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CHEMICAL ANALYSIS OF PRODUCTION WASTE FROM WEALDEN GLASSHOUSES

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Vanessa Castagnino

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Surrey and Sussex

Chemical Analysis of Production Waste from Wealden Glasshouses

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SUMMARY

The scientific analysis of surface finds from selected Wealden glasshouse sites provides clear information as to the chemical composition of both glassmaking crucibles and glassworking waste. The aim of the study is to determine whether this information can be used to establish an approximate date for each site in relation to the arrival of Jean Carré's immigrant glassworkers, *c* 1567, by looking for technical changes in both crucible construction and glass composition. This research forms part of the wider remit of the Wealden Glass Project (5299), funded by English Heritage and undertaken by Surrey Archaeological Unit. The project aims to locate and characterise the glasshouse sites in the region, in order to establish a sound framework for the management of these sites. The results of the study suggest multi-phased development of many of the glasshouses in terms of both crucible construction and glass composition supporting, and expanding, on previous research of the glass industry in the Weald of Surrey and Sussex.

ACKNOWLEDGEMENTS

Thanks must go to the Surrey Country Archaeology Unit for the materials and additional information. Special thanks must go to Dr Sarah Paynter for her time, patience, support and for comments on the original draft of this report; in addition, for sharing her wealth of knowledge, both in terms of material and analytical techniques.

ARCHIVE LOCATION

The samples taken for chemical analysis are held by English Heritage, Fort Cumberland, Portsmouth, PO4 9LD.

DATE OF RESEARCH

2013

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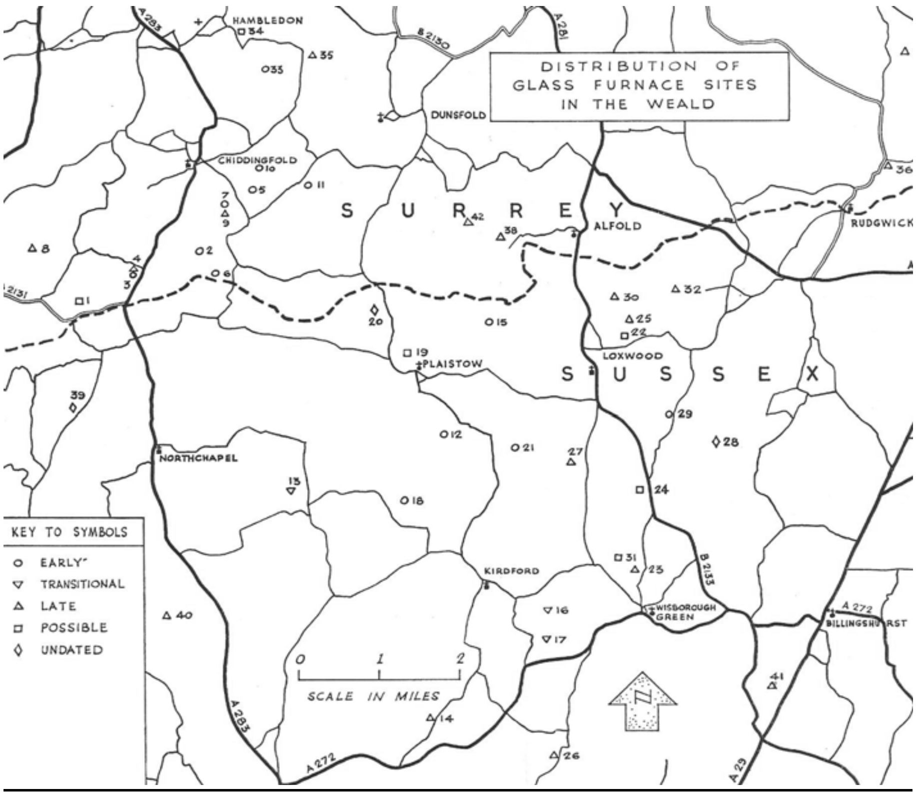

Figure 1: Map showing glass furnaces sites in the Weald of Surrey and Sussex (Kenyon 1967)

The development of small scale medieval glassworking into a post-medieval industry found its roots in the 1560s in the Weald. Before this period, the majority of glass was imported from the Continent (Crossley 1994). As entrepreneurial endeavours flourished in Tudor England, and standards of living improved, the demand for window glass increased.

Medieval high temperature activities (metal, pottery and glass production) were typically situated in forested areas due to the substantial quantity of wood required. Small groups of English glassmakers are known from documentary evidence to have been sited in both the Weald of Surrey and Sussex and in Staffordshire, such as Bishop's Wood (1584-1604) and Bagot's Park (1585) (Kenyon 1967, 213), and some other locations where fuel was abundant.

Wealden glassmaking

The Weald of Surrey and Sussex is of major importance in establishing the history of the medieval and post-medieval glassworking industry in England (Dungworth and Clark 2004, 3). Little is known of glass production in the region prior to the 16th century other than it was carried out on a small scale, with a handful of glassworking families producing limited quantities of window and vessel glass for a select clientele. Glassworking is suspected since the early 1300s, however physical evidence remains limited.

In 1567, the entrepreneur Jean Carré took advantage of this developing market and was granted a licence by the Crown to produce window glass in the Weald, where he stated he had two glasshouses running at Fernfold Wood, near Alfold (Godfrey 1975, 17); there was possibly a third glasshouse at Sidney Wood (Winbolt 1933). He employed his glassworkers from Normandy and the Lorraine Valley, both areas known for their expertise and quality of glass manufacture. In return for access to England's glass market, the licence stated that local glassworkers must be instructed in the imported technologies. Glassworking, and glassmaking recipes, were a highly guarded secret; kept within established generations of glassworking families (Godfrey 1975) and as a result the incomers were reluctant to share their knowledge and skill. It was not until second or third generation immigrants that a complete change of both technology and recipe is seen in the industry (Dungworth 2007). The archaeological record has offered some interesting examples of that process through the systematic change and development of glassmaking technologies (Paynter 2012), until its final end *c* 1618, following the ban on wood-fuelled glassworking furnaces in the region.

Wealden ironworking had been well attested since the Roman period, whereas glass production was a more recent addition to the industrial landscape. As both processes shared an intrinsic requirement for wood, there was a level of competition for the fuel source. In 1615, the glassmakers were legally ordered to stop using wood fuel, which led to the relocation of the industry to the coalfields (Crossley 2012) and shortly the end of the Wealden glass industry.

The glasshouse sites

Documentary evidence in the form has provided information on the Wealden glassworkers and has helped to identify areas where glassworking may have taken place. Place names and surface finds, such as crucible fragments and lumps of glass, are also indicators. Some glasshouses have been excavated, such as that at Blunden's Wood and Sidney Wood, and glass production waste from Wealden sites has been examined previously (Dungworth 2007; 2010; Dungworth and Clark 2004; 2010; Dungworth and Paynter 2010; Meek *et al* 2012; Mortimer 1993; Paynter 2012; Welham 2001; Kenyon 1967; Wood 1965; 1982) (Table 1).

Blunden's Wood (Wood 1965) is the earliest example excavated in the south of England but otherwise the sites producing glass between the 14th and 16th century have in general proved a rarity. Most others, such as Sidney Wood and Woodhouse Farm, have been dated to later periods on the basis of associated finds, such as pottery evidence. With the scientific analysis of materials from glasshouses some of those dates have been revised and re-assessed. The survival of these sites varies greatly depending largely on previous land use in the area (Crossley 1994; 2012).

Glass and crucible composition

From a compositional perspective, medieval glass changed little from the 14th to mid-16th century. Although slight variations in overall composition are noted when sites are compared, this is probably due to regional or local differences in the raw material sources (Dungworth 2010; Meek *et al* 2012). A significant change in glass composition, from potassium-rich 'potash glass' to a more lime-rich 'HLLA glass' (high lime, low alkali) (Mortimer 1997), broadly coincides with the arrival of immigrant glassworkers from the continent *c* 1567 (Dungworth 2007; 2010; Dungworth and Clark 2004; 2010; Dungworth and Paynter 2010; Mortimer 1993; 1997; Kenyon 1967; Welham 2001; Wood 1965; 1982) (Table 1).

Previous researchers have attempted to date identified glassworking sites in relation to the arrival of immigrant glassworkers from continental Europe based largely on the appearance of the glass, with differences in weathering thought to reflect differences in glass composition; Kenyon (1967) described sites as either 'early' (1330–1567) or 'late' (1567–1618).

Table 1: Blunden's Wood = Dungworth and Paynter 2010; Knightons = Wood 1982; Idehurst North and South = Dungworth and Clark 2004; June Hill = Dungworth 2007 and Sidney Wood = Welham 2001

Site	Date	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	K_2O	CaO	MnO	Fe_2O_3
Blunden's Wood	14th	2.7	7.0	1.2	59.8	2.7	10.3	13.8	1.0	0.9
Knightons	16th	2.2	6.1	2.5	57.2	2.9	10.2	16.2	0.9	0.8
Idehurst North	16th	2.1	7.2	1.1	55.3	3.2	11.6	17.0	1.1	0.6
Idehurst South	16th	3.0	8.7	1.4	53.3	3.9	10.8	16.6	1.0	0.6
June Hill	16th/17th	1.2	4.2	2.3	60.7	2.3	7.7	19.2	0.9	0.9
Sidney Wood	16th/17th	2.7	2.9	3.2	60.0	1.7	4.1	22.9	0.7	1.3

More recently, chemical analysis of Wealden glassworking debris has drawn attention to chronological changes in crucible technology as well as providing further data on glass composition (Dungworth and Clark 2004; Dungworth 2007; Dungworth and Paynter 2010; Paynter 2012). Sites producing potash glass, which (where dating evidence is available) are likely to predate the arrival of immigrant glassworkers, mostly used quartz-rich crucibles, whereas the sites making HLLA glass used a more alumina-rich clay of the type used to make contemporary tobacco pipes, which they tempered with grog. This transition may be due to the greater chemical resistance of the pipe-clay (Paynter 2012), and therefore the greater longevity and reliability of the pots. Two sites yielded pots with broadly intermediate compositions, both of which were making potash glass, which suggested that the crucible composition was changed before the glass composition.

AIMS

The aim of this analytical study was to characterise the crucible fragments and glass waste found during field walking during the initial stages of the Wealden Glass project. This information will be used to determine the likely date of each site. It is hoped that the final stages of the Wealden project, involving excavation of selected glass furnaces and archaeomagnetic dating of the remains, will provide independent dating evidence to test the validity of this approach.

MATERIAL

The materials analysed come from a selection of nine glasshouse sites, of the 48 sites most recently listed. Each of the sites has been allocated a number (Table 2), either by Kenyon (1967), or later by Crossley (1994). Some of the sites offered up large quantities of material, but others less so, such as Lordings Farm (one ceramic fragment and no glass). The glasshouse sites in this study are: Hogs Wood (E), Imbhams Farm (L), June Hill (L), Knightons (L) Lordings Farm (none given), Malham Farm (L), Primrose Copse (none given), Sidney Wood (L) and Woodhouse Farm (L); the letter in brackets denotes Kenyon's view on whether the site is early (E) or late (L) in date.

For this study, the chemical analysis of 53 samples of glass production waste (22 crucible fragments and 31 glass fragments) from nine located Wealden glasshouse sites was undertaken (Table 2). All of these samples are finds from field walking, however it has been noted in previous research that the location of crucible fragments is a strong indicator of a nearby furnace; glass fragments, too, are a good indicator but less accurate, possibly within "a few hundred yards" (Kenyon 1967, 49). Furthermore the material for this study represents manufacturing waste: the remnants of crucibles discarded after collapse or abandoned upon vacation of the site, and as such are likely to have been made nearby using clay brought to the area (Paynter 2012). The majority of these fragments are body sherds, with only three recognisable as the rounded rim sherds typical of Wealden sites (Kenyon 1967). The glass samples are all production waste lumps, mostly amorphous, rather than fragments of vessel or window glass.

