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Summary

Samples of glass and glassworking waste from an early post-medieval Wealden glasshouse were analysed to determine their chemical composition. The samples were recovered along with late 16th- and early 17th-century pottery. The glass from this site has a composition which is intermediate between medieval forest glass and early post-medieval high-lime low-alkali glass. The glass production represents an important technological transition.

Keywords

glass
post-medieval
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Introduction

The glass industry of the Weald operated from at least the 13th century to the second decade of the 17th century (Kenyon 1967). Glasshouses in use before the arrival of the French immigrant glassworkers manufactured forest glass: a glass containing high levels of potassium. The limited data available suggests that there were slight differences in glass composition between sites (Dungworth and Clark 2004). After the French glassworkers arrived in the Weald *c*1567 some (but significantly not all) glasshouses started to produce high-lime low-alkali (HLLA) glass (Dungworth and Clark 2004). It has been argued that the immigrant glassworkers brought new technology in the form of a new furnace in which subsidiary furnaces (eg for annealing) were integrated into the overall furnace structure (Crossley 1972, 431). It is possible that HLLA glass formed another element of the technology brought by the immigrant glassworkers. It is certainly true that HLLA glass had been produced in France since the 16th century (Barrera and Velde 1989) and in Germany since the 14th century (Wedepohl 1997). It is not clear yet whether the change from forest glass to HLLA glass represents differences in the raw materials used (in particular plant ashes) or the way in which these were processed (eg lixiviating, fritting or melting).

The letters patent of 1567 which provided for the arrival of the French glassworkers specified that they were to pass their skills on to the indigenous glassworkers (Godfrey 1975, 19–20). In the years that followed, however, there were serious disputes as the French glassworkers resisted revealing their methods. The examination of glassworking waste from two 16th-century glasshouses at Idehurst, where documentary evidence indicates English yeoman ownership, suggests that some English glasshouses continued to produce forest glass after the arrival of the French (Dungworth and Clarke 2004).

Substantial quantities of crucible and waste glass, with small quantities of blown vessel glass, have been collected from June Hill, Killinghurst Lane, Chiddingfold (Guildford Museum reference TRB 4857). The material, which includes some pottery, was collected by the landowners (Alan and Margaret Tomsett) from an area approximately 10m by 10m centred on NGR SU 9457 3331. This site is recorded as number 44 in Crossley's (1994) continuation of the Kenyon numbering of Wealden glasshouses. All material has been found on the ground surface (in particular in soil excavated by moles and rabbits). An assessment of the pottery by David McKay (volunteer with Guildford Museum) suggests activity in the late 16th century or early 17th century. The glassworking debris therefore probably dates to after the arrival of the immigrant glassworkers.

Sample Selection and Preparation

Twelve samples from June Hill were selected for analysis, comprising three crucible fragments and nine fragments of glass waste. The largest crucible fragment has vertical walls (>160mm high and 23–4mm thick) and an estimated external rim diameter of 370mm (the fragment comprises approximately 20% of the original circumference). The glassworking waste is green to blue-green in colour and comprises pieces of glass which had been stretched or pulled while soft and lumps of glass which had fallen to the floor. The latter had smooth upper surfaces but rough under surfaces. The larger lumps of glassworking waste were selected for analysis to ensure that weathered surfaces could be identified and avoided. The samples were cut and mounted in epoxy resin and ground and polished to a 3-micron finish.

Table 1. Sample descriptions

#	Description
1	Crucible with frothy glass waste adhering to outer surface
2	Crucible
3	Crucible
4	Frothy glass waste adhering to the outer surface of sample 1
5	Blue glass lump
6	Blue-green glass lump (with entrapped stones)
7	Fragment of glass working waste (punty pad ?)
8	Fragment of glass working waste (pulled/stretched)
9	Fragment of glass working waste (pulled/stretched)
10	Green glass lump (with entrapped stones)
11	Green glass lump
12	Green glass lump
13	Green glass lump

