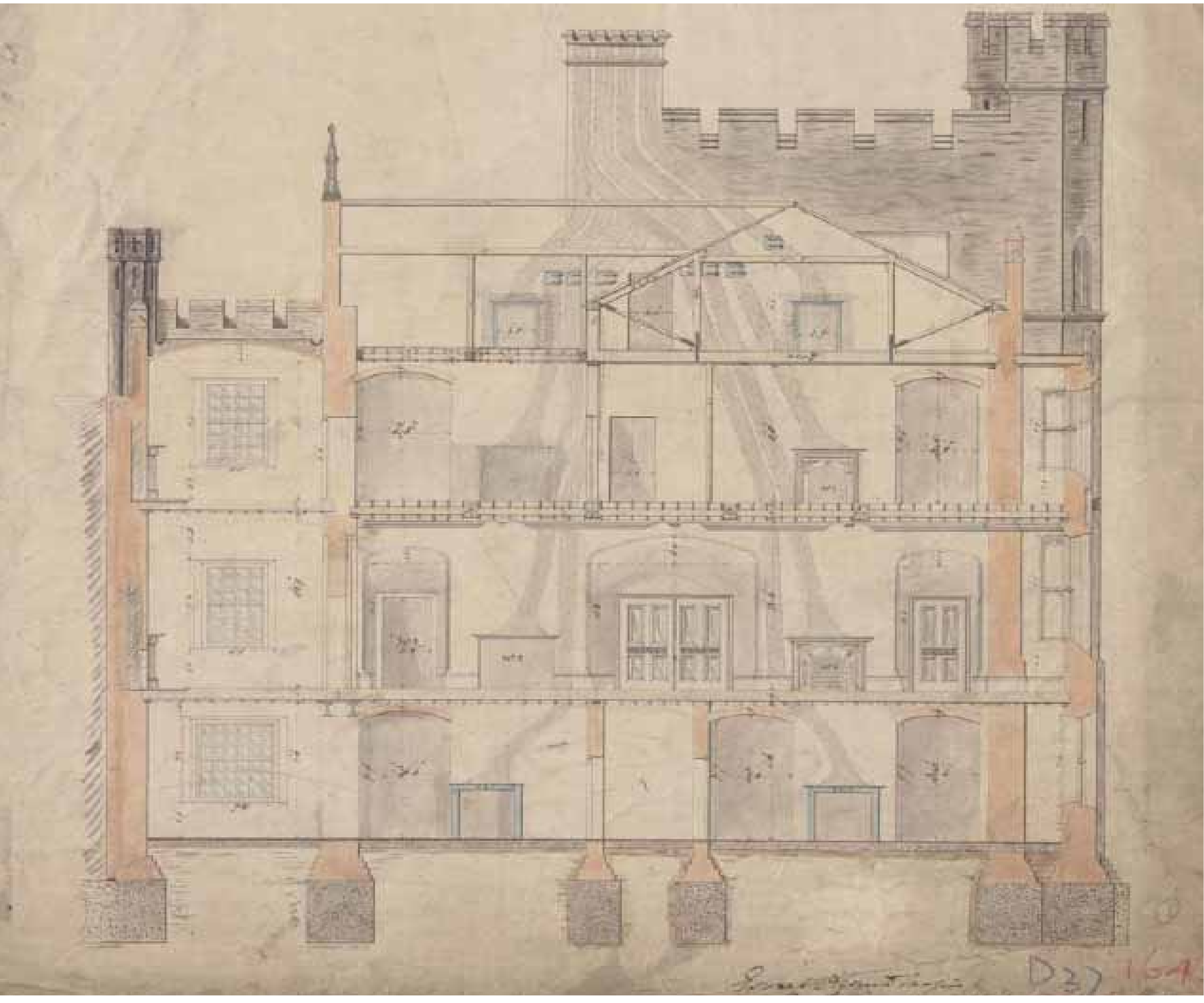
RESEARCH DEPARTMENT REPORT SERIES no. 23-2010 ISSN 1749-8775

