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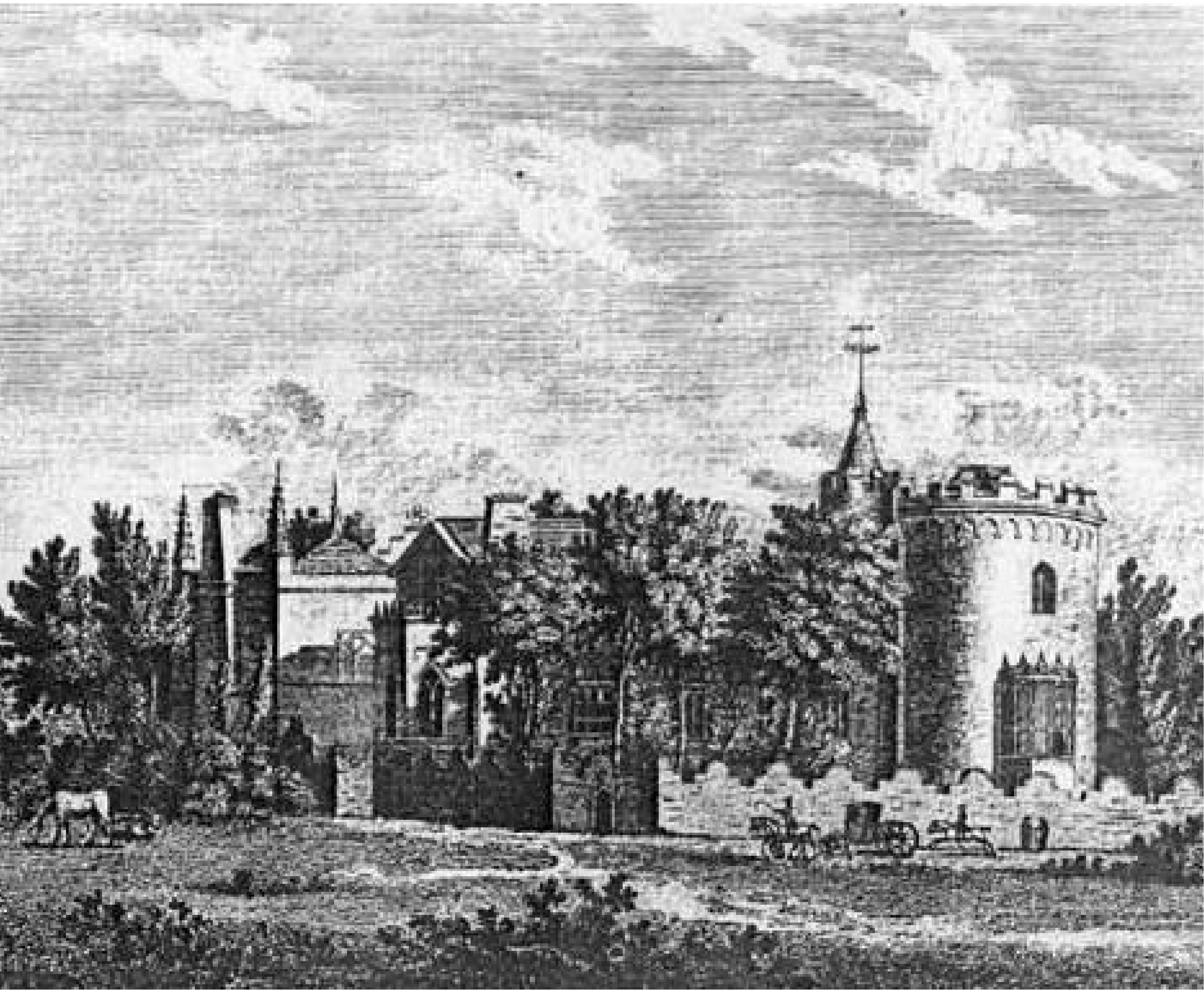
HORACE WALPOLE'S HOUSE AT STRAWBERRY HILL, TWICKENHAM, MIDDLESEX
CHEMICAL ANALYSIS OF WINDOW GLASS

TECHNOLOGY REPORT

David Dungworth



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Chemical analysis of window glass

David Dungworth

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SUMMARY

The chemical analysis of thirteen samples of window glass from Horace Walpole's house at Strawberry Hill, Twickenham was undertaken as part of a larger project investigating post-medieval window glass. While all other sites and assemblages investigated to date have been used to develop a model of chronological changes in window glass manufacturing practice and technology, the situation with this assemblage has been reversed. In this case the results of the chemical analysis have been used to suggest dates of manufacture and these dates have been compared with the prior dates suggested by architectural context. Four samples have compositions which are consistent with the suggested dates, five samples have compositions which suggest that the glass has been replaced at a later date, and four samples have unusual compositions which cannot currently be explained.