Analytical Techniques

The samples were analysed using two techniques: an energy-dispersive spectrometer attached to a scanning electron microscope (SEM-EDS) and an energy dispersive X-ray fluorescence spectrometer (EDXRF). The SEM-EDS provides good levels of accuracy, precision and detection for low energy (<4kV) X-rays while EDXRF provides better results for higher energy (4–20kV) X-rays (Table 2). Both techniques provide an indication of concentration of different elements present but no information about the oxidation state of those elements (the concentrations are expressed as oxides calculated stochiometrically ally). The analyses were conducted on areas of each sample away from surface corrosion. The SEM-EDS analyses were conducted on areas approximately 500 by 200 microns while the EDXRF analyses were conducted using a 300 micron spot size (the same conditions were used for all reference materials). The results were calibrated against a range of reference materials of similar composition to the June Hill samples (e.g. Corning, SGT, NBS and NIST). The results for the crucibles consistently gave low analysed totals due to the presence of porosity. Therefore the results for the crucibles have been normalised to 100wt%. The compositions of the samples are given in the Appendix (oxides which were not detected in any of the samples, eg copper and lead, are not included).

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

	SEM-EDS			EDXRF	
	MDL	Error		MDL	Error
Na_2O	0.1	0.1	**V_2O_5**	0.02	0.03
MgO	0.1	0.1	**Cr_2O_3**	0.02	0.03
Al_2O_3	0.1	0.1	**NiO**	0.02	0.03
SiO_2	0.5	0.2	**MnO**	0.02	0.03
P_2O_5	0.2	0.1	**Fe_2O_3**	0.02	0.03
SO_3	0.2	0.1	**CoO**	0.02	0.02
Cl	0.1	0.1	**CuO**	0.02	0.01
K_2O	0.1	0.1	**ZnO**	0.02	0.01
CaO	0.1	0.1	**As_2O_3**	0.01	0.01
TiO_2	0.1	0.1	**SnO_2**	0.1	0.05
BaO	0.2	0.1	**Sb_2O_5**	0.15	0.07
			Rb_2O	0.005	0.005
			SrO	0.01	0.005
			ZrO_2	0.004	0.005
			PbO	0.04	0.02

Four samples (three crucibles [#1–3] and a fragment of stone trapped in spilt glass[#6]) were also analysed using a Phillips X-Ray Diffractometer (XRD).

Results

The three crucibles are alumina-silicate ceramics which share near identical compositions (Appendix 1). They have similar microstructures (Figures 1 and 2), with moderately abundant small (<0.2mm) silica polymorphs (quartz and cristobalite) in a vitrified groundmass which contains small mullite crystals (Figure 2). Sample #2 also contains some sillimanite (Appendix 2). The mullite (and possibly the cristobalite) will have formed during the breakdown of kaolinite in the clay at temperatures above 1200°C (Eramo 2005). The ceramic fabric contains argillaceous inclusions (0.4–2mm) which are likely to represent the addition of grog to the clay during manufacture.

The analysis of the glass adhering to one of the surfaces of crucible 1 showed that it had a composition close to the glassworking waste (lumps, droplets, etc) but only where the glass was sufficiently thick. Areas of adhering glass within 0.3mm of the ceramic showed increased levels of alumina and titania (cf. Dungworth and Cromwell 2006, Fig 13).

The nine samples of glassworking waste share similar compositions; after silica, the main components are lime, potash, and magnesia (Table 3). Sample #6 consists of a lump of glass which contains large (>5mm) fragments of stone. This stone displays no microstructure, and is composed almost entirely of silica (>99wt% SiO_2). XRD analysis (Appendix 2) indicates the presence of the silica polymorphs tridymite and cristobalite indicating that the stone had been exposed to high temperatures — possibly as high as 1470°C (Deer *et al* 1966, 341).

