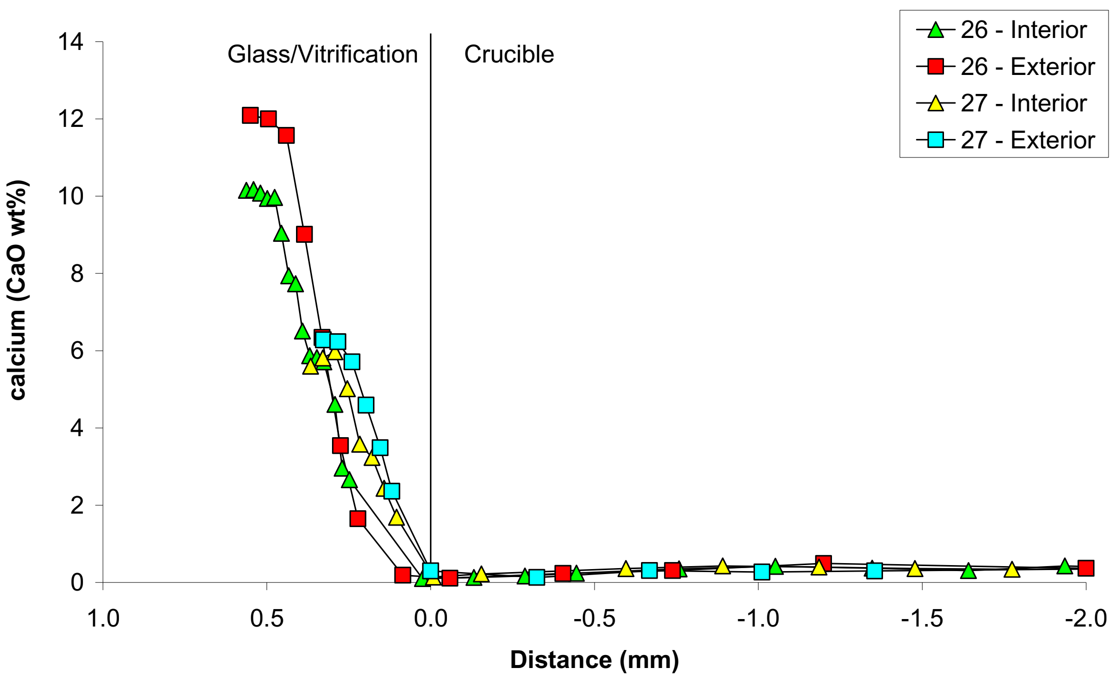

Figure 7. Calcium oxide content of the adhering glass or surface vitrification on two Blunden's Wood crucibles

Crucible #28 has no vitrified surfaces or adhering glass but does have a vitrified zone at the junction between the base and wall (Figure 8). This vitrified zone has a composition that shows some similarities with the surface vitrified zones/adhering glass on crucibles #26 and #27 (elevated aluminium, iron and titanium, see Appendix). In addition this vitrified zone contains droplets of lead-tin alloy, iron sulphates and iron phosphates (Appendix). The lead-tin alloy may derive from the accidental inclusion of fragments of lead calme (including soldered joints in the lead calme) with window glass cullet. The origins of the iron sulphates and iron phosphates are unknown.

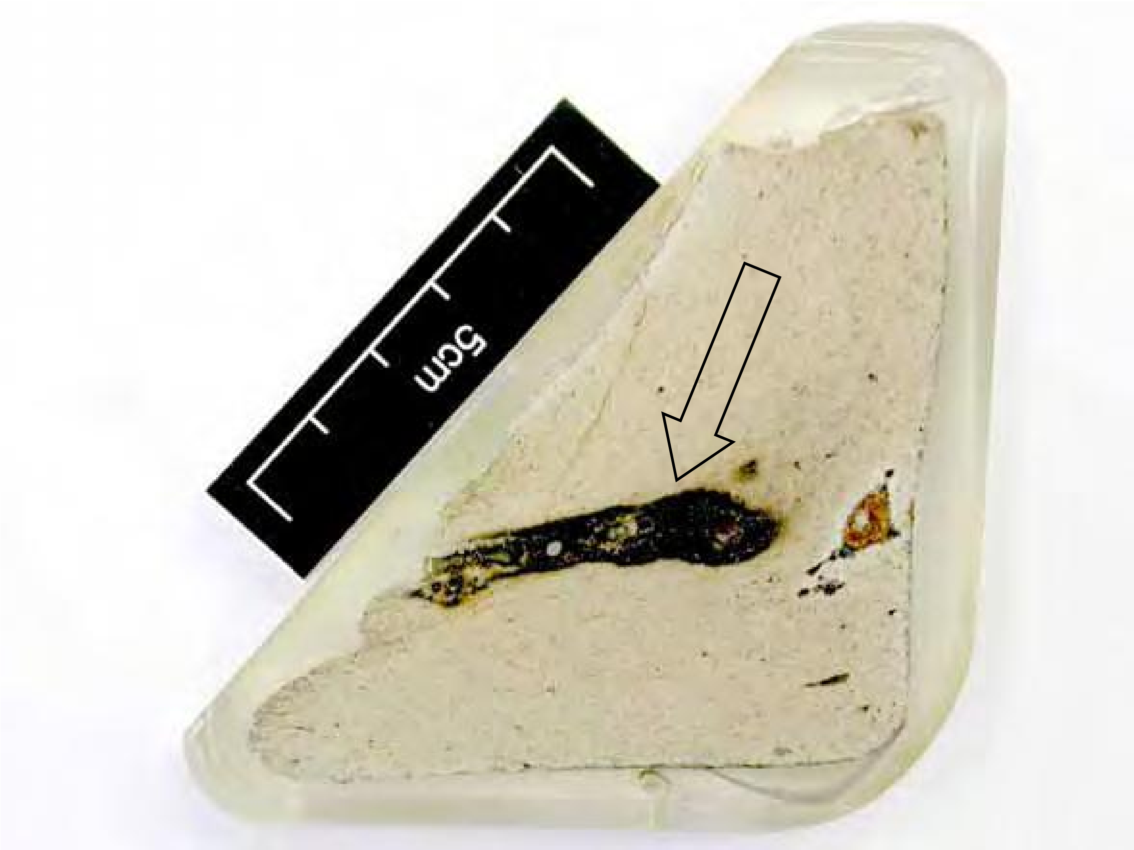

Figure 8. Crucible #28 showing the vitrified zone between the base and wall

DISCUSSION

The chemical composition of the glass manufactured at Blunden's Wood

The analysis of glass and glassworking samples from Blunden's Wood presented here is the fifth investigation of material from this site. Table 2 summarises the results obtained in this study and by other researchers; the data are also compared in Figures 9 and 10.