ACKNOWLEDGEMENTS

I would like to thank Kevin Rogers of Peter Inskip and Peter Jenkins (Architects) and staff of Chapel Studios who made the samples of window glass available for analysis.

ARCHIVE LOCATION

The samples of analysed glass are archived at English Heritage, Fort Cumberland, Fort Cumberland Road, Eastney, Portsmouth, PO4 9LD

DATE OF RESEARCH

2009–2010

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INTRODUCTION

The analysis of fragments of window glass from Strawberry Hill (for details about the location and history of the house see below) forms part of a much larger project undertaken to investigate the chemical composition of window glass produced and used in Britain during the past five centuries. Samples of window glass have been selected from archaeological excavations (including glass production sites) and from historic buildings. These have been analysed to determine their chemical composition. A comparison of the chemical composition with the available dating evidence shows that a series of changes in window glass manufacturing took place during this period. The aim of this research is to provide a technique to date the manufacture of individual panes of glass in historic buildings. This knowledge will allow architects and others to make more informed judgements about which glass to retain and which can be replaced (Clark 2001).

Almost all glass produced in Britain during the medieval period was produced using sand and terrestrial plant ashes (primarily bracken) and has a distinctive potassium-rich composition (Dungworth and Clark 2004). The arrival of French glassmakers in the late 16th century saw a change to a high-lime low-alkali (HLLA) glass. HLLA glass was probably made using sand and the ash of hardwoods (such as oak). This HLLA glass remained in use until the end of the 17th century when it was superseded by a glass made using sand and seaweed (kelp) ash (Dungworth *et al* 2009; Parkes 1823; Watson 1782). This kelp glass dominated the window glass industry until the early part of the 19th century when it was abandoned in favour of glass made using synthetic soda (Cooper 1835; Ure 1844; Muspratt 1860).

Nicholas Leblanc invented a process for the manufacture of synthetic soda at the end of the 18th century. Common salt was heated with sulphuric acid to produce sodium sulphate (soda saltcake), the sodium sulphate was then heated with lime and charcoal or coal to produce sodium carbonate. Initially, glass could only be made with sodium carbonate, but glassmakers soon discovered that the sulphate could be used directly if it was combined with charcoal or coal. Glass made for the century or so following the 1830s was a simple soda-lime-silica glass with low levels of impurities (Dungworth 2009).

The early decades of the 20th century saw the development of techniques for automatically drawing glass (Cable 2004; McGrath and Frost 1937) which initially had problems with glass devitrifying. These problems were solved by substituting a small amount of magnesia for lime and virtually all window glass made in Britain since 1930 has contained 2–5% magnesia (Smrcek 2005).

The small number of samples from Strawberry Hill available for analysis precludes the application of the analytical data to the establishment of a chronological model for changes in post-medieval window glass composition. Therefore the decision was taken to compare the assumed dates for the Strawberry Hill glass with the dates indicated by the chemical composition. It is hoped that this will illustrate the importance of a scientific dating technique for historic window glass.

BACKGROUND

Strawberry Hill, Twickenham, Middlesex (NGR TQ 158 723) is an example of Georgian Gothic Revival architecture built by Horace Walpole in the late 18th century. The original modest house was of 1698 was purchased by the son of Britain's first Prime Minister and author of *The Castle of Otranto* in 1748. Horace Walpole proceeded to transform it into 'a little Gothic castle', doubling its size and adding towers and battlements. The overall result was a mixture of elements borrowed from medieval castles and cathedrals (Figure 1).