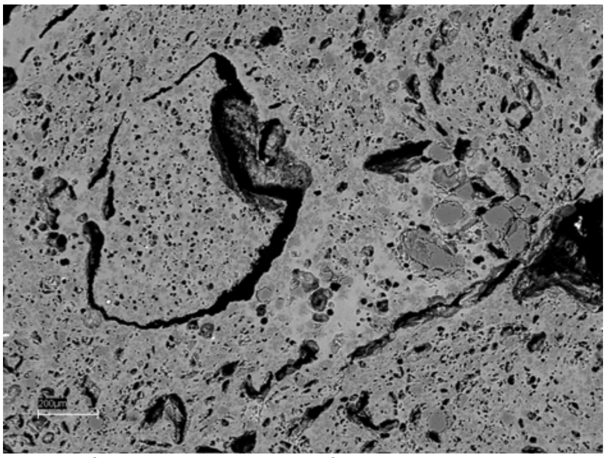

Figure 1. Microstructure of June Hill crucible (sample #1). The darkest areas are porosity while the medium grey areas are silica polymorphs (quartz/cristobalite) [scale bar = 200 microns]

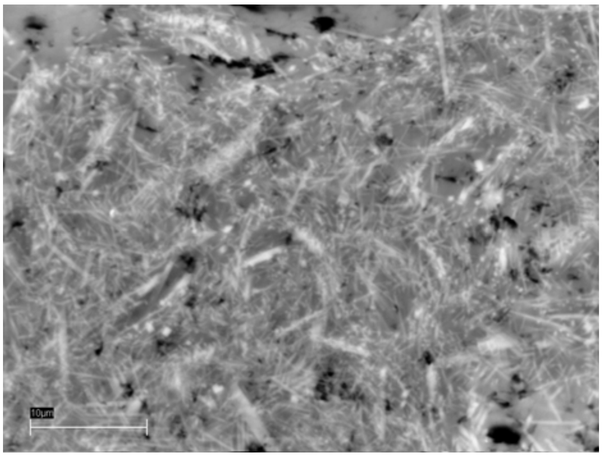

Figure 2. Microstructure of June Hill crucible (sample #1). The light grey crystals are mullite. [scale bar = 10 microns]

Discussion

The Glass

The glasshouse at June Hill appears to have been in use after the arrival of the immigrant French glassworkers, however, there are no indications whether this glasshouse was run by indigenous or immigrant glassworkers. Like all Wealden glasshouses, there appears to be no occupation after the early 17th century.

Table 3. Average compositions of the June Hill glass with typical compositions for medieval forest and post-medieval HLLA glass (Dungworth and Clark 2004; Welham 2001). All glass produced within the Weald.

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**
Tanland	16th/17th	1.5	2.8	2.2	61.2	2.2	3.8	24.2	0.7	1.2
Sidney Wood	16th/17th	2.7	2.9	3.9	60.0	1.7	4.1	22.9	0.7	1.3

The samples of June Hill glass all share the same broad composition indicating the production of a single type of glass (Table 3). The glass contains a wide range of oxides indicating the use of plant ashes as a flux. The composition of the glass is broadly similar to both medieval forest glass and post-medieval HLLA glass but actually lies between these two glass types (Table 3).

Sample 5 and 10 contained fragments of a silica-rich stone which lacked any microstructure. It is likely that this stone represents fragments of flint, however, it is not clear whether these flints were part of a furnace structure or represented a possible raw material used in material glass manufacture.

The Crucibles

The three samples of crucibles from June Hill all share the same chemical composition; they are rich in silica and alumina and would have been refractories capable of withstanding high temperatures. The compositions are broadly similar to those determined for other post-medieval glassmaking crucibles (cf Blakelock 2007; Dungworth 2003; Mortimer and Dungworth in Jackson 2005) outside the Weald. Slight differences exist in the composition of the clays used for crucibles between different sites. Bristol crucibles tend to have lower silica and potassium oxide concentrations but higher alumina and lime concentrations compared to those from Yorkshire. Seventeenth-century coal-fired glasshouses probably made use of the locally available refractory clays from the coal measures.

Substantial deposits of refractory clay are not known from the Weald but there are deposits of white-firing clays within the Reading Beds to the north and west (eg at Kingston, Nonsuch, Cheam and Farnborough). These clays were used in the medieval and post-medieval periods for the manufacture of whitewares (Pearce and Vince 1988) and clay pipes (Vince 2001). Another possible source of refractory clay would be the ball clays from Dorset and the Isle of Wight which were sought after for the manufacture of clay pipes and were widely traded as they were exposed along the coast. Unfortunately, there are insufficient data on the compositions of clays from these various sources to propose which was used to manufacture the crucibles used at June Hill.