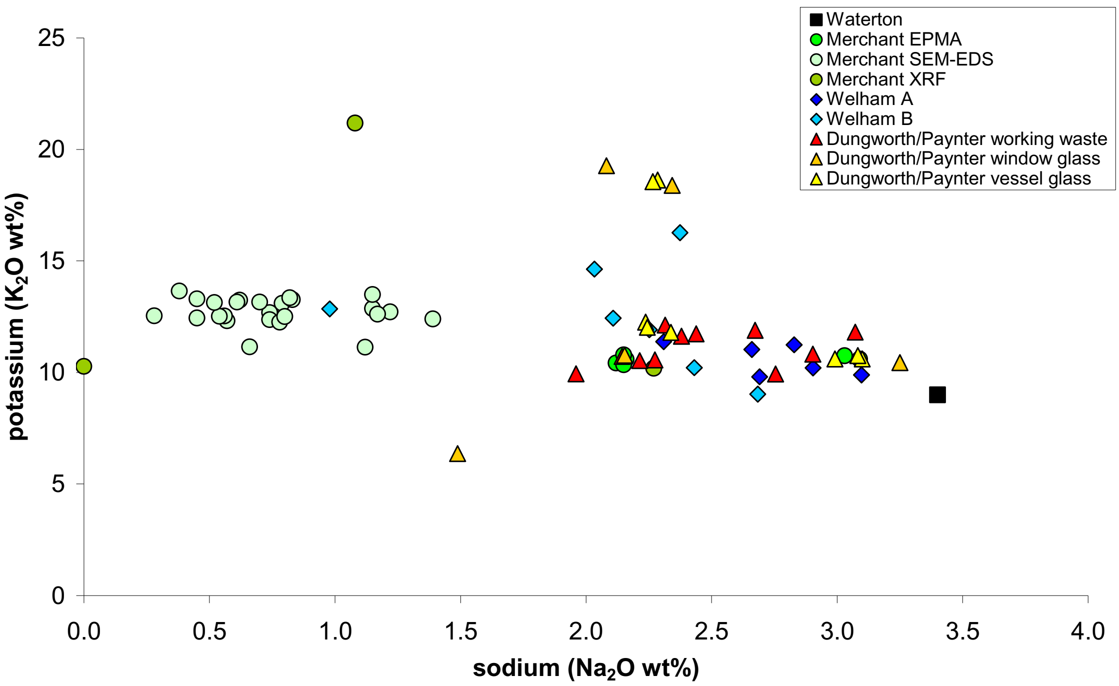

Figure 9. Sodium and potassium oxide contents of Blunden's Wood glass samples

Table 2. Chemical composition of glass and glassworking waste (average and standard deviation) from Blunden's Wood (Sources: Wood 1965; Merchant 1998; Welham 2001)

Analyst	No.	Na_2O	MgO	Al_2O_3	P_2O_5	K_2O	CaO	MnO	Fe_2O_3
Waterton	1	3.4	6.95	4.78	nr	9.0	17.5	<0.2	1.32
Merchant XRF	3	1.1±1.1	7.3±3.3	2.7±1.7	3.2±1.9	13.9±6.3	11.6±0.4	1.3±0.3	1.1±0.3
Merchant SEM-EDS	25	0.8±0.3	4.6±0.3	0.3±0.1	3.4±0.2	12.7±0.6	16.5±1.2	1.8±0.2	1.1±0.2
Merchant EPMA	6	2.5±0.5	6.4±0.6	0.9±0.1	3.1±0.1	10.6±0.2	13.4±0.9	1.2±0.1	0.7±0.1
Welham A	6	2.7±0.3	7.0±0.3	1.1±0.2	2.7±0.1	10.6±0.7	13.9±0.9	1.0±0.1	0.7±0.1
Welham B	8	2.2±0.6	4.1±3.0	2.8±2.0	2.0±1.7	13.4±3.5	7.8±5.5	0.6±0.4	1.4±0.6
this report	11	2.5±0.3	6.9±0.3	1.0±0.2	3.2±0.3	11.1±0.8	13.7±1.5	1.2±0.1	0.8±0.1

Most of the reported analyses of glass samples from Blunden's Wood show good agreement with each other; however, there are some anomalies. the most striking is the data provided by Merchant (1998). Merchant analysed samples of glass (window and vessel) using three different techniques (EDXRF, SEM-EDS and EPMA), but there are consistent differences in the results reported for each technique. This is likely to be due to differences in accuracy and precision between the techniques used. Comparing Merchant's results with those of later researchers (Table 2) suggests that the EPMA data are the most reliable but that the EDXRF and SEM-EDS data should be discounted.

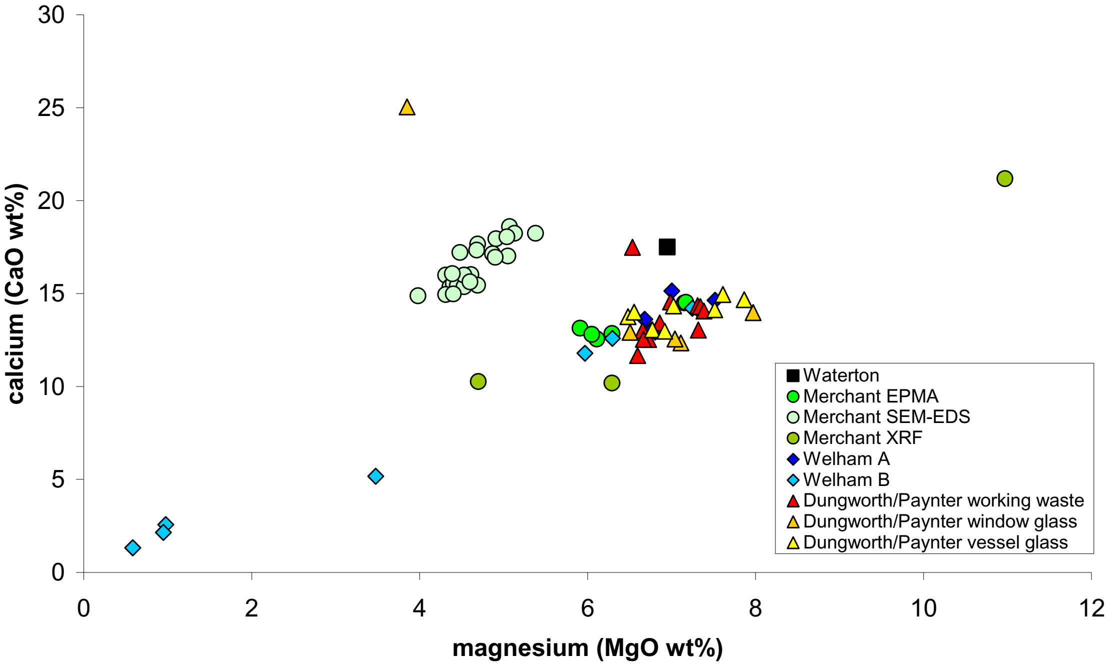

Figure 10. Magnesium and calcium oxide contents of the Blunden's Wood glass samples