ROYAL FUSILIERS REGIMENTAL MUSEUM, TOWER OF LONDON
AN INVESTIGATION OF THE WINDOW GLASS

TECHNOLOGY REPORT

Roger Wilkes and David Dungworth



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ROYAL FUSILIERS REGIMENTAL MUSEUM, TOWER OF LONDON

SCIENTIFIC EXAMINATION OF THE WINDOW GLASS

Roger Wilkes and David Dungworth

NGR: TQ 3361 8060

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ISSN 1749-8775

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SUMMARY

The scientific examination and chemical analysis of window glass from the Royal Fusiliers Regimental Museum at the Tower of London was undertaken to determine the composition. The Museum was originally constructed in 1845 and it was hoped the analysis of the window glass would contribute to a better understanding of developments in 19th-century window glass production. The results show that of the samples which were assigned into four groups based on their chemical composition, one group can be considered to be typical of mid 19th century window glass and is tentatively considered to represent the original windows. The remaining groups are considered to be replacement glass, typical of post 1930s manufacture, probably post 1960s.

ACKNOWLEDGEMENTS

We would like to thank Alex Attelsey who provided the samples of glass.

ARCHIVE LOCATION

Fort Cumberland, Fort Cumberland Road, Eastney, Portsmouth PO4 9LD

DATE OF RESEARCH

2009–2010

CONTACT DETAILS

Fort Cumberland, Fort Cumberland Road, Eastney, Portsmouth PO4 9LD
Roger Wilkes, Tel 023 9285 6784 roger.wilkes@english-heritage.org.uk

Front Cover
Section drawing of the completed officer's quarters dated 1849 (The National Archives)

INTRODUCTION

Seventeen fragments of window glass were recovered between June and August 2009 during work supporting a programme of stone and roof repairs at the Royal Fusiliers Regimental Museum, in the Tower of London. The analysis of this window glass contributes to a larger project investigating 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 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).

ROYAL FUSILIERS REGIMENTAL MUSEUM AND HEADQUARTERS, THE TOWER OF LONDON

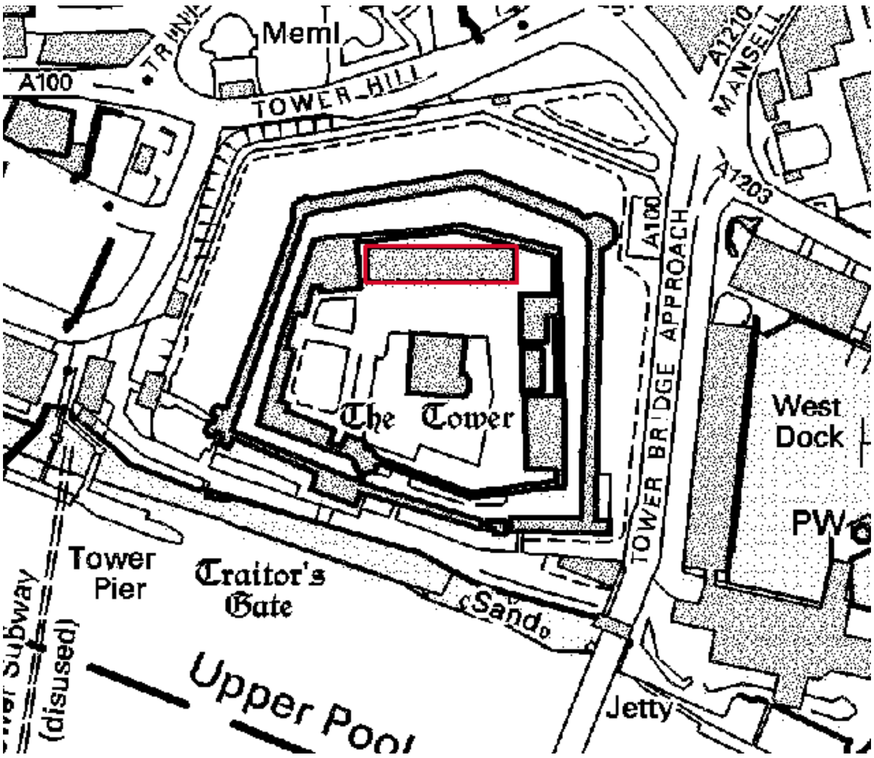

Figure 1. Plan of the Tower, and the Royal Fusiliers Regimental Museum within.
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The Tower of London is a UNESCO World Heritage Site and a Scheduled Ancient Monument; within the site is the Royal Fusiliers Regimental Museum and Headquarters which is a grade II listed building. This building, constructed in 1845 as the Waterloo Barracks and Officers Block, was built on the site of, and to some extent incorporated into the plan of, the 17th-century Grand Storehouse following its destruction in a fire in 1841.