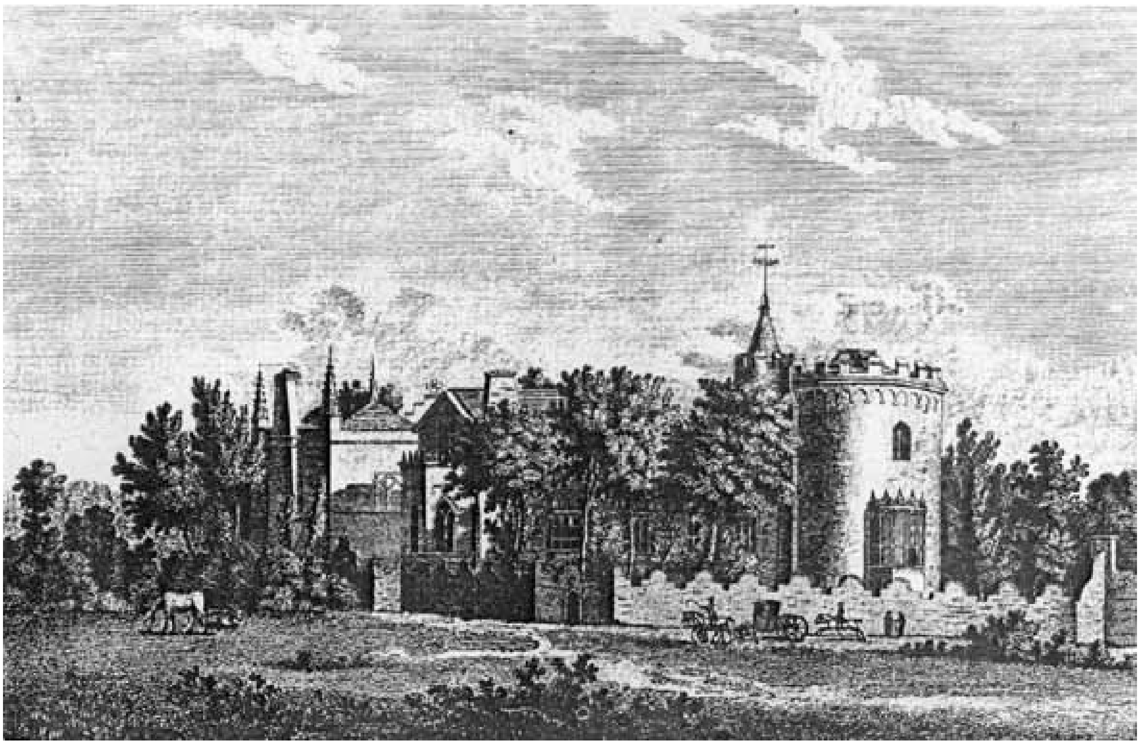

Figure 1. 18th-century engraving of Horace Walpole's house at Strawberry Hill

Following Walpole's death in 1797 the house passed into the hands of the Waldegrave family. In 1842 the 7th Earl Waldegrave sold the contents by auction and left it to fall into disrepair. In 1846 the house was inherited by Frances, Lady Waldegrave, who began restoring it in 1856. Following the death of Lady Waldegrave in 1879 the house passed into the ownership of the Stern family. In 1923 it was purchased by the Catholic Education Council and became part of a Teachers' Training College (and now part of Surrey University). In 2002 the Strawberry Hill Trust was set up to undertake restoration of the house. The Trust secured funding from a number of bodies (including the Heritage Lottery Fund) and the restored house opened to the public in 2010.

THE WINDOW GLASS

Walpole incorporated a wide range of 16th- and 17th-century English, Dutch and Flemish stained glass into the house. The glass examined for this report, however, includes only examples of plain (colourless) glass. The window glass to be examined was chosen by Kevin Rogers of Peter Inskip and Peter Jenkins (Architects) and samples removed by staff from Chapel Studios who undertook the conservation of the window glass. A total of thirteen fragments were submitted for analysis. Table 1 gives details of the provenance of the fragments, their colour, thickness (mm) and the proposed dates they were installed.