The data provided by Welham (2001) has been divided here into two groups: Group A, which shares the same composition as most other Blunden's Wood samples (including Meek forthcoming) and Group B, which comprises samples with widely varying chemical composition. It is likely that all of the Group B samples have been contaminated by reactions with refractory materials (especially crucibles) as well as fuel ash and/or fuel vapour.

The Blunden's Wood data presented in this report include samples of both glass working waste and finished artefacts (vessel and window glass). While the composition of the working waste forms a relatively tight cluster the glass artefacts show a wider range of compositions. Those samples of finished glass which do not correspond closely to the working waste are interpreted as artefacts produced elsewhere and brought to Blunden's Wood as cullet.

The chemical composition of cullet brought to Blunden's Wood (where did the cullet come from?)

Five fragments of finished artefacts analysed, found at Blunden's Wood had compositions that did not match the working waste from the site. Four fragments (two of vessel and two of window glass) are made of a distinctive potassium-rich glass for which there are few close parallels. The potassium content of this glass is substantially higher than the working waste from any English glasshouse. There are some similarities with glass from mainland Europe but the magnesium content is higher than any continental glass. The origin of this glass remains uncertain at this time.

The remaining sample of cullet is a HLLA glass (#19). HLLA glass was produced in mainland Europe from the 10th century but not in England until the later 16th century. This sample has a low iron content compared to HLLA glass produced in England in the late 16th century (Dungworth and Clark 2004; Dungworth 2007) but is similar to some medieval German glass (Wedepohl 2003).

Comparing Blunden's Wood glass with other medieval glasshouses

The combined Blunden's Wood data (this study, Merchant EPMA, Welham Group A) has been compared with available data from other medieval glasshouses (Table 3; Figure 11). The two Idehurst (Surrey) glasshouses were probably in operation during the sixteenth century (Dungworth and Clark 2004). The excavation of the glasshouse at Knightons, Surrey provided pottery and an archaeomagnetic date indicating it operated in the early 16th century (Wood 1982). Data on 16th-century glass production in Staffordshire is available from Little Birches (Welch 1997) and Bagot's Park (Crossley 1967).

Table 3. Chemical composition of medieval glassworking waste (average and standard deviation) (Sources: Merchant 1998; Welham 2001; Mortimer in Welch 1997; Dungworth and Clark 2004)

Site	No.	Na_2O	MgO	Al_2O_3	P_2O_5	K_2O	CaO	MnO	Fe_2O_3
Blunden's Wood	43	2.5±0.4	6.8±0.4	1.0±0.2	3.0±0.3	11.2±0.9	13.5±1.1	1.1±0.1	0.7±0.1
Idehurst North	5	2.1±0.2	7.2±0.2	1.1±0.1	3.2±0.5	11.6±0.6	17.0±0.3	1.1±0.1	0.6±0.1
Idehurst South	8	3.0±0.3	8.7±0.2	1.4±0.2	3.9±0.1	10.8±0.8	16.6±0.5	1.0±0.1	0.6±0.1
Knightons	16	2.2±0.3	5.9±0.4	2.5±0.4	3.0±0.3	10.0±0.7	16.7±0.9	0.9±0.1	0.8±0.1
Bagot's Park	6	2.6±0.2	7.8±0.3	1.4±0.2	3.7±0.2	11.2±1.1	10.7±0.7	1.7±0.2	0.6±0.1
Little Birches	40	2.4±0.8	7.8±0.6	1.2±0.3	3.4±0.3	12.5±1.3	13.4±1.2	1.5±0.1	0.5±0.1

The glass produced at both Wealden and Staffordshire sites from the 14th to the 16th centuries shows small differences in chemical composition from site to site. Some of these differences may be chronologically significant while others may be of more geographical importance.

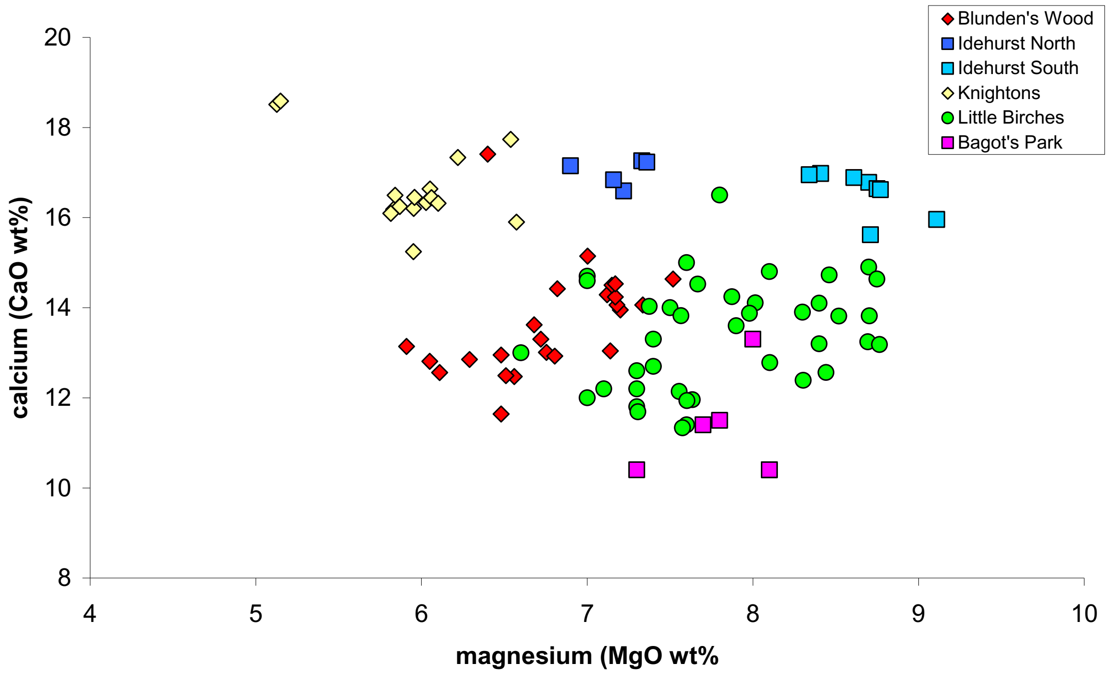

Figure 11. Magnesium and calcium oxide contents of glass from English medieval glasshouses