THE GLASS

Table1. Royal Fusiliers Regimental Museum glass.

#	Colour	Thickness (mm)	Finish
1	very pale blue-green	2.9	flat
2	clear	2.2	wavy
3	pale blue-green	2.8	slightly wavy
4	clear	1.7	wavy
5	clear	1.9	wavy
6	very pale blue-green	2.9	flat
7	very pale blue-green	2.9	flat
8	pale blue-green	2.8	slightly wavy
9	very pale blue-green	2.9	flat
10	pale blue-green	2.8	slightly wavy
11	very pale blue-green	2.9	flat
12	pale blue-green	2.8	slightly wavy
13	very pale blue-green	2.9	flat
14	very pale blue-green	2.9	flat
15	pale blue-green	3.8	patterned
16	pale blue-green	3.8	patterned
17	pale blue-green	3.8	patterned

Seventeen samples of window glass were made available for analysis (Table 1, Figure 2). These included three samples of rolled glass with a patterned surface on one face (#15–17, Figure 2). The process for manufacturing this type of glass was patented by James Hartley of Sunderland in 1847 (McGrath and Frost 1937, 26) and so these samples cannot represent the glass originally installed in 1845. The remaining flat glass samples include examples with a range of tints (pale blue to clear, see Figure 2), and a range of surface finishes. Some of the samples have a sufficiently smooth finish to suggest they are either polished plate glass or float glass. Three samples (#2, 4 and 5) are substantially thinner (~2mm) than the remaining samples (2.8–2.9mm) and have distinctly wavy surfaces. The chemical analysis of all samples (see below) suggests that the three thin samples may represent the glass originally installed.