Table 2: The nine glasshouse sites in the Weald of Surrey and Sussex from which crucible fragments and glassworking waste were gathered for chemical analysis (the Lordings Farm sample may be part of the furnace structure rather than crucible)*

Site	Crucible Fragment	Glass Waste	Total
Hogs Wood HWA (15)	2	2	4
Imbhams Farm IFG (8)	3	2	5
June Hill JHC (44)	1	3	4
Knightons KA (42)	1	4	5
Lordings Farm LFB (41)	*	0	1
Malham Farm MFL (28)	3	2	5
Primrose Copse PCR (46)	4	5	9
Sidney Wood SWA (38)	5	5	10
Woodhouse Farm WFR (32)	2	8	10
Total	22	31	53

METHODS

Some sites produced more evidence than others; however a representative sample for each site was selected for analysis and further examination, both in terms of crucible fragments and glass waste. All of the materials provided were photographed and measured; deposits on both the inner and outer surfaces were noted. Some of the glass analysed was adhered to a crucible; in some cases it remained attached during sampling and in others the glass was removed prior and analysed separately. Due to the hard nature of the ceramic, crucible samples were cut with an Isomet precision saw. All of the samples were sectioned and mounted in epoxy resin before being ground and hand polished to a 1-micron finish.

The crucible and glass samples were analysed using a scanning electron microscope (SEM) with an energy dispersive x-ray spectrometer (EDS) attached. The SEM was an FEI Inspect F which was operated at 25kV with a beam current of approximately 1nA, and data was gathered at 150 seconds/live time. The x-ray spectra generated by the sample were detected using an Oxford Instruments X-act SDD detector. In advance of the analysis, the EDS spectra were calibrated using a cobalt standard. The data were quantified using the Oxford Instruments INCA software. The data was gathered in weight % and then normalised.

Glass standards Corning A and D were analysed to check the accuracy and precision of the results. The minimum detection limit for most elements was 0.1wt%, rising to 0.2wt% for As_2O_3, BaO, CoO, P_2O_5 and SO_3. Three target areas were analysed at 150 times magnification and an overall average calculated for each sample; the average values are used within the text. The full compositional data for both crucible and glass are displayed in the appendices of this report.

RESULTS

For the full analytical results see Appendix 1. Backscattered electron images of the crucible samples are given in Appendix 2.

Crucible Fragments

A key characteristic of the pipe clay used for later (speculatively post-1560s) crucibles at Wealden sites (Paynter 2012) is the low ratio of iron oxide to titanium oxide, which will remain unchanged even if quartz-temper is added to the clay mixture. Plots featuring this ratio (Figure 2) show the analysed samples dividing into two groups, with the samples likely to be made from pipe clay grouping on the left.

Table 3: Average (of three) compositions of crucible samples determined by SEM-EDS, normalised weight percent oxides

Sample	Na_2O	MgO	Al_2O_3	SiO_2	K_2O	CaO	TiO_2	Fe_2O_3
HWA11.2	0.26	0.79	18.82	73.46	2.93	0.39	1.03	2.28
HWA11.1	0.30	0.67	15.75	77.87	2.25	0.40	0.91	1.81
IFG11 GS. 34.1	0.23	0.63	14.97	79.56	1.82	0.46	0.74	1.53
IFG11 GS 43.1	0.72	0.97	19.23	74.79	1.82	0.75	0.58	1.09
IFG 11 GS 43.2	0.26	0.86	18.04	76.97	1.77	0.27	0.64	1.11
KA11 (around furnace)	0.48	0.76	17.59	75.62	2.09	0.41	0.90	2.07
MFL11 Q6 C Quad	0.25	0.77	17.80	76.17	2.04	0.35	0.83	1.74
MFL11 SQ5 Q5	0.26	0.78	17.25	76.34	2.27	0.35	0.88	1.87
MFL 11 SQ 13 B Quad	0.14	0.69	16.86	77.56	2.07	0.29	0.81	1.55
PCR11 GEN 3	0.23	0.58	23.08	69.21	2.38	0.60	1.18	2.71
PCR11 GEN1	0.55	0.36	20.18	74.14	2.35	0.40	1.26	0.69
PCR 11 GEN .2	0.28	0.31	23.17	72.33	1.54	0.12	1.22	0.96
PCR11 SQ2	0.33	0.39	20.47	73.78	1.71	0.42	1.60	1.26
SWA11-5	0.78	0.67	16.79	76.81	2.24	0.32	0.77	1.59
SWA11 2.2	0.10	0.28	21.65	73.74	1.22	0.18	1.28	1.47
SWA11-6	0.18	0.46	18.98	75.55	1.69	0.33	1.27	1.50
SWA11 2.3	0.12	0.22	22.41	73.26	0.97	0.18	1.43	1.35
SWA11 4.1	0.19	0.36	20.13	74.45	1.43	0.48	1.66	1.21
JHC11 101	0.21	0.24	22.07	73.04	1.39	0.26	1.36	1.34
LFB11 US	0.27	0.22	19.29	75.60	1.22	0.38	1.49	1.46
WFR11.5 U/S	0.22	0.34	24.84	69.95	1.86	0.10	1.43	1.23
WFR11.7 U/S	0.13	0.37	18.76	76.41	1.59	0.34	1.27	1.08

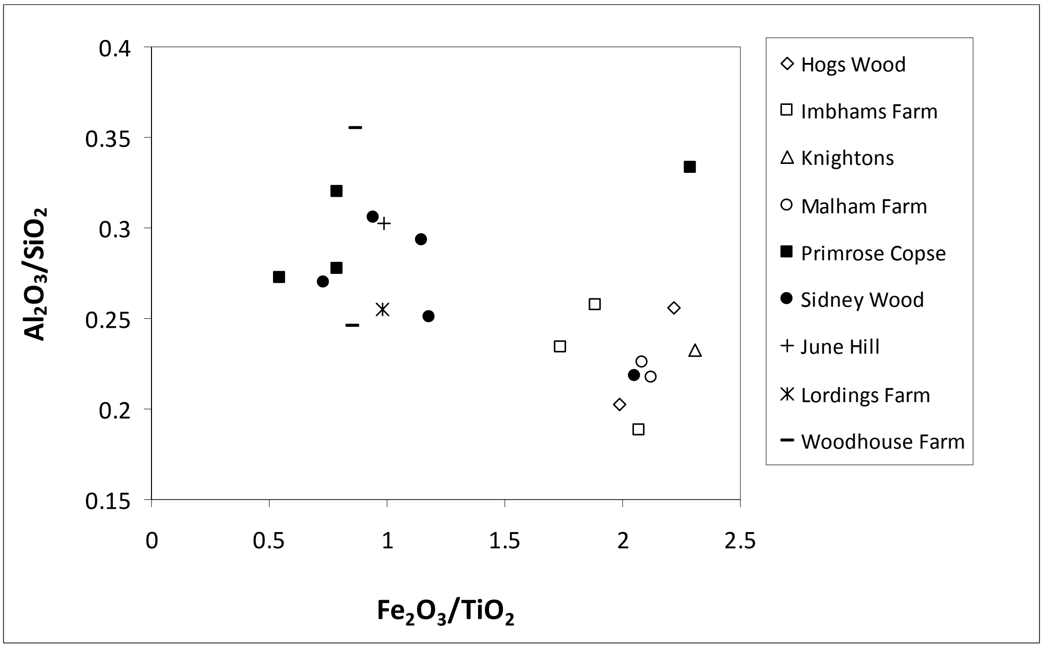

Figure 2: Iron/titanium (pipe clay) and alumina/silica (quartz-rich) content from a selection of crucibles from a selection of Wealden glasshouse sites. The outlier from Primrose Copse has atypically high levels of iron, but is otherwise consistent with the pipe clay group

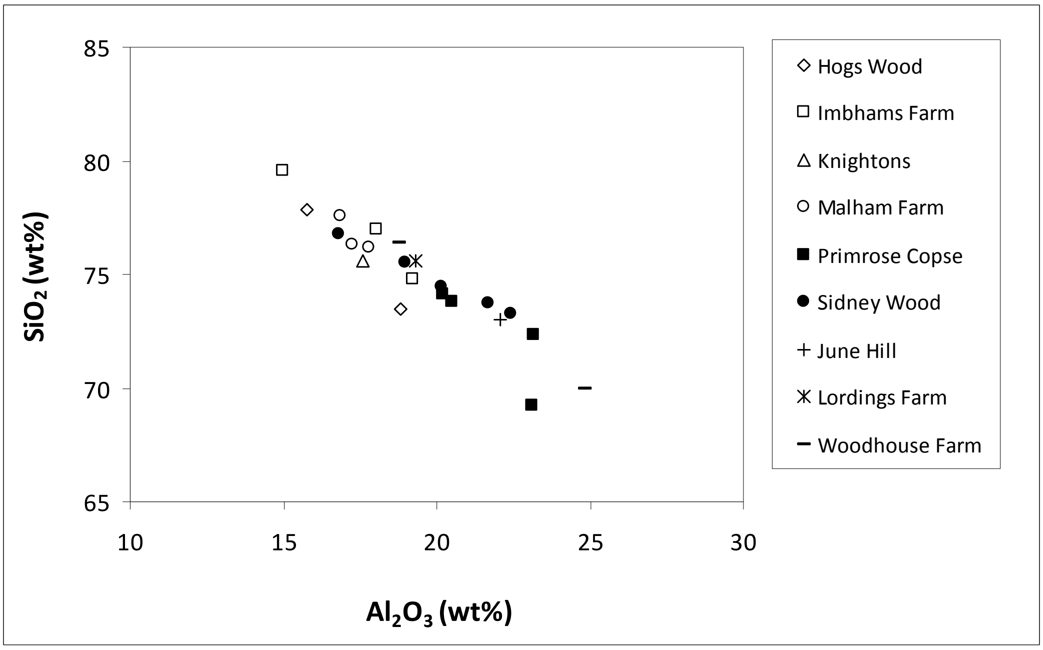

Figure 3: Alumina and silica oxide contents from a selection of crucibles from a selection of Wealden glasshouse sites

Crucibles made from quartz-rich clay, suggesting an earlier date, were found at Hogs Wood, Malhams Farm, Imbhams Farm and Knightons, and also one of the five samples from Sidney Wood. Crucibles containing pipe clay were found at Primrose Copse, Woodhouse Farm, June Hill and Sidney Wood (four out of the five samples).

No attempt has been made to define an intermediate composition, as in Paynter 2012, because there is a broad compositional range for both crucible types with some overlap in between (Figure 3) and so an intermediate composition cannot be clearly differentiated with the number of samples analysed.

Glass

The glass compositions are differentiated largely by their concentrations of calcium, potassium and magnesium oxides (Figure 4). HLLA glass from Wealden sites contains high levels of calcium oxide of up to around 25wt%; whereas potash glass contains less, as little as 13wt% in Wealden examples. However it is apparent from Table 4 that some of the glass samples fall somewhere between these extremes and that there is sometimes significant variation amongst the samples from a single site (Figure 5).