Medieval glass was undoubtedly made using sand and plant ashes. The chemical composition of plant ashes is influenced by a wide range of factors: differences in the chemical composition of a plant ash can be detected in between plant species, different parts of the same plant, the same plants harvested at different times of the year as well as in the same plants growing in different geological regions (Jackson et al 2005; Sanderson and Hunter 1981; Stern and Gerber 2004). This had led to a pessimistic view of the possibility of identifying which plants were used (Jackson *et al* 2005). The rather limited variability of the glass produced in the Weald and Staffordshire from both 14th- and 16th-century sites is in contrast to the apparent compositional variability of plant ashes. Whatever the nature of the plant ashes used and the strategies employed to obtain them, the limited chemical variability suggests that medieval glassmakers maintained similar practices over considerable distances and through many centuries.

Comparing English medieval glasshouses with glass in English cathedrals

Figure 12 compares the alkali content of glass produced in England during the medieval period with the alkali content of contemporary cathedral window glass (York, Canterbury, Coventry and Winchester, see Brill 1999). This illustrates that a proportion of English medieval cathedral window glass was almost certainly not made in England. The window glass samples with similar alkali contents to the samples from English glasshouses share other compositional similarities (eg high magnesium oxide content) and were almost certainly made in England. Out of the 38 samples of English cathedral window glass analysed by Brill, 15 (40%) have compositions that broadly match English medieval glasshouses while 23 have compositions that do not.

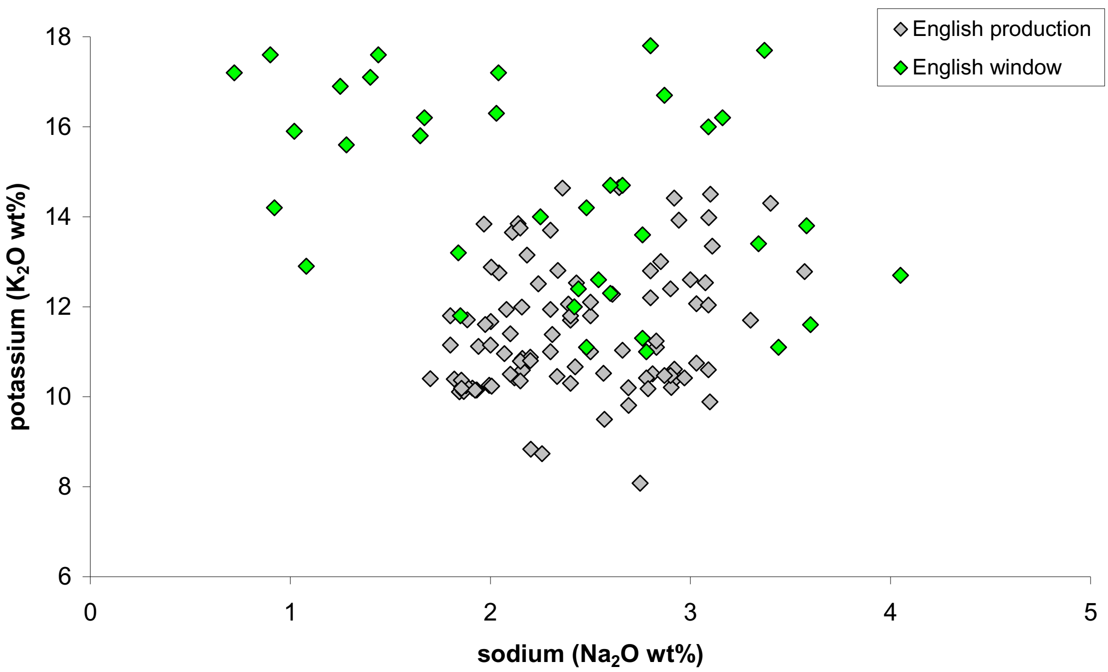

Figure 12. Sodium and potassium oxide contents of glass produced at medieval English glasshouses and in English cathedrals (Sources: see Table 3 and Brill 1999)

Comparing glass in English cathedrals with mainland European glasshouses

The 23 samples of English cathedral window glass analysed by Brill (1999) which do not match contemporary English production were almost certainly made in mainland Europe. Medieval documentary references to the supply of window glass often refer to the purchase of glass for English buildings from France, Flanders and Germany (Marks 1991, 266). Figure 13 compares the alkali content of glass produced in England during the medieval period with the alkali content of contemporary cathedral window glass (York, Canterbury, Coventry and Winchester, see Brill 1999) and contemporary glass from mainland Europe (Barrera and Velde 1989; Brill 1999; Wedepohl 2003). Glass produced in Germany is characterised by high potassium and low sodium oxide contents. French glass appears to show two separate compositional groups: one for vessel (Barrera and Velde 1989) and one for window glass (Brill 1999).