The presence of mullite and cristobalite in the crucibles provides some indication of the temperatures that they were exposed to during use. Mullite in refractory ceramics usually forms as a result of the breakdown of kaolinite at temperatures above 1200°C (Eramo 2005). The crucibles also contain cristobalite which is the stable form of silica above 1470°C at normal pressures, however, cristobalite is a reaction product of the kaolinite-mullite reaction at temperatures as low as 1200°C.

Conclusions

The recovery of glassworking debris from June Hill confirms that there was a glasshouse in the vicinity. The crucibles were manufactured using a refractory clay, possibly from the Reading Beds 30km to the north and west. In order to be certain of the source of the refractory clay, the June Hill samples would need to be compared with white-firing clays from all possible sources; unfortunately this data is not yet available. The analysis of the glass indicates that only one type of glass was manufactured at the site but that this glass type is significantly different to all previous analyses of Wealden glass. Wealden glass from all other sites is either a forest glass or a HLLA glass (the latter makes its first appearance with the arrival of the French glassmakers *c*1567). The June Hill glass has a composition which lies between forest and HLLA glass. It is possible that the June Hill glass represents an attempt by English glassmakers to reproduce the new glass that was made by the immigrant glassmakers.

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Appendix 1: Chemical composition (SEM-EDS and EDXRF)

#	Na_2O	MgO	Al_2O_3	SiO_2	P_2O5	SO_3	Cl	K_2O	CaO	TiO_2	MnO	Fe_2O_3	ZnO	As_2O_3	Rb_2O	SrO	ZrO_2
1	0.30	0.56	23.24	70.99	0.24	<0.2	<0.2	1.44	0.46	1.50	<0.1	1.27	<0.02	<0.01	0.015	0.015	0.101
2	0.21	0.48	22.66	70.67	0.21	<0.2	<0.2	1.82	0.44	1.63	<0.1	1.88	<0.02	<0.01	0.020	0.016	0.085
3	0.23	0.51	24.21	69.68	0.19	<0.2	<0.2	1.44	0.42	1.69	<0.1	1.64	<0.02	<0.01	0.019	0.015	0.126
4	1.43	4.22	2.96	61.02	2.50	0.27	0.34	7.32	18.08	0.49	1.41	1.35	0.03	0.04	0.016	0.114	0.043
5	1.27	4.10	2.77	60.95	2.22	0.33	0.33	7.63	17.40	0.42	1.35	1.24	0.03	0.04	0.012	0.112	0.042
6	1.02	4.34	1.91	59.36	1.97	0.30	0.42	7.40	19.34	0.18	1.35	0.63	<0.02	0.02	0.007	0.079	0.032
7	1.06	4.00	2.49	61.36	2.26	0.37	0.34	7.73	18.09	0.27	1.14	1.17	0.03	0.03	0.009	0.094	0.033
8	0.98	5.04	2.18	56.49	2.62	0.28	0.41	8.38	20.00	0.33	1.50	0.98	0.02	0.02	0.010	0.101	0.027
9	1.39	3.93	2.16	63.41	2.20	0.27	0.37	6.80	19.10	0.28	0.46	0.62	0.02	<0.01	0.007	0.059	0.027
10	1.07	4.22	1.78	60.68	2.25	0.23	0.41	8.58	20.74	0.23	0.58	0.61	0.02	<0.01	0.009	0.073	0.028
11	0.95	4.21	1.77	60.28	2.18	0.26	0.40	8.24	20.19	0.21	0.57	0.55	0.02	<0.01	0.007	0.074	0.055
12	1.21	4.33	2.48	62.90	2.06	0.25	0.50	7.62	18.37	0.22	0.46	0.76	0.02	<0.01	0.006	0.051	0.031
13	1.28	3.78	2.04	60.01	2.26	0.21	0.52	7.17	20.72	0.36	0.41	0.80	0.02	<0.01	0.007	0.052	0.052

Appendix 2: XRD analysis

#	Minerals identified
1	Mullite, Quartz, Cristobalite (low)
2	Mullite, Quartz, Sillimanite, Cristobalite (low)
3	Mullite, Quartz, Cristobalite (low)
6	Tridymite, Cristobalite (low)