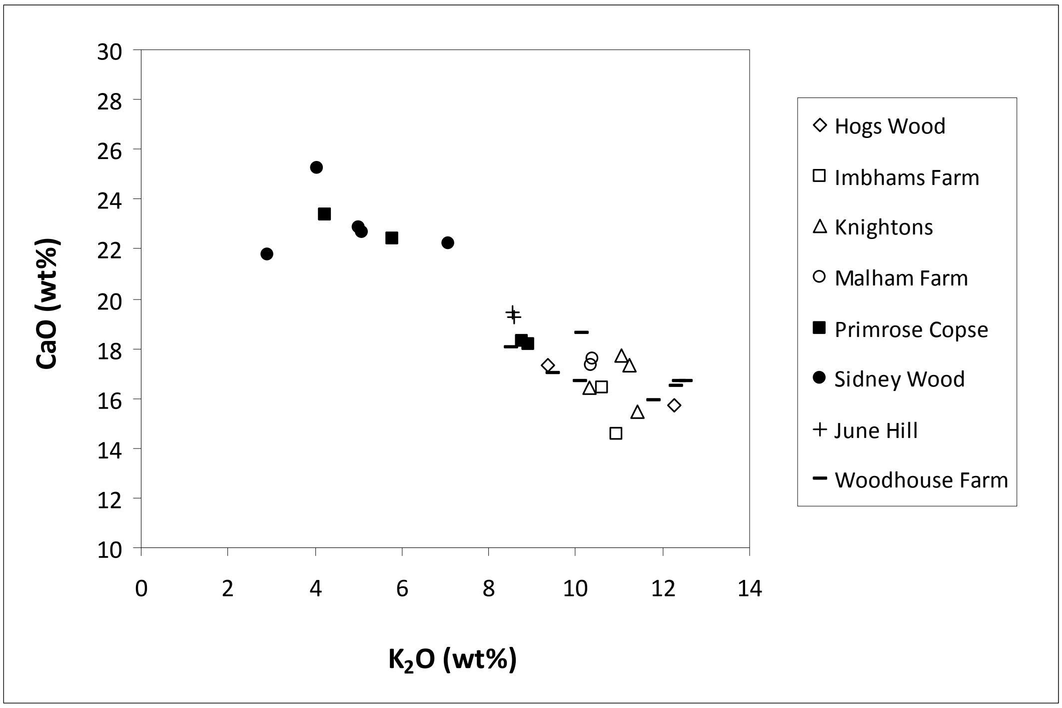

Figure 4: Calcium and potassium oxide contents of glass working waste from the Wealden glasshouse sites in this study showing the Sidney Wood and Primrose Copse HLLA samples in the top left

Table 4: Average (of four) compositions of glass samples determined by SEM-EDS, normalised weight percent oxides

Sample	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	Cl	K_2O	CaO	TiO_2	MnO	Fe_2O_3	CoO	As_2O_3	Bi_2O_3
HWA 1	2.35	6.05	2.09	57.17	2.95	0.27	0.43	9.37	17.36	0.23	0.99	0.68	bd	bd	bd
HWA 3	2.94	8.01	1.34	53.40	3.34	0.33	0.57	12.28	15.74	0.20	1.09	0.61	bd	bd	bd
IFG 7	2.30	7.29	0.95	58.50	2.70	0.43	0.60	10.95	14.58	0.18	1.16	0.43	bd	bd	bd
IFG11 GS23 5	2.61	6.85	1.44	56.24	3.10	0.40	0.58	10.61	16.41	0.21	0.97	0.57	bd	bd	bd
JHC11 2	1.11	4.65	2.30	58.22	2.16	0.46	0.32	8.60	19.28	0.37	1.40	0.93	bd	bd	bd
JHC-5	1.26	5.35	2.30	57.03	2.50	0.44	0.24	8.54	19.43	0.31	1.51	0.86	bd	bd	bd
JHC11 6	0.87	3.75	2.51	56.39	3.09	0.40	0.33	11.42	18.35	0.39	1.23	1.08	bd	bd	bd
KA11 1	1.52	7.33	1.89	55.12	2.89	0.27	0.42	11.25	17.32	0.22	1.01	0.67	bd	bd	bd
KA11 2	1.50	6.73	1.58	58.72	2.02	0.40	0.29	11.41	15.49	0.25	0.73	0.67	bd	bd	bd
KA11 3	1.63	6.81	2.10	55.18	2.94	0.26	0.39	11.04	17.74	0.23	0.98	0.63	bd	bd	bd
KA11 4	2.53	6.99	2.05	55.23	3.39	0.44	0.55	10.32	16.40	0.24	1.16	0.74	bd	bd	bd
MFL 1	2.39	5.96	2.05	55.74	3.43	0.20	0.47	10.34	17.34	0.24	0.97	0.79	bd	bd	bd
MFL 2	2.21	5.99	2.21	55.17	3.48	bd	0.42	10.39	17.61	0.22	1.09	0.93	bd	bd	bd
PCR11-2	0.98	2.95	4.16	58.36	2.16	0.32	bd	5.77	22.42	0.48	0.78	1.44	bd	bd	bd
PCR11-5	1.01	2.29	2.37	62.44	1.66	0.23	0.23	4.24	23.40	0.30	0.71	0.97	bd	bd	bd
PCR11 GEN3	1.00	2.30	2.39	62.38	1.68	bd	0.23	4.25	23.38	0.31	0.75	0.98	bd	bd	bd
PCR11 SQ4 1	1.90	5.26	1.74	58.62	2.41	0.31	0.54	8.90	18.15	0.24	0.91	0.86	bd	bd	bd
PCR11 SQ4 2	1.90	5.45	1.68	58.47	2.41	0.35	0.58	8.75	18.27	0.24	0.92	0.82	bd	bd	bd
SWA11 1	0.70	2.21	2.42	61.40	1.66	0.25	bd	4.07	25.24	0.31	0.64	0.90	bd	bd	bd
SWA11 2	2.03	2.52	2.81	63.14	1.56	0.35	bd	2.90	21.77	0.44	0.70	0.91	bd	bd	bd
SWA11 3	0.96	2.88	4.83	57.08	1.75	0.29	bd	7.08	22.22	0.46	1.17	1.07	bd	bd	bd
SWA11 4	2.51	3.74	2.12	58.60	2.16	0.72	0.37	5.07	22.68	0.28	0.79	0.84	bd	bd	bd
SWA11 5	2.46	3.73	2.10	58.54	2.19	0.69	0.37	5.02	22.84	0.28	0.78	0.85	bd	bd	bd
WFR11 2	1.75	5.32	1.92	56.44	2.87	0.33	0.38	10.14	18.59	0.25	0.87	0.97	bd	bd	bd
WFR11 3	1.99	5.30	2.04	56.68	2.73	0.33	0.48	9.47	17.01	0.29	1.03	1.17	0.25	0.55	0.40
WFR11 4	1.49	5.21	1.80	56.52	2.96	0.26	0.42	12.51	16.72	0.26	0.84	0.87	bd	bd	bd
WFR11 5	1.55	5.37	1.77	56.62	3.02	0.25	0.46	12.31	16.51	0.30	0.86	0.81	bd	bd	bd
WFR11 6	2.89	6.05	2.53	55.79	3.02	bd	0.35	8.50	18.03	0.33	1.15	0.94	bd	bd	bd
WFR11 7	2.26	5.70	1.81	56.28	3.27	0.21	0.58	11.80	15.93	0.25	0.90	0.78	bd	bd	bd
WFR11 U/S	2.14	6.06	1.88	57.46	2.83	0.26	0.39	10.09	16.68	0.25	1.00	0.80	bd	bd	bd
WFR11 U/S 5	1.53	5.11	1.79	56.84	2.92	bd	0.42	12.38	16.70	0.28	0.82	0.85	bd	bd	bd

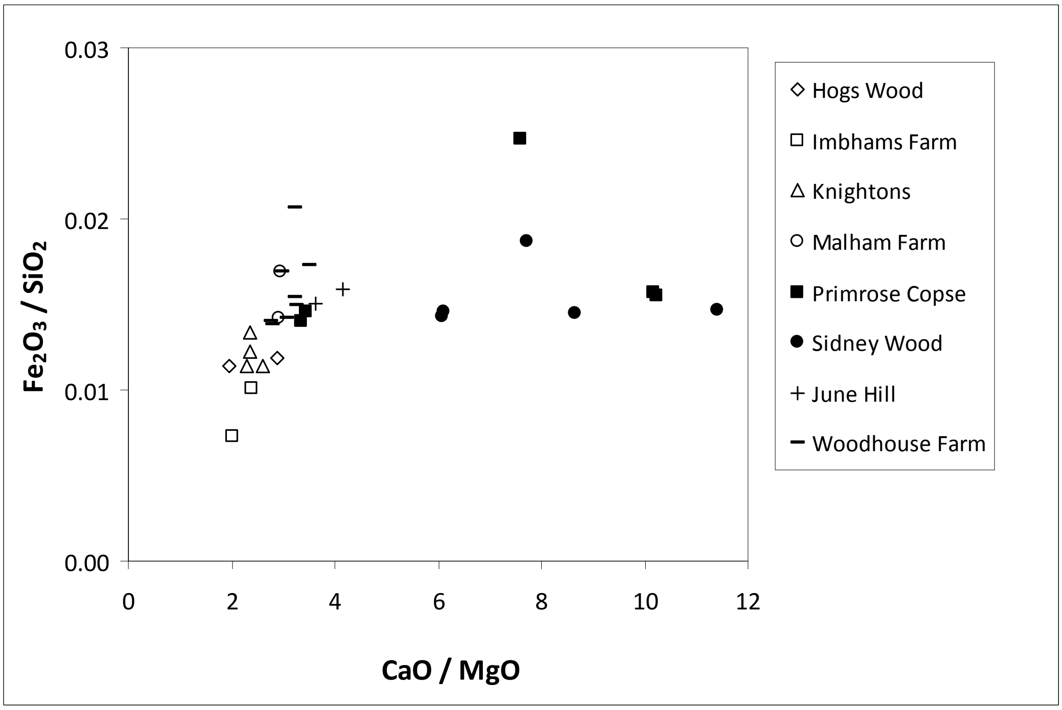

Figure 5: Plot of the ratio of lime to magnesia versus iron oxide to silica in the glass working waste from the Wealden glasshouse sites in this study, again showing the differentiation between HLLA (right) and potash (left) glass

The high levels of lime, in excess of 20wt%, in three samples from Primrose Copse and all of the samples from Sidney Wood are consistent with HLLA glass. The high levels of magnesia and potash, in excess of 5.5wt% and 10wt% respectively, in the glass from Hogs Wood, Imbhams Farm, Knightons farm and Malhams Farm and most samples from Woodhouse Farm are consistent with potash glass. However the samples from June Hill, two samples from Primrose Copse and some of the samples from Woodhouse Farm are somewhere in between.

DISCUSSION

The analysis of glassworking waste from nine Wealden glasshouses provides information as to the types of crucible used and glass produced at each site. The arrival of immigrant French glassworkers in the 1560s denotes the beginning of significant changes in the production of glass in post-medieval England. However it appears that these changes in practice develop over a period of time, and perhaps at different rates depending on the particular site, and the products being made, whether windows, fineware or utilitarian vessels. More detailed interpretation will be possible when the final stages of the Wealden Glass project have been completed, but here we compare the types of crucible and glass found at each site using the results to date (Table 5), with an updated conclusion on whether the sites maybe early (e), late (l) or transitional (t) based on the materials that they were using and producing.