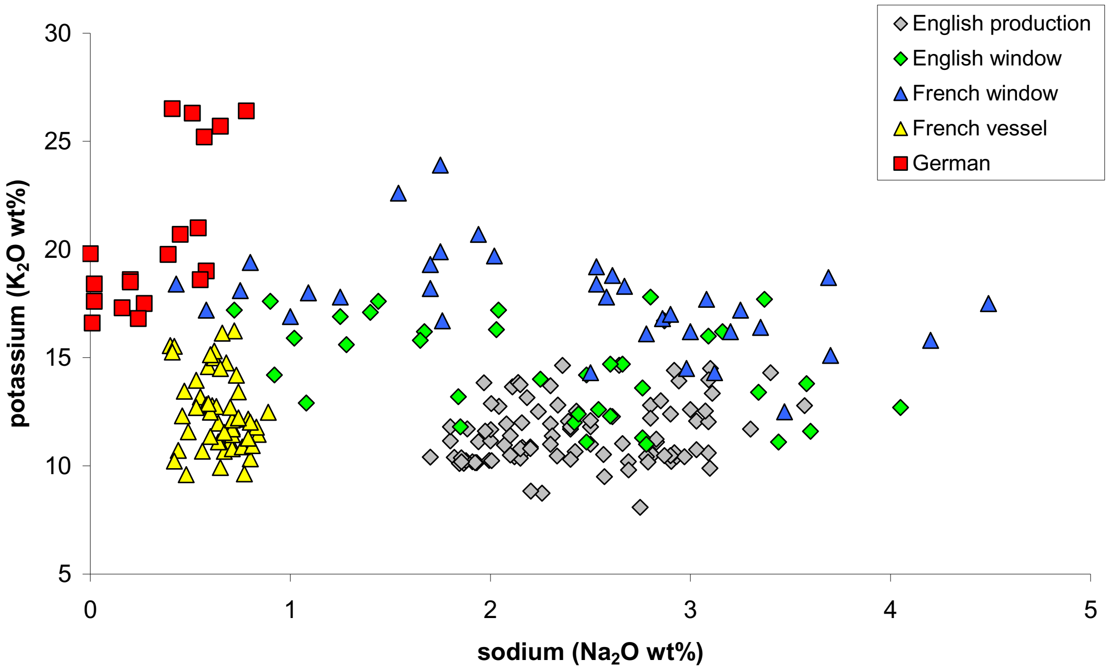

Figure 13. Sodium and potassium oxide contents of glass produced at medieval English glasshouses, used in English cathedrals and produced and used in mainland Europe (Sources: see Table 3, Barrera and Velde 1989; Brill 1999; Wedepohl 2003)

These data were derived from different studies, using a variety of techniques and so must be compared with caution. As discussed previously, some variability in accuracy and precision for each element is likely between the results of different studies. However, the results suggest similarities between some of the English cathedral glass, which does not match contemporary English production, and that used in French cathedrals. Therefore, at least some of the English cathedral glass not made in England may have been made in France.

CONCLUSIONS

The scientific examination of the glass and glassworking debris from Blunden's Wood has characterised the chemical composition of the glass produced there. Comparing the data with that obtained by previous researchers showed a high degree of agreement, with the exception of some of the data obtained by Merchant (1998), highlighting the difficulties of comparing data obtained in different studies and using different techniques. In addition, some of the samples analysed by Welham (2001) display signs of having been contaminated by crucibles, fuel ash, fuel vapour, etc.

The analysis of working waste and finished artefacts demonstrates that Blunden's Wood produced both window and vessel glass. Five fragments of cullet were identified as they had chemical compositions which did not match the glassworking waste from the site. While one of these (a HLLA glass) may have come from Germany, the origin of the other four is not known. The examination of the crucibles provides substantial evidence for the thesis that medieval glass-melting crucibles were quartz-tempered in contrast with the grog-tempered crucibles of the 16th century.

The chemical composition of the glass produced at Blunden's Wood has been compared with that of glass produced at other English medieval glasshouses. Although slight differences can be detected between different glasshouses, it is striking that glass produced in medieval England shows little compositional variation. This is in contrast to the view that the plant ash resources used in medieval glass manufacture were subject to wide variations in their chemical composition. The limited variation suggests that similar resources and technologies were used in different parts of England from the 14th to the 16th centuries.

English medieval glass displays chemical differences from glass produced in mainland Europe. A comparison of data from a number of researchers suggests that 40% of the medieval window glass in English cathedrals may have been made in England while the remainder may have been obtained from mainland Europe.

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APPENDIX 1. CHEMICAL COMPOSITION OF THE GLASS AND GLASSWORKING DEBRIS

Major oxides

#	Description	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	K_2O	CaO
BL01	Working waste: drip	2.67	7.32	0.71	58.23	3.07	11.89	13.04
BL02	Working waste: drip	2.14	6.66	0.92	60.43	3.17	10.72	13.01
BL03	Window glass, thick? (heavily weathered)	2.34	7.11	1.32	49.96	5.47	18.38	12.35
BL04	Window glass, thick? (heavily weathered)	2.08	7.04	1.42	49.06	5.49	19.27	12.55
BL05	Working waste: moil	2.90	7.31	1.15	57.33	3.19	10.83	14.35
BL06	Working waste: moil	2.75	7.34	1.15	58.51	2.90	9.93	14.30
BL07	Working waste: moil	2.21	6.73	0.86	61.31	3.01	10.53	12.53
BL08	Working waste: moil	2.27	6.66	0.83	61.20	3.05	10.56	12.54
BL09	Vessel glass, body sherd (heavily weathered)	2.29	6.77	1.39	49.34	5.32	18.63	13.06
BL10	Vessel glass, body sherd (heavily weathered)	2.27	6.92	1.44	49.41	5.35	18.55	12.98
BL11	Working waste: run	2.31	6.53	1.43	53.41	3.65	12.13	17.49
BL12	Working waste: lump	1.96	6.60	0.63	63.35	2.87	9.94	11.67
BL13	Working waste: lump	2.38	6.99	1.06	56.92	3.76	11.63	14.55
BL14	Working waste: lump	2.44	6.86	0.89	58.42	3.36	11.73	13.42
BL15	Working waste: lump	3.07	7.39	1.06	56.41	3.30	11.80	14.06
BL16	Window glass, thick	3.25	7.97	1.10	57.37	3.05	10.44	13.98
BL17	Window glass, thick	2.15	6.50	0.99	60.73	3.09	10.77	12.92
BL18	Vessel glass, rim sherd	2.24	6.48	0.69	57.92	3.92	12.26	13.76
BL19	Window glass, thin	1.49	3.85	2.35	54.13	3.65	6.36	25.05
BL20	Window glass, thin	2.72	7.33	1.35	56.33	3.54	10.20	15.61
BL21	Vessel glass, wrythen decoration	2.99	7.87	1.05	56.61	3.27	10.60	14.67
BL22	Lampbase	3.10	7.51	1.08	57.51	3.18	10.61	14.13
BL23	Vessel glass, rim sherd	2.34	7.02	1.07	56.92	3.87	11.80	14.34
BL24	Vessel glass, rim sherd	2.24	6.55	0.95	57.50	3.78	12.03	14.00
BL25	Vessel glass, wrythen decoration	3.08	7.61	1.05	56.38	3.22	10.76	14.95
BL26	Crucible (bucket-shaped)	0.18	0.64	14.28	78.88	0.14	1.89	0.36
BL27	Crucible (bucket-shaped)	0.19	0.70	16.26	77.13	0.16	2.08	0.39
BL28	Crucible (barrel-shaped)	0.31	0.72	16.29	76.94	0.11	2.21	0.33
BL29	Crucible (barrel-shaped)	0.27	0.78	17.00	75.91	0.16	2.23	0.34
BL30	Crucible (barrel-shaped)	0.23	0.73	16.26	77.28	0.12	2.10	0.36

NB the results for the crucibles represent the composition of the ceramic fabric of the crucible. For information on the chemical composition of the adhering glass and/or surface vitrification see Appendix 2.