Table 1. Details of the Strawberry Hill House window glass samples submitted for analysis

Lab	Room	Room Name	Other ref	Colour	Th	Date?
#01	F19	Great North Bedchamber	A72	colourless	3.0	1772?
#02	F19	Great North Bedchamber	W2-224	very pale blue-green	1.8	1772?
#03		Mr Walpole's Bedchamber	Upper panel	colourless	2.7	1840s/50s
#04	G8	Great Cloister	W3	very pale grey	4.0	1820s
#05	S14	Round Tower	Second floor W1	colourless	3.2	1862
#06	G8	Great Cloister	W3	colourless	1.9	1820s
#07	S15	Upper Closet		colourless	3.1	1762?
#08	F19	Great North Bedchamber		very pale grey	2.9	1772?
#09	G8	Great Cloister	W3	very pale grey	3.6	1826?
#10	F18	Small Closet	Transom lights	colourless	2.1	post 1842
#11	S14	Round Tower	Attic floor	colourless	2.0	1862
#12	F19	Great North Bedchamber	from casement	pale grey	2.9	1772?
#13	F19	Great North Bedchamber	from casement	very pale blue-green	2.2	1772?

METHODS

All of the fragments of glass were mounted in epoxy resin and ground and polished to a 3-micron finish to expose a cross-section through the glass. The samples were inspected using an optical microscope (brightfield and darkfield illumination) to identify corroded and uncorroded regions. None of the Strawberry Hill samples exhibited any substantial corroded surfaces. The samples were analysed using two techniques to determine chemical composition: SEM-EDS and EDXRF. The energy dispersive X-ray spectrometer (EDS) attached to a scanning electron microscope (SEM) provided accurate analyses of a range of elements while the energy dispersive X-ray fluorescence (EDXRF) spectrometer provided improved sensitivity and accuracy for some minor elements (in particular manganese, iron, arsenic, strontium and zirconium) due to improved peak to background ratios (Table 2).

The SEM used was a FEI Inspect F which was operated at 25kV with a beam current of approximately 1.2nA. The X-ray spectra generated by the electron beam were detected using an Oxford Instruments X-act SDD detector. The quantification of detected elements was achieved using the Oxford Instruments INCA software. The EDS spectra were calibrated (optimised) using a cobalt standard. Deconvolution of the X-ray spectra and quantification of elements was improved by profile optimisation and element standardisation using pure elements and compounds (MAC standards). The chemical composition of the samples is presented in this report as stoichiometric oxides with oxide weight percent concentrations based on likely valence states (the exception being chlorine which is expressed as element wt%). The accuracy of the quantification of all oxides was checked by analysing a wide range reference materials (Corning, NIST, DGG and Newton/Pilkington). A number of elements were sought but not detected: phosphorus, titanium, vanadium, chromium, cobalt, nickel, copper, zinc, tin, antimony, rubidium and barium.

Table 2. Minimum Detection limits (MDL) and analytical errors (two standard deviations) 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	0.02	0.01
K_2O	0.1	0.1	ZnO	0.02	0.01
CaO	0.1	0.1	As_2O_3	0.03	0.01
TiO_2	0.1	0.1	SnO_2	0.1	0.05
BaO	0.2	0.1	Sb_2O_5	0.15	0.07
			Rb_2O	0.005	0.005
			SrO	0.005	0.005
			ZrO_2	0.005	0.005
			PbO	0.03	0.02

RESULTS

Table 3. Major elements (the results presented in this table and Table 4 have been normalised to 100wt%)

Lab Ref	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	K_2O	CaO	PbO
#01	12.64	0.11	0.75	71.0	<0.1	0.16	14.62	<0.05
#02	8.58	5.52	1.25	66.0	1.75	3.95	11.03	<0.05
#03	12.06	<0.1	1.30	71.6	<0.1	0.57	13.34	<0.05
#04	5.91	1.36	0.55	58.8	<0.1	11.07	5.93	15.00
#05	13.28	3.99	1.11	72.4	<0.1	0.55	8.26	<0.05
#06	11.67	0.15	0.84	70.6	<0.1	0.20	15.55	<0.05
#07	13.50	3.92	1.35	72.5	<0.1	0.65	7.88	<0.05
#08	6.45	1.17	0.52	59.6	<0.1	9.85	5.52	15.67
#09	5.88	1.39	0.57	58.6	<0.1	11.01	5.86	15.26
#10	11.45	0.11	1.58	72.3	<0.1	0.55	12.49	<0.05
#11	12.74	<0.1	0.57	71.1	<0.1	<0.1	14.01	<0.05
#12	6.33	1.27	0.47	59.6	<0.1	9.86	5.54	15.72
#13	12.23	0.16	0.66	71.1	<0.1	<0.1	15.19	<0.05