Table 5: Showing the range of sites and, based on the material in this study, what materials were used and produced

Site	Crucible		Glass			Date
	Quartz-rich	Pipe clay grogged	Potash	Intermediate	HLLA	
Hogs Wood	*		*			e
Imbhams Farm	*		*			e
June Hill		*	*	*		t
Knightons	*		*			e
Lordings Farm		*				l
Malham Farm	*		*			e
Primrose Copse		*	*	*	*	t
Sidney Wood	(1)	*(4)			*	l
Woodhouse Farm		*	*	*		t

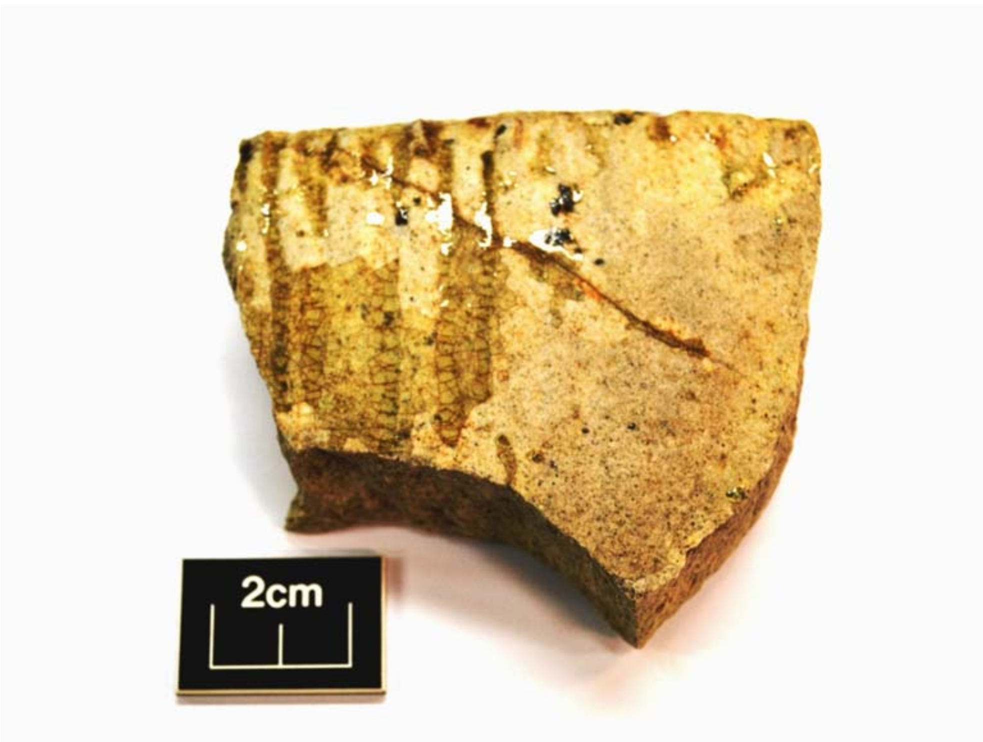

Figure 6: Round-rimmed body fragment of pipe clay crucible from Sidney Wood (SWA11 5). There is a glazed appearance to both the outer and inner surfaces, partly from the glass contained in the pot and partly from the furnace atmosphere

Figure 7: Fragment of quartz-rich crucible from Malham Farm (MF11 SQ5 Q5)

The crucibles from Imbhams Farm, Malham Farm, Knightons and Hogs Wood were all of the quartz-rich type, and probably made from the nearby Nonsuch clay or similar (Paynter 2012). The glass from all of these sites is also potash glass. It is therefore likely that these sites predate the arrival of glassworkers from continental Europe around the 1560s and the accompanying changes in technology. Hogs Wood was described as an 'early' glasshouse by Kenyon because of a possible 14th-century deed reference (Kenyon 1967, 31). Knightons is thought to be early 16th century on the basis of a previous archaeomagnetic date and associated archaeological evidence (Wood 1982). Kenyon was uncertain of the date of Malham Farm on the basis of the glass appearance but ultimately opted for post 1560s production (Kenyon 1967, 190), although these results suggest that is probably incorrect.

The crucibles from Woodhouse Farm, June Hill and Primrose Copse, plus most of the crucibles from Sidney Wood and the refractory fragment from Lordings Farm are made from grogged pipe clay, however only Sidney Wood and Primrose Copse produced HLLA glass. Sidney Wood is mentioned in documentary evidence at the time of Carré's application in 1567 (Winbolt 1933) and so was anticipated to post-date the 1560s although one quartz-rich crucible was also found, which may suggest that there was also earlier glass production in the nearby area. No glass was recovered during field walking at Lordings Farm.

June Hill and Woodhouse Farm produced glass with intermediate compositions. This is supported by previous data for June Hill (Dungworth 2007), which similarly shows an intermediate glass composition. Unpublished data for other samples from Woodhouse

Farm (Paynter pers comm) are closer to the HLLA composition than to the potash one, which supports the conclusion that a range of compositions were produced at this site.

Cobalt blue glass from the Weald

Both potash-glass and HLLA glass are usually greenish in colour, although the potash-glass tends to weather more rapidly, and so can have an opaque brown or pearlescent outer layer of deteriorated glass (Figure 8). Some HLLA glassworking waste can appear blue or opaque as a result of phase separation in the glass (Figure 9), however these fragments are transparent green-brown in colour when held up to the light. In addition there were some fragments amongst the fieldwalking finds that had been intentionally coloured deep blue by the addition of small amounts of cobalt oxide colourant. Some of these were fragments of window glass, and maybe cullet that was brought to the site, and so were not selected for analysis, but others were clearly waste glass (Figure 10) indicating that coloured glass was being used at the sites in question.

Figure 8: Typical discoloured, pearlescent appearance of weathered potash-rich glass from Imbhams Farm

Only very low concentrations of cobalt are required to produce a strong colour, for example the 18th-century glass trade ingots from the Albion shipwreck contained only 0.037% cobalt oxide but had a strong blue colour (Redknap and Freestone 1995, 148). The levels present in the Wealden glass fragments are for the most part below the detection limit of the EDS used in this study, however XRF analysis confirmed the presence of cobalt oxide in some glass from Woodhouse Farm (WFR11 3) and Sidney Wood (SWA11 2) (Figure 10).

Coloured glass has been reported previously at several sites in the Weald (Kenyon 1967), but it is rarely clear whether this is cullet brought to the site or glass made at the site. Kenyon states that coloured glass tends to be from the later sites (1967, 204); the colours include ruby red and an intense blue. Kenyon notes that of all the glasshouse sites, only Woodhouse Farm had physical evidence of cobalt blue glassworking, in the form of one fragment of glass waste and that the shade of blue is unlike the blue-green seen elsewhere (Kenyon 1967, 192-3). This was also observed amongst the assemblage studied here, because the levels of colourant were highest in one of the Woodhouse Farm examples, giving deep blue streaks. One sample from Sidney Wood, a thin distorted fragment with a rounded edge, had a peacock green colour (SWA11 2).

Figure 9: Typical greenish, better preserved appearance of HLLA glass (from Primrose Copse); the central example appears opaque because of phase separation, which is quite common in HLLA glass

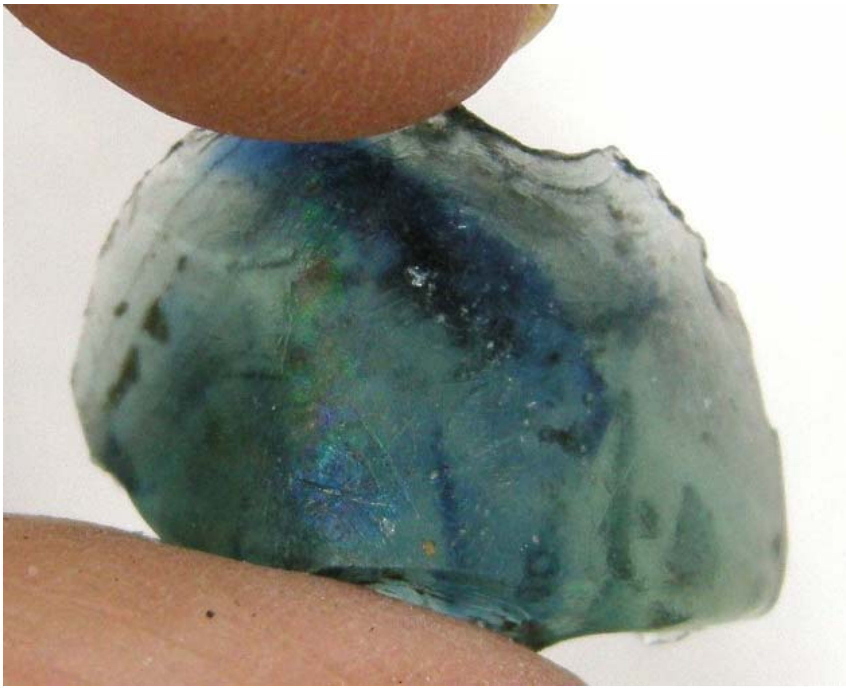

Figure 10: A fragment of glass from Woodhouse Farm (WFR11 3) with streaks of deep blue cobalt oxide colourant and an overall peacock green colour

There are different sources of cobalt colourant, which can be differentiated by the elements that appear with that particular cobalt source and the patterns of use vary chronologically and geographically (Gratuze *et al* 1995, 124). Typical associated elements include arsenic, bismuth, zinc and nickel, which were detected in the highlighted samples from Woodhouse Farm and Sidney Wood using XRF but in most cases at levels of below 0.1wt%; this is below the detection limit for these elements using SEM-EDS, therefore nickel and zinc are not shown in Table 4. Part of the XRF spectrum showing peaks for bismuth, arsenic, zinc, copper and nickel for sample SWA11 2 is shown in Figure 11.

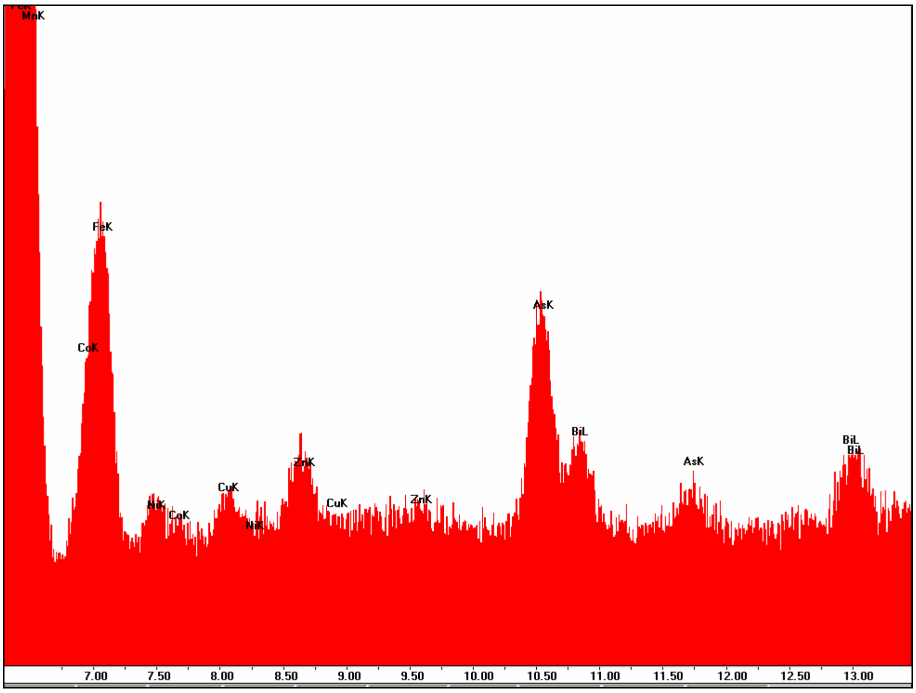

Figure 11: Part of the XRF spectrum of Sidney Wood glass fragment (SWA11 2) showing small peaks for arsenic (AsK), bismuth (BiL), zinc (ZnK) and nickel (NiK)

CONCLUSIONS

The results of this study have been interpreted with caution because all of the analysed material comes from field walking. Although the material is unlikely to have been displaced far from the glasshouse where it was originally used, the finds may reflect different periods of use, or may have originated from separate glasshouses in close proximity. Several of the sites display variation in glass and crucible composition, which in some cases is probably a result of factors like these.