APPENDIX 1. CHEMICAL COMPOSITION OF THE GLASS AND GLASSWORKING DEBRIS

Minor oxides

#	SO_3	Cl	TiO_2	MnO	Fe_2O_3	ZnO	Rb_2O	SrO	ZrO_2	BaO	PbO
BL01	0.19	0.68	0.03	1.27	0.70	0.04	0.021	0.057	0.005	<0.2	<0.02
BL02	0.22	0.62	0.10	1.09	0.91	0.03	0.016	0.062	0.008	<0.2	0.14
BL03	0.24	0.51	0.11	1.25	0.94	0.04	0.034	0.061	0.013	<0.2	0.11
BL04	0.25	0.49	0.16	1.17	1.00	0.04	0.037	0.065	0.014	<0.2	0.10
BL05	0.16	0.58	0.06	1.28	0.86	0.04	0.017	0.068	0.007	<0.2	0.10
BL06	0.20	0.70	0.11	1.20	0.91	0.04	0.016	0.072	0.019	<0.2	<0.02
BL07	0.17	0.57	0.06	1.12	0.90	0.04	0.016	0.062	0.011	<0.2	<0.02
BL08	0.21	0.55	0.08	1.12	0.90	0.04	0.017	0.062	0.009	<0.2	<0.02
BL09	0.24	0.46	0.12	1.29	1.08	0.04	0.034	0.066	0.015	<0.2	0.13
BL10	0.24	0.48	0.12	1.25	0.99	0.04	0.034	0.065	0.014	<0.2	0.13
BL11	0.12	0.41	0.11	1.42	0.77	0.04	0.018	0.079	0.009	0.21	0.06
BL12	0.22	0.68	0.09	1.10	0.89	0.04	0.017	0.059	0.013	<0.2	<0.02
BL13	0.17	0.53	0.09	1.21	0.70	0.04	0.018	0.065	0.006	<0.2	0.09
BL14	0.18	0.56	0.10	1.22	0.81	0.04	0.020	0.061	0.011	<0.2	<0.02
BL15	0.24	0.55	0.09	1.21	0.81	0.04	0.019	0.073	0.009	<0.2	0.03
BL16	0.32	0.51	0.07	1.20	0.75	0.04	0.017	0.074	0.011	<0.2	<0.02
BL17	0.18	0.59	0.04	1.11	0.91	0.04	0.018	0.064	0.013	<0.2	0.06
BL18	0.12	0.64	0.06	1.24	0.67	0.04	0.019	0.055	0.004	<0.2	0.02
BL19	0.12	0.36	0.15	1.58	0.49	0.02	0.005	0.147	0.024	0.42	<0.02
BL20	0.13	0.65	0.14	1.27	0.74	0.05	0.026	0.097	0.016	<0.2	0.05
BL21	0.31	0.57	0.09	1.27	0.69	0.04	0.017	0.075	0.012	<0.2	0.05
BL22	0.14	0.62	0.09	1.26	0.77	0.04	0.016	0.069	0.010	<0.2	0.10
BL23	0.15	0.52	0.06	1.19	0.72	0.04	0.017	0.080	0.008	<0.2	0.08
BL24	0.11	0.65	0.05	1.20	0.69	0.04	0.019	0.063	0.008	0.24	0.04
BL25	0.27	0.57	0.10	1.32	0.67	0.04	0.017	0.074	0.013	<0.2	0.07
BL26	<0.1	<0.1	1.14	<0.02	2.27	<0.02	0.014	0.042	0.039	<0.2	<0.02
BL27	<0.1	<0.1	0.74	<0.02	2.16	<0.02	0.013	0.050	0.051	<0.2	<0.02
BL28	<0.1	<0.1	0.67	<0.02	2.07	<0.02	0.015	0.047	0.039	<0.2	<0.02
BL29	<0.1	<0.1	0.77	<0.02	2.38	<0.02	0.016	0.081	0.044	<0.2	<0.02
BL30	<0.1	<0.1	0.67	<0.02	2.01	<0.02	0.014	0.045	0.049	<0.2	<0.02

APPENDIX 2. CHEMICAL ANALYSIS OF THE CRUCIBLES

The data for the following crucibles represents a series of area analyses carried out through adhering glass and/or surface vitrification. Each analysis is identified by a distance value; positive equals adhering glass and/or surface vitrification, negative equals ceramic fabric of the crucible.

BL26 (Interior)

Dist (mm)	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	K_2O	CaO	TiO_2	MnO	Fe_2O_3
0.562	1.99	4.30	4.33	62.78	1.30	12.54	10.15	0.32	0.83	1.27
0.540	1.93	4.42	4.38	62.75	1.24	12.77	10.17	0.25	0.90	1.06
0.519	1.89	4.32	4.44	63.06	1.15	12.69	10.08	0.34	0.88	1.05
0.498	1.92	4.43	4.45	62.87	1.09	12.76	9.94	0.26	0.83	1.20
0.476	1.85	4.27	4.46	62.74	1.22	12.81	9.97	0.30	0.86	1.29
0.455	1.85	4.03	4.96	63.46	1.04	13.02	9.04	0.30	0.79	1.38
0.433	1.85	3.83	5.60	63.89	0.87	13.25	7.94	0.31	0.76	1.53
0.412	1.83	3.71	5.68	64.15	0.90	13.33	7.73	0.30	0.72	1.59
0.391	1.74	3.31	6.66	64.88	0.65	13.69	6.51	0.33	0.69	1.48
0.369	1.69	3.02	7.33	65.13	0.50	13.91	5.87	0.29	0.58	1.46
0.347	1.64	3.09	7.19	65.45	0.56	13.90	5.82	0.31	0.58	1.45
0.326	1.57	2.95	7.12	65.61	0.63	13.72	5.71	0.38	0.60	1.47
0.292	1.57	2.50	8.34	66.14	0.66	13.97	4.61	0.31	0.44	1.26
0.270	1.36	1.69	9.51	68.56	0.23	14.04	2.96	0.24	0.31	1.01
0.248	1.21	1.45	7.15	73.45	<0.2	12.49	2.66	0.23	0.32	0.96
0.025	0.33	0.45	14.25	76.14	<0.2	6.60	0.10	0.56	<0.1	1.25
-0.132	0.31	0.34	11.21	81.75	<0.2	4.60	0.13	0.38	<0.1	1.14
-0.288	0.18	0.58	12.42	80.57	<0.2	3.59	0.17	0.51	<0.1	1.81
-0.445	0.28	0.73	18.19	73.19	<0.2	4.14	0.24	0.68	<0.1	2.06
-0.758	0.19	0.65	16.41	76.56	<0.2	3.08	0.35	0.62	<0.1	1.92
-1.052	0.23	0.76	17.25	75.63	<0.2	2.62	0.42	0.58	<0.1	2.21
-1.347	0.17	0.83	17.91	74.59	<0.2	2.73	0.37	0.72	<0.1	2.35
-1.641	0.20	0.70	14.73	78.71	<0.2	2.13	0.31	0.61	<0.1	2.17
-1.935	0.16	0.55	10.46	82.18	<0.2	1.40	0.43	2.25	<0.1	2.32
-2.229	0.20	0.65	14.41	76.16	<0.2	1.89	0.37	2.77	<0.1	3.24
-2.524	0.12	0.58	13.99	80.04	<0.2	1.89	0.34	0.69	<0.1	2.08
-2.818	0.13	0.40	10.70	84.43	<0.2	1.47	0.27	0.52	<0.1	1.60
-3.407	0.20	0.73	15.96	77.17	<0.2	2.05	0.41	0.75	<0.1	2.21
-3.922	0.27	0.90	19.55	72.66	<0.2	2.46	0.47	0.84	<0.1	2.57
-4.438	0.18	0.60	14.43	79.67	<0.2	1.85	0.31	0.65	<0.1	1.99