Table 4. Minor elements (the results presented in this table and Table 3 have been normalised to 100wt%)

Lab Ref	SO_3	Cl	MnO	Fe_2O_3	As_2O_3	SrO	ZrO_2
#01	0.43	<0.2	<0.02	0.28	<0.03	0.012	0.009
#02	<0.2	0.68	<0.02	0.45	<0.03	0.73	0.049
#03	0.48	<0.2	<0.02	0.17	0.40	0.007	<0.005
#04	<0.2	0.63	0.50	0.27	<0.03	<0.1	0.006
#05	0.23	<0.2	<0.02	0.15	<0.03	0.005	0.007
#06	0.57	<0.2	0.15	0.26	<0.03	0.013	0.005
#07	<0.2	<0.2	<0.02	0.17	<0.03	0.017	0.015
#08	<0.2	0.61	0.35	0.28	<0.03	<0.1	0.012
#09	<0.2	0.63	0.50	0.26	<0.03	<0.1	0.011
#10	0.40	<0.2	<0.02	0.61	0.53	0.009	0.006
#11	0.43	<0.2	0.51	0.32	0.13	0.031	0.014
#12	<0.2	0.58	0.34	0.28	<0.03	<0.1	0.016
#13	0.34	<0.2	<0.02	0.19	<0.03	0.007	0.008

The compositions of the samples are provided below in Tables 3 and 4. The chemical compositions of the analysed samples of window glass display considerable variation. A single sample (#02) contains significant quantities of phosphorus and is likely to have been manufactured using a plant ash. Eight samples are soda-lime-silica (SLS) glasses and are likely to have been manufactured after the development of processes to synthesise sodium carbonate (or sulphate) from common salt (sodium chloride) in the early 19th century. Two of the samples of SLS glass (#05 and #07) contain elevated magnesium concentrations and are likely to have been manufactured after c1930; the remaining SLS samples have compositions which indicate manufacture between c1830 and c1930. Four samples have chemical compositions which are unusual in that they contain significant quantities of lead (15–16wt% PbO). Such high concentrations of lead have not previously been detected in any historic glass window glass. The four lead-rich window glass samples form two pairs (#08 and #12, and #04 and #09) which share almost identical compositions.

DISCUSSION

As only a relatively small number of samples of Strawberry Hill window glass were available for analysis the results will be treated differently compared to other assemblages recently examined. Other assemblages have comprised scores or hundreds of samples (eg Dungworth 2009; Dungworth and Wilkes 2010a) and the chemical analysis of these samples has usually allowed the identification of original and later, replacement glass. The composition of the original glass has then contributed to the development of a model for chronological changes in the composition of window glass manufactured in England during the last five centuries. This report will use the newly developed model (see Table 5 for a summary) to verify (or refute) the dating for the Strawberry Hill as indicated by architectural context. It is hoped that this will illustrate the importance of a scientific dating technique for historic window glass. The results are discussed in greater detail below, room by room.

Table 5. Chemical composition of historic window glass (nr = not reported) (Sources: 1 = Dungworth and Loaring 2009; 2= Dungworth and Adams 2010; 3= Dungworth 2009; 4 = Hatton 2004; 5 = Dungworth and Wilkes 2010c; 6 = Dungworth and Wilkes 2010a; 7 = Dungworth and Wilkes 2010b; 8 = Dungworth 2010a; 9 = Dungworth 2010b; 10 = Smrcek 2005)