Despite these limitations, the theory that the raw materials used for crucible construction changed in advance of the glass composition; put simply old glass in new pots but never new glass in old pots, is supported by the results of this study. The quartz-rich crucibles were replaced with grogged refractory pipe clay pots, which probably had improved longevity, prior to changing the glass composition. These refractory clays were sourced from elsewhere, for example from Dorset or Devon, and brought into the glassmaking region.

It is notable from this study that only four sites, Malham Farm, Imbhams Farm, Knightons and Hogs Wood, plus one of the five samples from Sidney Wood, had crucibles typical of earlier sites. Overall these sites are the minority, perhaps reflecting the smaller scale of the industry before the influx of skilled glassworkers from the continent.

Most of the sites used later types of crucible, which were formed with high titanium/low iron pipe clay; this clay was used for its refractory properties and resistance to chemical attack but had to be sourced from elsewhere. Two of these sites, Sidney Wood and Primrose Copse, also produced HLLA glass typical of later periods (no glass was found during field walking at Lordings Farm).

Unexpectedly, the study has shown a great variation in the glass produced at some of the sites, probably dating from the 1560s or later (based on the crucible composition), particularly at June Hill and Woodhouse Farm, but also Primrose Copse, and there are a number of possible explanations for this. At some sites there may be more than one furnace in close proximity or different phases of glass production resulting in multiple dumps of waste; this is more likely where different compositions of glass were retrieved from different areas, as at Primrose Copse. There may have been experimentation with the composition used or slightly different compositions used for different types of product. Finally recycling of potash glass cullet in the production of an otherwise HLLA glass batch, or vice versa, would result in intermediate glass compositions.

Similarly, it may be possible that when grogged crucibles first began to be used, the older pots, those with a quartz-rich composition, were broken down and reused for grogging new crucibles. This could explain atypical finds, such as the single quartz-rich crucible from Sidney Wood.

As with the majority of research, more questions have arisen as a result of these analyses. One of the most interesting is the production of intentionally coloured blue or blue-green glass at two sites, which contained low levels of cobalt. Both sites where cobalt was clearly detected in glassworking waste, Woodhouse Farm and Sidney Wood, had later-type grogged crucibles and so are likely to date from the 1560s or later. The cobalt itself is difficult to detect but the colourant also contained nickel, zinc, bismuth and arsenic, which were easier to detect, and together confirmed the intentional addition of a cobalt colourant, or cobalt coloured glass cullet.

Future work on the finds from this project and comparison with material from other regions will help to answer some of these questions.

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APPENDIX 1

Table 1: Known standard compositions, normalised wt%, bd = below detection limit (Vicenzi et al. 2012, Brill 1999)

Sample	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	Cl	K_2O	CaO	TiO_2	MnO	Fe_2O_3	CoO	CuO	ZnO	Sb_2O_5	BaO	PbO
Corning A	14.00	2.63	0.94	66.86	0.07	0.17	0.10	2.97	5.29	0.87	1.12	1.24	0.21	1.30	bd	1.67	0.43	0.03
	14.00	2.63	0.94	66.82	0.10	0.17	0.11	2.98	5.23	0.91	1.08	1.15	0.16	1.32	bd	1.77	0.45	0.12
	14.10	2.72	0.96	66.94	0.09	0.18	0.11	2.93	5.22	0.85	1.10	1.15	0.17	1.26	bd	1.73	0.42	0.02
	14.07	2.63	0.92	67.02	0.08	0.14	0.14	2.91	5.16	0.78	1.10	1.17	0.13	1.30	bd	1.82	0.53	0.03
	14.29	2.64	0.94	67.05	0.09	0.14	0.14	2.91	5.19	0.89	1.02	1.17	0.18	1.25	bd	1.54	0.44	0.08
	14.07	2.63	0.99	66.55	0.15	0.12	0.16	2.91	5.25	0.83	1.10	1.22	0.17	1.32	bd	1.86	0.56	0.09
Mean	14.09	2.65	0.95	66.87	0.10	0.15	0.13	2.94	5.22	0.85	1.09	1.18	0.17	1.29	bd	1.73	0.47	0.06
Std.Dev	0.11	0.04	0.02	0.18	0.03	0.02	0.02	0.03	0.04	0.04	0.03	0.04	0.03	0.03	-	0.12	0.06	0.04
Known	14.30	2.66	1.00	66.15	0.13	0.13	0.06	2.87	5.03	0.79	1.00	1.09	0.17	1.17	0.05	1.75	0.56	0.12
Corning D	1.34	4.03	5.20	55.29	3.50	0.21	0.18	11.71	15.15	0.47	0.59	0.57	bd	0.43	0.11	0.66	0.22	0.28
	1.34	4.01	5.21	55.27	3.61	0.22	0.23	11.68	15.11	0.34	0.56	0.52	bd	0.42	0.16	0.68	0.36	0.27
	1.39	3.86	5.23	55.50	3.63	0.24	0.18	11.80	15.17	0.42	0.60	0.49	bd	0.33	0.12	0.61	0.18	0.23
	1.31	3.94	5.28	55.20	3.72	0.18	0.21	11.79	15.15	0.47	0.56	0.51	bd	0.38	0.11	0.56	0.26	0.33
	1.43	4.02	5.27	55.50	3.64	0.19	0.20	11.55	14.97	0.39	0.58	0.56	bd	0.31	0.14	0.70	0.36	0.20
	1.38	3.94	5.18	55.38	3.63	0.22	0.22	11.69	15.21	0.44	0.63	0.52	bd	0.41	0.03	0.60	0.23	0.30
	1.34	4.07	5.20	55.42	3.57	0.26	0.18	11.59	14.97	0.38	0.59	0.56	bd	0.40	0.10	0.79	0.36	0.23
Mean	1.36	3.98	5.23	55.37	3.61	0.22	0.20	11.69	15.10	0.42	0.59	0.53	bd	0.38	0.11	0.66	0.28	0.26
St.Dev	0.04	0.07	0.04	0.12	0.07	0.03	0.02	0.09	0.10	0.05	0.02	0.03	-	0.05	0.04	0.08	0.08	0.04
Known	1.20	3.94	5.30	55.49	3.93	0.30	0.40	11.30	14.80	0.38	0.55	0.52	0.02	0.38	0.10	0.97	0.34	0.25

Table 2: Crucible analyses, SEM-EDS wt% oxides, normalised (bd = below detection limit)

Sample	Na_2O	MgO	Al_2O_3	SiO_2	Cl	K_2O	CaO	TiO_2	Fe_2O_3
HWA11.1	0.34	0.62	15.28	78.21	bd	2.68	0.36	0.86	1.60
	0.25	0.73	16.16	77.65	bd	2.04	0.43	0.82	1.90
	0.32	0.66	15.81	77.76	bd	2.04	0.40	1.06	1.94
HWA11.2	0.35	0.79	18.78	73.19	bd	2.51	0.49	1.21	2.62
	0.18	0.83	19.04	73.29	bd	3.25	0.31	0.97	2.09
	0.26	0.74	18.64	73.9	bd	3.04	0.36	0.9	2.13
IFG11 GS. 34.1	0.26	0.66	14.89	79.73	bd	1.75	0.42	0.73	1.47
	0.26	0.66	14.89	79.73	bd	1.75	0.42	0.73	1.47
	0.17	0.57	15.12	79.22	bd	1.96	0.54	0.75	1.64
IFG11 GS 43.1	0.29	0.98	19.05	75.57	bd	1.84	0.62	0.56	1.03
	0.87	0.88	19.82	73.97	bd	1.86	0.84	0.57	1.12
	1.00	1.04	18.81	74.82	bd	1.77	0.78	0.60	1.11
IFG 11 GS 43.2	0.33	0.91	18.84	76.09	bd	1.72	0.34	0.61	1.08
	0.27	0.82	17.33	77.81	bd	1.80	0.24	0.62	1.03
	0.18	0.84	17.97	77.02	bd	1.78	0.23	0.69	1.22
JHC11 101	0.14	0.21	21.98	73.54	bd	1.16	0.32	1.32	1.25
	0.33	0.29	21.85	73.08	bd	1.16	0.31	1.37	1.57
	0.17	0.23	22.39	72.49	0.13	1.86	0.15	1.38	1.21
KA11(around furnace)	0.56	0.77	17.61	75.64	bd	2.08	0.41	0.81	2.06
	0.42	0.76	17.68	75.62	bd	2.07	0.40	0.93	2.07
	0.47	0.76	17.49	75.60	0.10	2.12	0.43	0.95	2.07
MFL 11 SQ 13 B Quad	0.15	0.65	16.71	77.72	bd	2.05	0.28	0.81	1.58
	0.13	0.66	17.35	76.95	bd	2.20	0.30	0.80	1.58
	0.13	0.75	16.53	78.00	bd	1.97	0.30	0.81	1.48
MFL11 Q6 C Quad	0.25	0.79	18.53	75.30	bd	2.07	0.36	0.85	1.83
	0.23	0.67	17.00	77.32	bd	1.99	0.35	0.79	1.59
	0.28	0.85	17.88	75.90	bd	2.05	0.33	0.86	1.79
MFL11 SQ5 Q5	0.25	0.74	17.26	76.44	bd	2.24	0.35	0.88	1.82
	0.26	0.80	17.24	76.29	bd	2.29	0.35	0.88	1.89
	0.26	0.80	17.24	76.29	bd	2.29	0.35	0.88	1.89
PCR 11 GEN 1	0.70	0.42	19.92	73.73	bd	2.90	0.43	1.26	0.58
	0.58	0.34	19.95	74.14	bd	2.42	0.42	1.28	0.78
	0.38	0.31	20.66	74.55	bd	1.73	0.35	1.23	0.70
PCR11 GEN 2	0.35	0.35	22.75	72.74	bd	1.57	0.12	1.17	0.92
	0.23	0.25	22.98	72.72	bd	1.45	0.10	1.18	1.01
	0.26	0.32	23.79	71.53	bd	1.60	0.14	1.31	0.96
PCR11 GEN 3	0.18	0.56	23.07	69.35	bd	2.36	0.61	1.20	2.65
	0.26	0.60	23.23	68.91	bd	2.41	0.58	1.21	2.78
	0.24	0.57	22.95	69.38	bd	2.37	0.61	1.14	2.69