BL26 (Exterior)

Dist (mm)	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	K_2O	CaO	TiO_2	MnO	Fe_2O_3
0.550	1.94	5.03	3.80	60.84	2.19	11.38	12.09	0.25	1.02	1.26
0.495	2.02	4.96	3.95	60.59	2.18	11.40	12.00	0.30	0.95	1.25
0.440	1.95	4.98	4.02	61.00	2.20	11.46	11.57	0.35	0.99	1.39
0.385	1.85	4.36	5.34	63.26	1.54	12.23	9.01	0.24	0.72	1.26
0.331	1.63	3.29	6.98	65.93	0.97	12.84	6.34	0.26	0.65	1.04
0.275	1.42	2.19	8.64	68.77	0.41	13.13	3.54	0.23	0.38	1.24
0.222	1.42	1.18	12.30	67.28	0.60	13.57	1.65	0.50	0.17	1.43
0.085	0.78	0.26	9.66	80.70	<0.2	6.59	0.19	0.50	<0.1	1.11
-0.059	0.30	0.21	11.06	81.87	<0.2	5.00	0.11	0.48	<0.1	0.92
-0.404	0.33	0.59	15.34	77.34	<0.2	3.51	0.23	0.64	<0.1	1.72
-0.738	0.26	0.66	17.52	75.02	<0.2	3.09	0.31	0.63	<0.1	2.24
-1.199	0.26	0.66	16.36	76.78	<0.2	2.34	0.49	0.60	<0.1	2.14

BL27 (Interior)

Dist (mm)	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	K_2O	CaO	TiO_2	MnO	Fe_2O_3
0.366	3.96	3.20	7.18	61.57	1.14	15.10	5.60	0.33	0.50	1.20
0.329	4.31	3.21	7.00	60.80	1.24	15.28	5.81	0.30	0.44	1.16
0.292	4.45	3.07	6.73	60.38	1.23	15.81	5.97	0.26	0.50	1.29
0.254	3.94	2.60	7.08	61.67	1.27	16.15	5.02	0.35	0.43	1.20
0.216	3.44	1.83	6.41	67.07	0.64	15.41	3.58	0.24	0.23	0.89
0.179	3.11	1.38	3.54	73.75	<0.2	13.61	3.24	0.22	0.26	0.57
0.142	2.92	1.16	4.06	75.32	0.20	12.86	2.44	0.12	0.16	0.51
0.104	2.15	0.93	3.73	79.36	0.26	10.65	1.69	0.15	0.13	0.65
-0.008	0.29	0.23	10.98	81.98	<0.2	4.90	0.14	0.43	<0.1	0.79
-0.155	0.31	0.38	13.58	78.98	<0.2	4.34	0.22	0.60	<0.1	1.15
-0.596	0.24	0.70	17.76	74.22	<0.2	3.18	0.36	0.96	<0.1	2.25
-0.891	0.26	0.87	21.59	69.99	<0.2	2.90	0.43	0.89	<0.1	2.75
-1.185	0.19	0.80	19.09	73.19	<0.2	2.59	0.40	0.78	<0.1	2.59
-1.478	0.21	0.60	15.56	78.49	<0.2	1.98	0.36	0.68	<0.1	1.90
-1.774	0.12	0.65	14.53	79.65	0.28	1.85	0.34	0.56	<0.1	1.91
-2.598	0.19	0.76	17.05	76.09	<0.2	2.18	0.38	0.69	<0.1	2.40
-3.010	0.25	0.78	17.89	74.27	<0.2	2.31	0.49	1.02	<0.1	2.44

BL27 (Exterior)

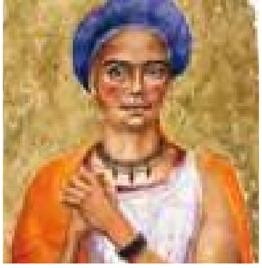
Dist (mm)	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	K_2O	CaO	TiO_2	MnO	Fe_2O_3
0.327	2.33	3.25	7.71	63.33	0.48	12.87	6.28	0.40	0.54	2.58
0.283	2.06	3.18	7.84	64.00	0.59	12.56	6.23	0.37	0.57	2.36
0.240	1.96	2.93	8.60	64.42	0.48	12.82	5.71	0.38	0.43	2.12
0.197	1.82	2.38	9.86	64.86	0.38	13.22	4.59	0.42	0.43	1.96
0.154	1.64	1.97	10.80	65.87	0.35	13.34	3.49	0.36	0.29	1.74
0.118	1.35	1.56	9.60	70.43	0.24	12.41	2.36	0.36	0.24	1.35
0.000	0.28	0.32	7.76	85.34	<0.2	4.39	0.30	0.38	<0.1	0.79
-0.324	0.23	0.56	15.76	77.15	<0.2	3.52	0.13	0.73	<0.1	1.63
-0.668	0.24	0.81	18.58	73.29	<0.2	3.16	0.31	0.82	<0.1	2.31
-1.011	0.18	0.63	14.91	79.25	<0.2	1.99	0.27	0.60	<0.1	1.81
-1.355	0.18	0.54	13.33	81.51	<0.2	1.72	0.30	0.63	<0.1	1.71
-2.042	0.21	0.73	15.86	76.69	<0.2	2.03	0.35	1.15	<0.1	2.86
-2.729	0.22	0.70	16.40	76.52	<0.2	2.09	0.37	1.20	<0.1	2.37