		Date	Na_2O	MgO	SiO_2	P_2O_5	K2O	CaO	Fe_2O_3	As_2O_3	SrO
Shaw House	1	1700–30	8.2	5.3	66.0	1.0	4.2	10.4	0.63	<0.02	0.49
Margam Castle	2	1830	8.2	5.3	66.0	1.4	3.8	11.9	0.62	<0.02	0.61
Chatsworth	3	1837–40	14.0	<0.1	70.3	<0.1	<0.1	14.1	0.20	0.41	0.02
Nailsea	4	1830–70	13.1	0.2	68.9	<0.1	0.1	13.5	0.33	0.22	0.02
Flint Lodge	5	1851	11.6	0.1	71.5	<0.1	<0.1	14.9	0.16	0.02	0.02
Wentworth	6	1877	11.9	0.4	71.5	<0.1	0.3	14.3	0.28	<0.02	0.03
Highland House	7	1880s	12.1	<0.1	71.7	<0.1	0.6	13.2	0.21	<0.02	0.01
Welch Road	8	1895	11.6	0.1	72.5	<0.1	0.6	13.1	0.20	<0.02	0.02
Fort Cumberland	9	1940	14.3	2.9	72.5	<0.1	<0.1	9.4	0.13	<0.02	0.01
Drawn	10	1930–60	13.8	2.7	72.1	<0.1	nr	9.8	0.12	nr	nr
Float	10	1960–99	13.8	4.1	71.9	<0.1	0.6	8.7	0.13	nr	nr

Room S15 (Upper Closet)

A single fragment of window glass (#07) from this room was analysed. Prior to analysis the presumed date was 1762. Chemical analysis shows that this is a SLS glass with low levels of impurities. The most striking aspect of the chemical composition is the low calcium and high magnesium content. An examination of the magnesium content of 20th-century window glass suggests the presence of two groups: a low magnesium group (~3wt% MgO) and a high magnesium group (~4wt% MgO). Comparison with data from 20th-century manufacturers suggests that the former group was probably manufactured between c1930 and c1960 while the latter group was manufactured after 1960 (Dungworth and Wilkes 2010b, Fig 2). The composition of sample #07 (in particular the magnesium content) indicates that this glass was manufactured after the development of automatic sheet drawing techniques in c1930, and probably after the introduction of float glass c1960.

Room F19 (Great North Bedchamber)

Five samples of glass from this room were analysed (#01, #02, #08, #12 and #13). Prior to analysis the presumed date for all windows was 1772. Chemical analysis indicates that one sample (#02) was manufactured using seaweed (kelp) ash, two (#01 and #13) are SLS glass made between 1830 and 1930 and two (#08 and #12) are of an unusual lead glass.

Sample #02 contains phosphorus (unlike any of the other Strawberry Hill window glass analysed) which is most likely to derive from the use of a plant ash as the source of alkali. The mixed alkali composition of this glass is similar to 18th-century window glass (Dungworth 2007; Dungworth and Loaring 2009). The relatively high strontium content of this glass indicates that the glass was made using seaweed (kelp) ash as a source of alkali (Dungworth *et al* 2009).

Samples #01 and #13 are both SLS glass with similar compositions. Nevertheless the small differences in chemical composition (in particular the iron content) are sufficient to suggest that the two samples were probably manufactured at different times or places. The nature of the SLS glass indicates these samples were manufactured after the introduction of synthetic soda c1830. Both samples have low magnesium concentrations indicating that they were manufactured before the development of automatic sheet drawing techniques in c1930. The absence of arsenic in the SLS samples from this room indicate that they were probably manufactured after c1850. Most analysed SLS glass made between c1830 and c1850 contains significant quantities of arsenic (Dungworth 2009) but this element is rarely detected in later 19th-century glass (Dungworth and Wilkes 2010a; 2010b).

The remaining two samples (#08 and #12) from this room share almost identical chemical compositions and were probably made at the same time and place. This glass has an unusual composition (in particular the presence of significant quantities of lead) which is not shared by any of the hundreds of other historic window glass samples analysed (eg Dungworth 2009). The absence of phosphorus indicates that this glass was made using a synthetic soda rather than a plant ash, which would place manufacture after c1830.

The use of lead in the manufacture of window glass is not indicated by any contemporary documentary sources and has not been detected during the analysis of hundreds of historic window glass samples. The composition is, however, paralleled in two samples from room G8 (see below). The source of the lead, and the motivation behind its addition, are not immediately apparent. The general absence of lead from most historic window glass is easily explained by reference to its density. Until the early 20th century, most window glass was fabricated by inflating a bubble of glass. The size of the sheets of glass that could be produced in this way were limited by the mass of glass that a single worker could manipulate by hand. Adding lead would increase the density of the glass and so reduce the volume and area of flat glass that could be produced. The only production technique in which lead might be advantageous would be plate glass. Plate glass was manufactured by pouring molten glass onto a metal table and then rolling the glass flat. Once cool the flat glass was ground and polished. Plate glass was manufactured in England from the 1770s but there are no contemporary references to the use of lead in its manufacture (Douglas and Frank 1972, 147). The unusual composition of this glass from Strawberry Hill suggests that it was specially formulated. Inspection of the range of elements present suggests that this glass might be a blend of standard SLS glass and a lead crystal/flint glass; however, the potassium to lead ratio is too high for a lead crystal/flint glass.