Sample	Na_2O	MgO	Al_2O_3	SiO_2	Cl	K_2O	CaO	TiO_2	Fe_2O_3
PCR11 SQ2	0.30	0.36	20.39	73.90	bd	1.73	0.41	1.61	1.26
	0.46	0.40	20.45	73.66	bd	1.68	0.45	1.61	1.29
	0.22	0.40	20.57	73.77	bd	1.73	0.41	1.59	1.23
SWA11 1.5	0.23	0.39	20.50	73.79	0.10	1.48	0.54	1.73	1.25
	0.20	0.30	19.50	75.39	bd	1.38	0.45	1.57	1.15
	0.15	0.40	20.38	74.17	0.12	1.43	0.45	1.68	1.23
SWA11 2.2	0.10	0.28	21.54	73.89	bd	1.22	0.17	1.29	1.43
	0.10	0.28	21.54	73.89	bd	1.22	0.17	1.29	1.43
	0.11	0.29	21.88	73.45	bd	1.22	0.21	1.26	1.55
SWA11 2.3	0.11	0.22	22.68	72.91	bd	1.02	0.17	1.44	1.40
	0.12	0.25	23.08	72.55	bd	0.97	0.17	1.45	1.33
	0.14	0.20	21.48	74.31	bd	0.91	0.19	1.41	1.32
SWA11-5	0.97	0.68	16.89	76.60	bd	2.03	0.37	0.77	1.65
	0.70	0.64	17.04	76.67	bd	2.24	0.33	0.76	1.59
	0.68	0.68	16.45	77.16	bd	2.44	0.26	0.79	1.52
SWA11-6	0.20	0.45	18.79	75.66	bd	1.69	0.36	1.29	1.50
	0.14	0.54	18.99	75.65	bd	1.55	0.34	1.25	1.50
	0.21	0.40	19.15	75.33	bd	1.82	0.29	1.28	1.50
WFR11.5 U/S	0.23	0.37	25.66	69.02	bd	1.92	0.07	1.47	1.21
	0.22	0.33	24.54	70.29	bd	1.79	0.11	1.41	1.28
	0.20	0.33	24.33	70.54	bd	1.86	0.12	1.40	1.21
WFR11.7 U/S	0.10	0.37	19.36	75.83	bd	1.66	0.33	1.21	1.08
	0.15	0.38	18.34	76.82	bd	1.55	0.35	1.31	1.07
	0.14	0.37	18.57	76.59	bd	1.56	0.34	1.29	1.10
LFB11 US	0.29	0.98	19.05	75.57	bd	1.84	0.62	0.56	1.03
	0.87	0.88	19.82	73.97	bd	1.86	0.84	0.57	1.12
	1.00	1.04	18.81	74.82	bd	1.77	0.78	0.60	1.11

Table 3: Glass analyses, SEM-EDS wt% oxides, normalised (bd = below detection limit)

Sample	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	Cl	K_2O	CaO	TiO_2	MnO	Fe_2O_3	CoO	As_2O_3	Bi_2O_3
HWA 1	2.34	6.09	2.12	57.14	2.99	0.26	0.42	9.42	17.35	0.24	0.98	0.66	bd	bd	bd
	2.38	6.06	2.12	57.06	2.94	0.25	0.45	9.36	17.31	0.20	1.01	0.68	bd	bd	bd
	2.34	5.99	2.04	57.30	2.93	0.30	0.43	9.34	17.41	0.24	0.99	0.69	bd	bd	bd
Average	2.35	6.05	2.09	57.17	2.95	0.27	0.43	9.37	17.36	0.23	0.99	0.68	bd	bd	bd
HWA 3	2.92	7.98	1.39	53.23	3.32	0.36	0.59	12.31	15.58	0.22	1.10	0.61	bd	bd	bd
	3.00	8.06	1.30	53.50	3.42	0.25	0.53	12.29	15.84	0.20	1.08	0.63	bd	bd	bd
	2.89	8.00	1.32	53.46	3.29	0.38	0.58	12.23	15.80	0.17	1.10	0.58	bd	bd	bd
Average	2.94	8.01	1.34	53.40	3.34	0.33	0.57	12.28	15.74	0.20	1.09	0.61	bd	bd	bd
IFG 7	2.30	7.24	0.94	58.65	2.76	0.40	0.56	10.88	14.62	0.17	1.16	0.43	bd	bd	bd
	2.26	7.39	0.98	58.33	2.67	0.49	0.61	11.01	14.69	0.19	1.18	0.41	bd	bd	bd
	2.34	7.23	0.94	58.51	2.68	0.41	0.63	10.97	14.44	0.17	1.15	0.44	bd	bd	bd
Average	2.30	7.29	0.95	58.50	2.70	0.43	0.60	10.95	14.58	0.18	1.16	0.43	bd	bd	bd
IFG11 GS23 5	2.55	6.88	1.48	56.22	3.09	0.40	0.59	10.60	16.37	0.18	0.94	0.56	bd	bd	bd
	2.57	6.80	1.44	56.32	3.11	0.39	0.58	10.62	16.38	0.23	1.02	0.57	bd	bd	bd
	2.70	6.88	1.40	56.19	3.09	0.42	0.58	10.61	16.49	0.23	0.94	0.58	bd	bd	bd
Average	2.61	6.85	1.44	56.24	3.10	0.40	0.58	10.61	16.41	0.21	0.97	0.57	bd	bd	bd
JHC11 2	1.16	4.73	2.32	58.00	2.19	0.44	0.34	8.49	19.46	0.39	1.40	0.85	bd	bd	bd
	1.12	4.63	2.33	58.25	2.19	0.47	0.32	8.58	19.28	0.36	1.39	0.94	bd	bd	bd
	1.05	4.60	2.25	58.40	2.10	0.47	0.31	8.73	19.09	0.36	1.40	0.99	bd	bd	bd
Average	1.11	4.65	2.30	58.22	2.16	0.46	0.32	8.60	19.28	0.37	1.40	0.93	bd	bd	bd
JHC-5	1.21	5.44	2.14	56.76	2.64	0.40	0.30	8.55	19.68	0.32	1.56	0.81	bd	bd	bd
	1.30	5.09	2.39	57.91	2.47	0.34	0.30	8.61	18.80	0.32	1.41	0.86	bd	bd	bd
	1.27	5.52	2.37	56.43	2.39	0.59	0.12	8.45	19.81	0.30	1.55	0.90	bd	bd	bd
Average	1.26	5.35	2.30	57.03	2.50	0.44	0.24	8.54	19.43	0.31	1.51	0.86	bd	bd	bd

Sample	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	Cl	K_2O	CaO	TiO_2	MnO	Fe_2O_3	CoO	As_2O_3	Bi_2O_3
JHC11 6	0.87	3.75	2.56	56.45	3.16	0.38	0.33	11.39	18.27	0.42	1.22	1.05	bd	bd	bd
	0.89	3.77	2.45	56.29	3.13	0.39	0.35	11.45	18.43	0.39	1.22	1.09	bd	bd	bd
	0.85	3.72	2.53	56.42	2.98	0.43	0.31	11.42	18.34	0.37	1.24	1.09	bd	bd	bd
Average	0.87	3.75	2.51	56.39	3.09	0.40	0.33	11.42	18.35	0.39	1.23	1.08	bd	bd	bd
KA11 1	1.55	7.45	1.81	55.24	2.91	bd	0.41	11.26	17.25	0.23	1.06	0.66	bd	bd	bd
	1.46	7.23	1.97	55.30	2.85	0.25	0.37	11.36	17.12	0.22	1.02	0.71	bd	bd	bd
	1.56	7.30	1.88	54.83	2.92	0.38	0.49	11.13	17.59	0.21	0.95	0.65	bd	bd	bd
Average	1.52	7.33	1.89	55.12	2.89	0.27	0.42	11.25	17.32	0.22	1.01	0.67	bd	bd	bd
KA11 2	1.44	5.94	1.72	60.72	1.65	0.36	0.24	10.24	16.02	0.27	0.65	0.71	bd	bd	bd
	1.53	7.00	1.51	58.15	2.15	0.41	0.32	11.84	15.31	0.23	0.79	0.66	bd	bd	bd
	1.52	7.25	1.51	57.29	2.27	0.43	0.31	12.15	15.15	0.26	0.76	0.64	bd	bd	bd
Average	1.50	6.73	1.58	58.72	2.02	0.40	0.29	11.41	15.49	0.25	0.73	0.67	bd	bd	bd
KA11 3	1.64	6.81	2.07	55.31	2.96	0.22	0.37	11.16	17.66	0.22	0.96	0.61	bd	bd	bd
	1.60	6.80	2.08	54.92	2.99	0.32	0.40	11.01	17.89	0.25	0.98	0.63	bd	bd	bd
	1.65	6.82	2.14	55.31	2.86	0.24	0.39	10.94	17.67	0.22	0.99	0.65	bd	bd	bd
Average	1.63	6.81	2.10	55.18	2.94	0.26	0.39	11.04	17.74	0.23	0.98	0.63	bd	bd	bd
KA11 4	2.52	6.99	2.05	55.08	3.42	0.50	0.57	10.29	16.24	0.29	1.15	0.72	bd	bd	bd
	2.66	7.12	2.03	55.21	3.44	0.42	0.55	10.35	16.24	0.24	1.20	0.76	bd	bd	bd
	2.41	6.87	2.08	55.40	3.30	0.39	0.52	10.31	16.73	0.20	1.14	0.73	bd	bd	bd
Average	2.53	6.99	2.05	55.23	3.39	0.44	0.55	10.32	16.40	0.24	1.16	0.74	bd	bd	bd
MFL 1	2.38	5.88	2.04	55.70	3.43	0.21	0.50	10.35	17.29	0.26	1.01	0.75	bd	bd	bd
	2.43	5.95	2.11	55.65	3.41	0.20	0.45	10.29	17.39	0.23	0.99	0.83	bd	bd	bd
	2.35	6.04	2.01	55.87	3.46	bd	0.45	10.39	17.33	0.23	0.92	0.80	bd	bd	bd
Average	2.39	5.96	2.05	55.74	3.43	0.20	0.47	10.34	17.34	0.24	0.97	0.79	bd	bd	bd

Sample	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	Cl	K_2O	CaO	TiO_2	MnO	Fe_2O_3	CoO	As_2O_3	Bi_2O_3
MFL 2	2.26	5.97	2.06	55.71	3.41	bd	0.43	10.52	17.51	0.17	1.00	0.82	bd	bd	bd
	2.16	6.00	2.25	54.74	3.55	0.22	0.44	10.25	17.67	0.28	1.15	0.97	bd	bd	bd
	2.21	6.00	2.32	55.07	3.48	bd	0.39	10.40	17.66	0.21	1.13	1.01	bd	bd	bd
Average	2.21	5.99	2.21	55.17	3.48	bd	0.42	10.39	17.61	0.22	1.09	0.93	bd	bd	bd
PCR11-2	0.97	2.91	4.16	58.26	2.13	0.37	0.13	5.74	22.39	0.50	0.76	1.48	bd	bd	bd
	1.04	2.93	4.14	58.38	2.15	0.27	bd	5.75	22.41	0.50	0.77	1.39	bd	bd	bd
	0.93	3.00	4.17	58.43	2.20	0.32	bd	5.82	22.45	0.43	0.81	1.45	bd	bd	bd
Average	0.98	2.95	4.16	58.36	2.16	0.32	bd	5.77	22.42	0.48	0.78	1.44	bd	bd	bd
PCR11-5	0.96	2.27	2.38	62.55	1.69	0.21	0.23	4.26	23.35	0.32	0.69	0.99	bd	bd	bd
	1.04	2.25	2.32	62.36	1.73	0.27	0.23	4.25	23.39	0.27	0.73	0.96	bd	bd	bd
	1.02	2.34	2.41	62.42	1.57	0.21	0.24	4.21	23.46	0.32	0.71	0.96	bd	bd	bd
Average	1.01	2.29	2.37	62.44	1.66	0.23	0.23	4.24	23.40	0.30	0.71	0.97	bd	bd	bd
PCR11 GEN3	0.96	2.34	2.34	62.34	1.71	bd	0.23	4.26	23.49	0.31	0.73	0.98	bd	bd	bd
	0.99	2.23	2.47	62.55	1.64	bd	0.22	4.25	23.15	0.32	0.77	0.97	bd	bd	bd
	1.05	2.32	2.36	62.26	1.68	bd	0.24	4.23	23.51	0.30	0.74	0.98	bd	bd	bd
Average	1.00	2.30	2.39	62.38	1.68	bd	0.23	4.25	23.38	0.31	0.75	0.98	bd	bd	bd
PCR11 SQ4 1	1.85	5.20	1.75	58.81	2.38	0.28	0.55	8.88	18.08	0.22	0.85	0.88	bd	bd	bd
	1.93	5.33	1.74	58.57	2.36	0.34	0.52	8.93	18.15	0.26	0.94	0.82	bd	bd	bd
	1.92	5.26	1.73	58.47	2.48	0.32	0.55	8.89	18.21	0.23	0.93	0.87	bd	bd	bd
Average	1.90	5.26	1.74	58.62	2.41	0.31	0.54	8.90	18.15	0.24	0.91	0.86	bd	bd	bd
PCR11 SQ4 2	1.88	5.44	1.68	58.59	2.47	0.30	0.59	8.85	18.23	0.23	0.95	0.79	bd	bd	bd
	1.91	5.57	1.63	58.50	2.34	0.35	0.56	8.80	18.29	0.24	0.89	0.85	bd	bd	bd
	1.91	5.34	1.72	58.32	2.42	0.39	0.60	8.61	18.28	0.25	0.93	0.82	bd	bd	bd
Average	1.90	5.45	1.68	58.47	2.41	0.35	0.58	8.75	18.27	0.24	0.92	0.82	bd	bd	bd