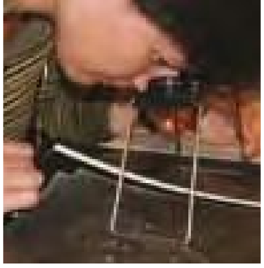
BL28 (vitrified layer at junction of crucible wall and base, see Figure 8)

Area	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	K_2O	CaO	TiO_2	MnO	Fe_2O_3	PbO
1	0.64	1.57	13.24	65.47	1.25	7.31	2.79	0.57	0.15	5.46	1.26
2	0.61	1.84	12.66	66.38	1.05	6.37	2.88	0.46	0.25	5.70	1.39
3	0.54	1.64	13.89	64.12	1.33	5.76	2.37	0.53	0.19	7.50	1.79
4	0.57	1.43	15.39	63.44	1.27	4.88	1.69	0.68	0.12	8.47	1.99
5	1.90	2.74	10.50	60.88	1.22	12.57	6.92	0.42	0.55	1.94	<0.2
6	1.68	2.06	10.97	64.96	0.53	13.74	3.34	0.39	0.32	1.84	<0.2
7	1.48	1.77	11.54	65.59	0.57	13.80	1.96	0.44	0.13	2.51	<0.2

BL30

Dist (mm)	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	K_2O	CaO	TiO_2	MnO	Fe_2O_3
1.069	2.04	3.58	7.23	64.62	0.31	12.81	6.83	0.32	0.61	1.59
0.995	2.05	3.37	7.67	65.05	0.32	12.80	6.24	0.28	0.52	1.50
0.921	2.08	3.60	6.98	65.53	0.26	12.69	6.49	0.33	0.51	1.48
0.848	2.16	3.63	6.77	65.43	0.22	12.65	6.74	0.37	0.55	1.47
0.774	2.20	3.80	6.44	65.35	0.30	12.44	6.93	0.30	0.55	1.62
0.701	2.27	3.73	6.62	65.26	0.29	12.28	7.00	0.31	0.61	1.52
0.631	2.19	3.75	6.82	65.40	0.30	12.29	6.71	0.33	0.59	1.53
0.558	2.26	3.55	6.75	65.70	0.27	12.27	6.42	0.37	0.54	1.63
0.485	2.09	3.23	7.20	66.12	0.30	12.31	5.58	0.36	0.49	1.97
0.411	1.85	2.90	6.99	67.57	0.52	11.96	4.63	0.39	0.37	2.72
0.338	1.74	3.10	6.85	67.75	0.47	11.51	5.07	0.37	0.53	2.61
0.265	1.74	3.30	6.79	67.27	0.46	11.23	5.50	0.38	0.54	2.74
0.191	1.54	2.22	7.94	68.49	0.48	11.59	3.28	0.45	0.28	3.69
0.117	1.06	1.50	9.52	70.58	0.47	11.18	1.44	0.45	0.21	3.71
0.044	0.98	1.19	12.33	68.23	0.36	11.70	1.33	0.45	0.14	3.17
-0.030	0.97	1.07	14.48	66.70	0.20	12.10	1.10	0.59	0.15	2.65
-0.104	1.02	1.18	16.70	64.47	<0.2	11.89	1.29	0.53	0.11	2.38
-0.177	1.03	0.76	15.81	68.73	<0.2	10.35	1.09	0.55	<0.1	1.37
-0.236	0.80	0.52	14.00	73.28	<0.2	8.55	0.80	0.56	<0.1	1.17
-0.527	1.10	0.76	16.02	69.63	<0.2	8.81	0.85	0.66	<0.1	1.95
-0.856	0.52	0.51	16.35	74.18	<0.2	5.66	0.19	0.53	<0.1	1.74
-1.184	0.28	0.56	16.17	76.47	<0.2	3.50	0.27	0.71	<0.1	1.85
-1.841	0.15	0.73	15.66	77.99	<0.2	2.37	0.28	0.67	<0.1	1.82
-2.506	0.39	0.71	16.82	76.46	<0.2	2.20	0.43	0.70	<0.1	2.15
-3.171	0.29	0.90	18.82	73.82	<0.2	2.35	0.45	0.75	<0.1	2.24
-3.835	0.24	0.70	16.17	77.42	<0.2	1.99	0.45	0.64	<0.1	1.93
-4.499	0.29	0.77	16.91	76.05	<0.2	2.18	0.36	0.73	<0.1	2.13
-5.165	0.19	0.59	14.25	80.34	<0.2	1.85	0.28	0.61	<0.1	1.79
-5.830	0.16	0.69	14.17	80.13	<0.2	1.86	0.32	0.54	<0.1	1.73


ENGLISH HERITAGE RESEARCH DEPARTMENT

English Heritage undertakes and commissions research into the historic environment, and the issues that affect its condition and survival, in order to provide the understanding necessary for informed policy and decision making, for sustainable management, and to promote the widest access, appreciation and enjoyment of our heritage.

The Research Department provides English Heritage with this capacity in the fields of buildings history, archaeology, and landscape history. It brings together seven teams with complementary investigative and analytical skills to provide integrated research expertise across the range of the historic environment. These are:

* *Aerial Survey and Investigation*
* *Archaeological Projects (excavation)*
* *Archaeological Science*
* *Archaeological Survey and Investigation (landscape analysis)*
* *Architectural Investigation*
* *Imaging, Graphics and Survey (including measured and metric survey, and photography)*
* *Survey of London*

The Research Department undertakes a wide range of investigative and analytical projects, and provides quality assurance and management support for externally-commissioned research. We aim for innovative work of the highest quality which will set agendas and standards for the historic environment sector. In support of this, and to build capacity and promote best practice in the sector, we also publish guidance and provide advice and training. We support outreach and education activities and build these in to our projects and programmes wherever possible.

We make the results of our work available through the Research Department Report Series, and through journal publications and monographs. Our publication Research News, which appears three times a year, aims to keep our partners within and outside English Heritage up-to-date with our projects and activities. A full list of Research Department Reports, with abstracts and information on how to obtain copies, may be found on www.english-heritage.org.uk/researchreports

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