The lack of any clear parallels in documentary sources or other analysed historic glass samples makes it difficult to provide any likely date of manufacture. If this glass is plate glass (and it was manufactured in England) then it was produced after c1770.

Room G8 (Great Cloister)

Three samples of glass from this room were analysed (#04, #06 and #09). Prior to analysis the presumed date was 1820s. One sample (#06) is a SLS glass with low magnesium and no arsenic indicating manufacture between 1850 and 1930. The two remaining samples (#04 and #09) share almost identical compositions and are likely to have been manufactured at the same time and place. These samples (like sample #08 and #12 from room F19 discussed above) have unusual compositions, in particular the lead content. This is likely to be plate glass manufactured after 1770.

Mr Walpole's Bedchamber

A single sample of glass from this room was analysed (#03). Prior to analysis the presumed date was 1840s or 1850s. This glass is a SLS glass with low magnesium indicating manufacture between c1830 and c1930. The presence of arsenic suggests that manufacture probably took place between c1830 and c1850.

Room F18 (Small Closet)

A single sample of glass from this room was analysed (#10). Prior to analysis the presumed date was post-1842. This glass is a SLS glass with low magnesium indicating manufacture between c1830 and c1930. The presence arsenic suggests that manufacture probably took place between c1830 and c1850.

Room S18 (Round Tower)

Two samples of glass from this room were analysed (#05 and #11). Prior to analysis the presumed date was post-1862. Both samples of glass are SLS glasses but one (#11) has a low magnesium content indicating manufacture between c1830 and c1930 while the other (#05) has a high magnesium content indicating that it was probably manufactured after c1960.

CONCLUSIONS

Table 6. Comparison of prior dating (architectural context) and posterior dating (chemical composition)

Lab	Prior Date	Posterior Date	Agreement
#01	1772?	1850–1930	No
#02	1772?	1700–1830	Yes
#03	1840s/50s	1830–1850?	Yes
#04	1820s	?	?
#05	1862	1960+	No
#06	1820s	1850–1930	No
#07	1762?	1960+	No
#08	1772?	?	?
#09	1826?	?	?
#10	post 1842	1830–1850	Yes
#11	1862	1830–1850	Yes
#12	1772?	?	?
#13	1772?	1850–1930	No

The analysis of thirteen samples of historic window glass from Strawberry Hill was undertaken to test the benefits of chemical analysis as an aid to dating the manufacture of such glass. Table 6 provides the prior dates based on considerations of architectural context and the posterior dates based on a comparison of the chemical composition of the glass with available data from other sites (eg Table 5). In four cases (#02, #03, #10 and #11) the prior and posterior dates are in agreement. In four cases (#04, #08, #09 and #12) the glass displays unique chemical composition which cannot be paralleled in contemporary sources or modern analyses. The unusual composition of this glass makes it difficult to provide any useful date on the basis of the chemical composition. The glass was probably not manufactured before 1770 but could have been made as late as the early 20th century. The remaining five samples have compositions which suggest a manufacturing date later than the date indicated by architectural context. In two cases (#05 and #07) the compositions suggest that the glass had been replaced in the latter half of the 20th century. The other samples have compositions which suggest the windows are not original but were replaced prior to c1930.

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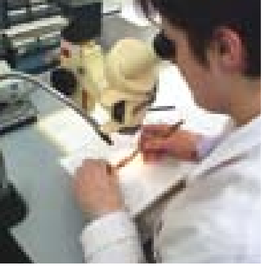
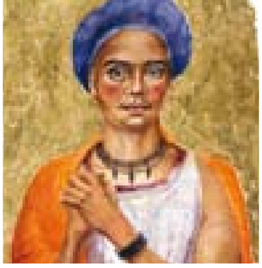



ENGLISH HERITAGE RESEARCH DEPARTMENT

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

For further information visit www.english-heritage.org.uk

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