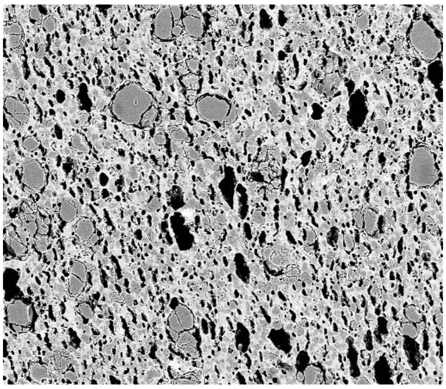
Sample	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	Cl	K_2O	CaO	TiO_2	MnO	Fe_2O_3	CoO	As_2O_3	Bi_2O_3
SWA11 1	0.74	2.21	2.38	61.33	1.65	0.30	0.10	4.04	25.09	0.32	0.62	0.95	bd	bd	bd
	0.66	2.22	2.47	61.30	1.63	0.23	bd	4.09	25.35	0.32	0.61	0.88	bd	bd	bd
	0.69	2.21	2.42	61.56	1.69	0.21	bd	4.08	25.29	0.29	0.68	0.87	bd	bd	bd
Average	0.70	2.21	2.42	61.40	1.66	0.25	bd	4.07	25.24	0.31	0.64	0.90	bd	bd	bd
SWA11 2	2.04	2.50	2.89	62.94	1.64	0.32	bd	2.89	21.87	0.49	0.74	0.89	bd	bd	bd
	2.06	2.53	2.74	63.10	1.48	0.39	bd	2.90	21.65	0.47	0.69	0.96	bd	bd	bd
	1.99	2.53	2.80	63.39	1.56	0.35	bd	2.90	21.80	0.35	0.68	0.89	bd	bd	bd
Average	2.03	2.52	2.81	63.14	1.56	0.35	bd	2.90	21.77	0.44	0.70	0.91	bd	bd	bd
SWA11 3	1.01	2.91	4.59	57.10	1.78	0.22	bd	7.58	21.95	0.42	1.16	1.10	bd	bd	bd
	0.98	2.63	5.68	58.26	1.55	0.24	bd	7.74	20.05	0.46	1.12	1.09	bd	bd	bd
	0.89	3.09	4.21	55.88	1.92	0.42	bd	5.91	24.67	0.51	1.23	1.01	bd	bd	bd
Average	0.96	2.88	4.83	57.08	1.75	0.29	bd	7.08	22.22	0.46	1.17	1.07	bd	bd	bd
SWA11 4	2.55	3.79	2.05	58.34	2.09	0.78	0.41	5.02	22.89	0.33	0.77	0.81	bd	bd	bd
	2.51	3.69	2.21	58.97	2.20	0.63	0.32	5.16	22.32	0.23	0.79	0.84	bd	bd	bd
	2.47	3.74	2.09	58.49	2.18	0.74	0.37	5.04	22.84	0.28	0.82	0.87	bd	bd	bd
Average	2.51	3.74	2.12	58.60	2.16	0.72	0.37	5.07	22.68	0.28	0.79	0.84	bd	bd	bd
SWA11 5	2.43	3.73	2.07	58.78	2.20	0.75	0.36	5.09	22.62	0.27	0.79	0.87	bd	bd	bd
	2.52	3.76	2.06	58.34	2.16	0.72	0.40	4.98	22.98	0.27	0.75	0.83	bd	bd	bd
	2.44	3.70	2.16	58.49	2.21	0.60	0.36	5.00	22.92	0.30	0.79	0.86	bd	bd	bd
Average	2.46	3.73	2.10	58.54	2.19	0.69	0.37	5.02	22.84	0.28	0.78	0.85	bd	bd	bd
WFR11 2	1.81	5.31	1.96	56.49	2.84	0.33	0.39	10.08	18.49	0.27	0.88	0.97	bd	bd	bd
	1.74	5.36	1.95	56.41	2.94	0.29	0.37	10.17	18.63	0.26	0.85	0.97	bd	bd	bd
	1.71	5.29	1.85	56.41	2.84	0.38	0.38	10.18	18.66	0.23	0.88	0.98	bd	bd	bd
Average	1.75	5.32	1.92	56.44	2.87	0.33	0.38	10.14	18.59	0.25	0.87	0.97	bd	bd	bd

Sample	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	Cl	K_2O	CaO	TiO_2	MnO	Fe_2O_3	CoO	As_2O_3	Bi_2O_3
WFR11 3	1.98	5.23	2.07	56.75	2.66	0.35	0.51	9.74	16.86	0.27	0.83	1.21	0.25	0.58	0.42
	2.01	5.34	2.09	56.68	2.75	0.39	0.48	9.35	17.09	0.30	1.13	1.19	0.22	0.52	0.39
	1.97	5.32	1.97	56.62	2.78	0.25	0.46	9.31	17.07	0.31	1.13	1.11	0.28	0.56	0.40
Average	1.99	5.30	2.04	56.68	2.73	0.33	0.48	9.47	17.01	0.29	1.03	1.17	0.25	0.55	0.40
WFR11 4	1.54	5.21	1.76	56.49	3.01	0.29	0.44	12.54	16.61	0.26	0.84	0.84	bd	bd	bd
	1.50	5.25	1.80	56.52	2.82	0.27	0.43	12.53	16.85	0.24	0.83	0.86	bd	bd	bd
	1.43	5.16	1.84	56.54	3.05	0.21	0.40	12.47	16.70	0.27	0.84	0.91	bd	bd	bd
Average	1.49	5.21	1.80	56.52	2.96	0.26	0.42	12.51	16.72	0.26	0.84	0.87	bd	bd	bd
WFR11 5	1.56	5.28	1.80	56.73	2.99	bd	0.44	12.32	16.47	0.29	0.85	0.86	bd	bd	bd
	1.55	5.41	1.75	56.63	3.04	0.28	0.45	12.35	16.52	0.29	0.84	0.80	bd	bd	bd
	1.54	5.41	1.76	56.50	3.02	0.29	0.48	12.27	16.53	0.32	0.88	0.76	bd	bd	bd
Average	1.55	5.37	1.77	56.62	3.02	0.25	0.46	12.31	16.51	0.30	0.86	0.81	bd	bd	bd
WFR11 6	2.85	6.05	2.50	55.94	3.04	bd	0.33	8.55	18.08	0.30	1.14	0.99	bd	bd	bd
	2.86	6.14	2.50	55.81	2.95	0.23	0.34	8.46	18.07	0.34	1.17	0.94	bd	bd	bd
	2.96	5.95	2.58	55.61	3.07	bd	0.38	8.49	17.94	0.34	1.15	0.90	bd	bd	bd
Average	2.89	6.05	2.53	55.79	3.02	bd	0.35	8.50	18.03	0.33	1.15	0.94	bd	bd	bd
WFR11 7	2.29	5.68	1.86	56.22	3.33	bd	0.57	11.75	15.91	0.23	0.89	0.80	bd	bd	bd
	2.31	5.66	1.79	56.24	3.26	0.25	0.59	11.88	15.93	0.23	0.87	0.77	bd	bd	bd
	2.19	5.77	1.78	56.37	3.22	0.20	0.58	11.78	15.95	0.30	0.93	0.77	bd	bd	bd
Average	2.26	5.70	1.81	56.28	3.27	0.21	0.58	11.80	15.93	0.25	0.90	0.78	bd	bd	bd
WFR11 U/S	2.31	6.44	1.91	58.23	2.74	0.27	0.38	9.92	15.44	0.24	1.03	0.76	bd	bd	bd
	2.39	6.52	1.78	58.05	2.93	bd	0.38	10.08	15.87	0.25	1.02	0.69	bd	bd	bd
	1.71	5.23	1.94	56.11	2.82	0.34	0.40	10.28	18.74	0.26	0.94	0.96	bd	bd	bd
Average	2.14	6.06	1.88	57.46	2.83	0.26	0.39	10.09	16.68	0.25	1.00	0.80	bd	bd	bd

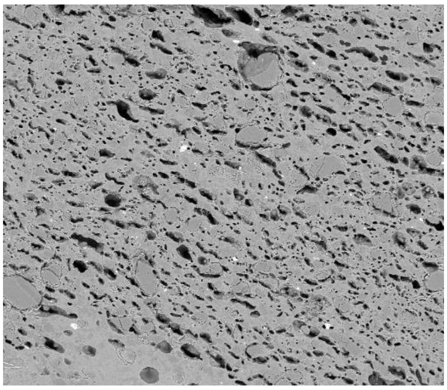
Sample	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	Cl	K_2O	CaO	TiO_2	MnO	Fe_2O_3	CoO	As_2O_3	Bi_2O_3
WFR11 U/S 5	1.54	5.06	1.76	56.85	2.86	0.24	0.43	12.41	16.64	0.25	0.83	0.83	bd	bd	bd
	1.55	5.01	1.82	56.86	2.93	0.20	0.41	12.36	16.82	0.27	0.80	0.87	bd	bd	bd
	1.51	5.27	1.78	56.82	2.98	bd	0.41	12.36	16.65	0.31	0.83	0.85	bd	bd	bd
Average	1.53	5.11	1.79	56.84	2.92	bd	0.42	12.38	16.70	0.28	0.82	0.85	bd	bd	bd

APPENDIX 2

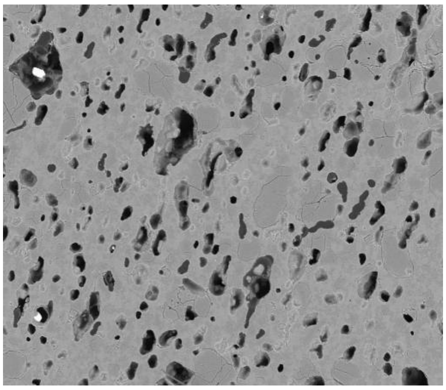
SEM backscattered electron images of crucible samples at x150 magnification



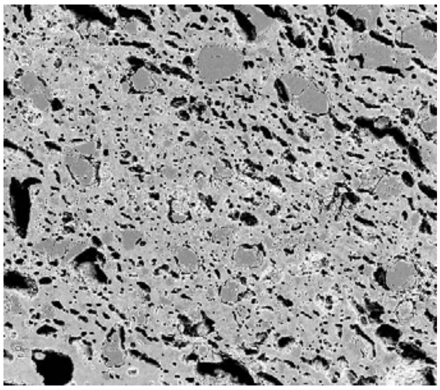
HWA 11 1



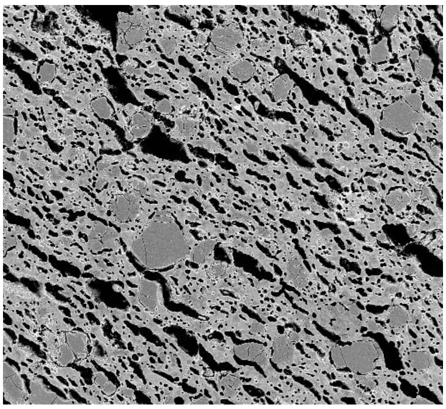
HWA 11 2



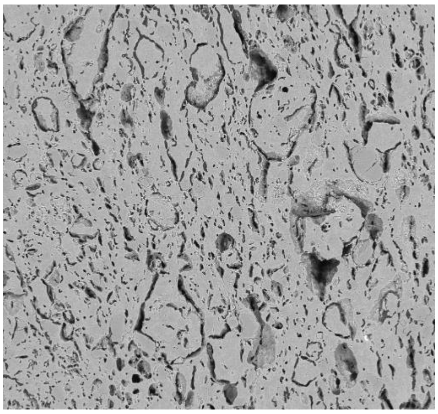
IFG 11 GS34.1



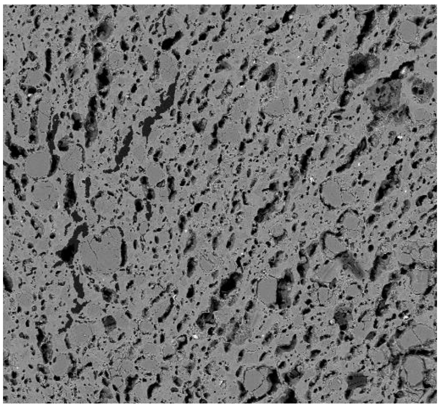
IFG11 GS 43.1



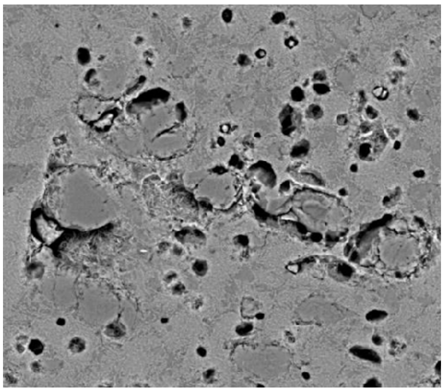
IFG 11 GS 43.2



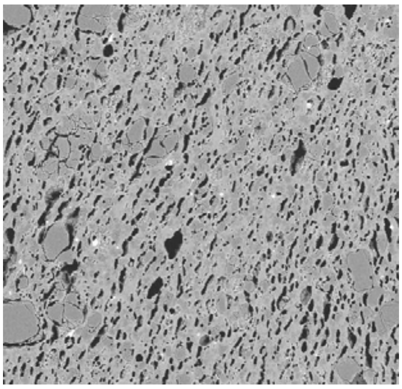
JHC 11 101



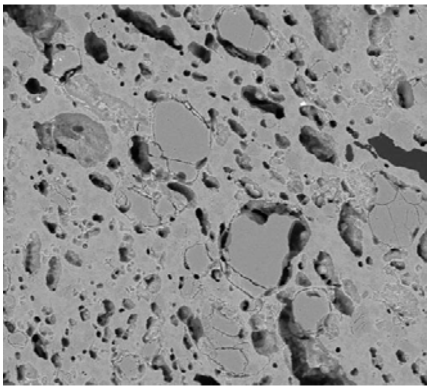
KA 11 (around furnace)



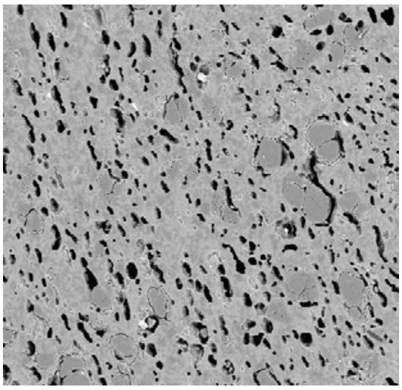
LFB 11 U/S



MFL 11 SQ5 Q5



MFL 11 Q6C Quad



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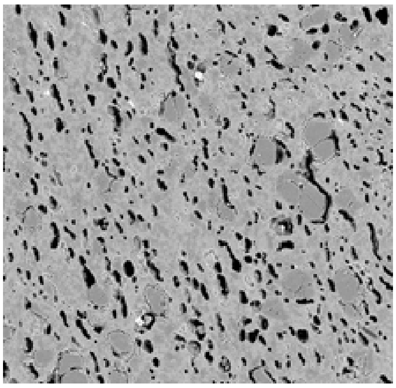

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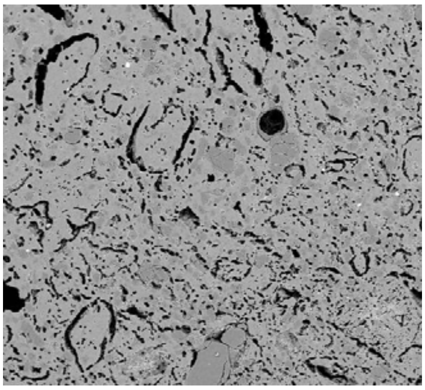
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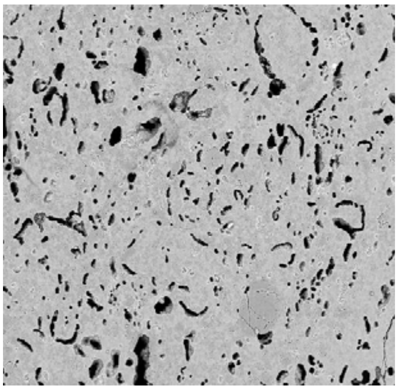
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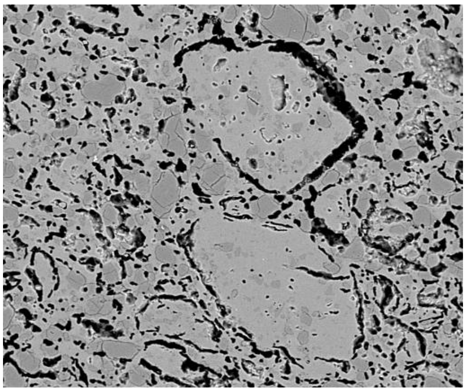
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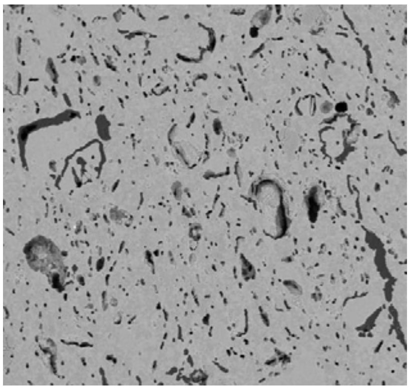
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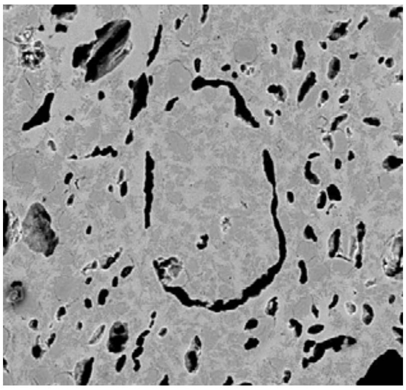
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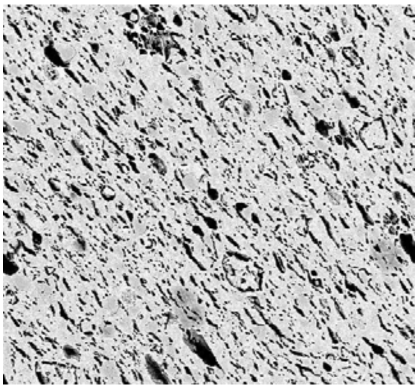
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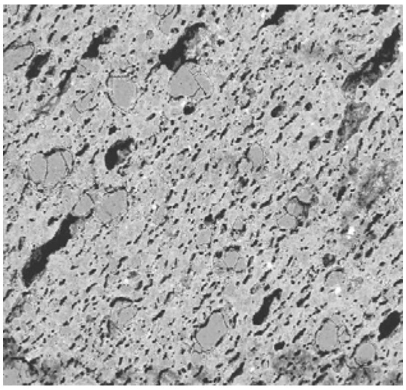

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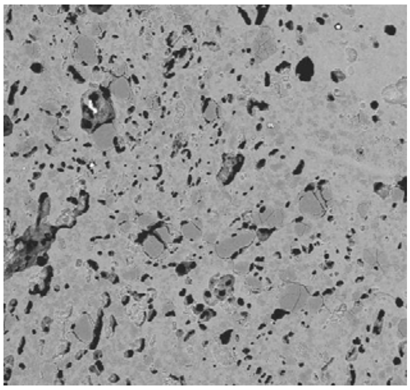

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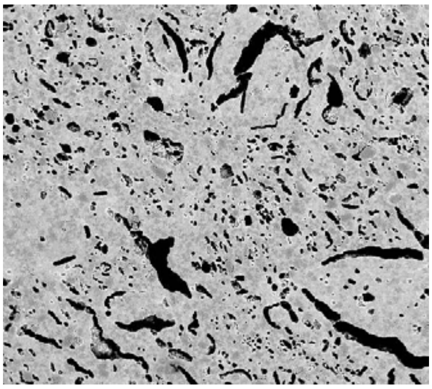

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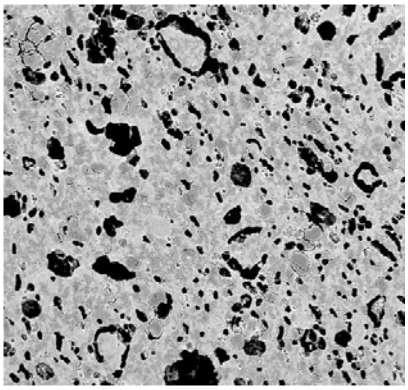

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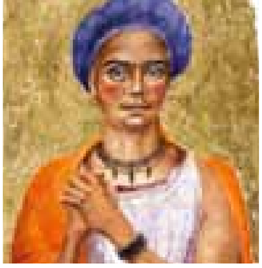


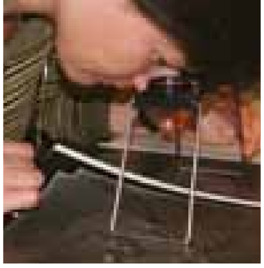


ENGLISH HERITAGE RESEARCH AND THE HISTORIC ENVIRONMENT

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 the protection and sustainable management of the resource, and to promote the widest access, appreciation and enjoyment of our heritage. Much of this work is conceived and implemented in the context of the National Heritage Protection Plan. For more information on the NHPP please go to http://www.english-heritage.org.uk/professional/protection/national-heritage-protection-plan/.

The Heritage Protection Department provides English Heritage with this capacity in the fields of building history, archaeology, archaeological science, imaging and visualisation, landscape history, and remote sensing. It brings together four teams with complementary investigative, analytical and technical skills to provide integrated applied research expertise across the range of the historic environment. These are:

* Intervention and Analysis (including Archaeology Projects, Archives, Environmental Studies, Archaeological Conservation and Technology, and Scientific Dating)
* Assessment (including Archaeological and Architectural Investigation, the Blue Plaques Team and the Survey of London)
* Imaging and Visualisation (including Technical Survey, Graphics and Photography)
* Remote Sensing (including Mapping, Photogrammetry and Geophysics)

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