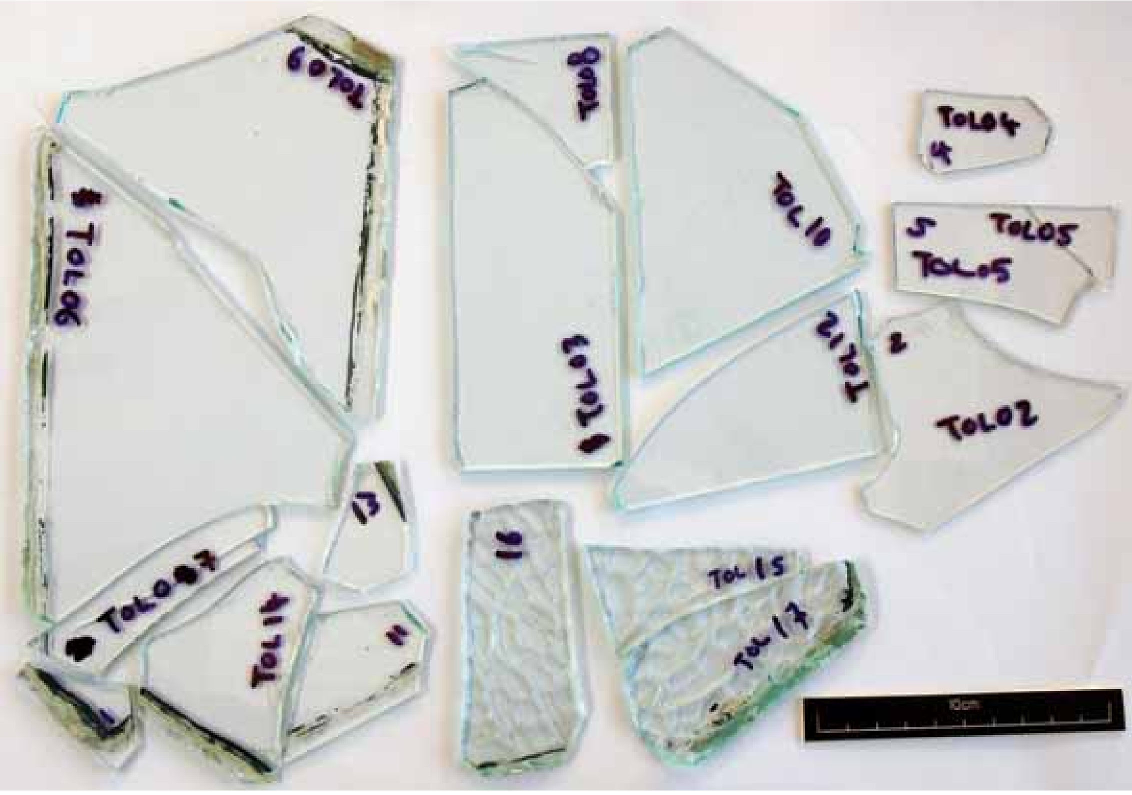

Figure 2. All pieces of glass, showing slight blue-green tint to most glass. Note the tint is less strong for samples 2, 4 and 5.

METHODS

All seventeen of the fragments of glass were mounted in epoxy resin and ground then polished to a 3-micron finish to expose a cross-section through the glass. The samples were inspected using an optical microscope (bright field and dark field illumination) to identify any corrosion. None of the Royal Fusiliers Regimental Museum samples exhibited any corroded surfaces. The samples were analysed by SEM-EDS and EDXRF to determine chemical composition. The energy dispersive X-ray spectrometer (EDS) attached to a scanning electron microscope (SEM) provided accurate analyses of the required elements while the energy dispersive X-ray fluorescence spectrometer (EDXRF) allowed an improved sensitivity of detection limit, due to enhanced peak to background noise of minor elements such as manganese, iron, arsenic, strontium and zirconium.

The SEM used was a FEI Inspect F 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 Oxford Instruments INCA software. The EDS spectra were calibrated using a cobalt standard. De-convolution of the X-ray spectra and quantification of elements were improved by profile optimisation and element standardisation using pure elements and compounds (MAC standards). The chemical composition of the samples is presented in this report as stoichiometric oxides with oxide weight percent concentrations based on likely valence states (except chlorine which is expressed as element wt %). The accuracy of the quantification of all oxides was checked by analysing a range of reference materials ie Corning, DGG, MPI, NIST and Newton/Pilkington. A number of elements (vanadium, chromium, cobalt, nickel, copper, zinc, antimony, tin, rubidium and barium) were sought but not detected.

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

	EDXRF			SEM-EDS	
	MDL	ERROR		MDL	ERROR
V_2O_5	0.02	0.03	Na_2O	0.1	0.1
Cr_2O_3	0.02	0.03	MgO	0.1	0.1
MnO	0.02	0.03	Al_2O_3	0.1	0.1
Fe_2O_3	0.02	0.03	SiO_2	0.1	0.2
CoO	0.02	0.02	P_2O_5	0.1	0.1
NiO	0.02	0.03	SO_3	0.1	0.1
CuO	0.02	0.01	Cl	0.1	0.1
ZnO	0.02	0.01	K_2O	0.1	0.1
As_2O_3	0.03	0.01	CaO	0.1	0.1
SnO_2	0.10	0.05	TiO_2	0.1	0.1
Sb_2O_5	0.15	0.07	BaO	0.2	0.1
Rb_2O	0.005	0.005			
SrO	0.005	0.005			
ZrO_2	0.005	0.005			
PbO	0.03	0.02			

RESULTS

All of the glass is soda-lime glass. The samples can be grouped into four Groups. Groups 1–3 are broadly similar to each other but can all be distinguished from Group 4 by the levels of sodium, magnesium, potassium and calcium (Figures 3 and 4) as well as a range of minor elements (Table 3). The distinctions between Groups 1, 2 and 3 are relatively subtle but are sufficient to indicate that the glass is not of identical manufacture. The differences in the chemical composition of the four groups is reinforced by differences in the appearance of the glass: Group 1 samples are all very pale blue-green and have perfectly flat surfaces, Group 2 samples are all pale blue-green with slightly wavy surfaces, Group 3 samples are all pale blue-green, patterned, rolled glass, and Group 4 samples are the clearest and thinnest but with rather wavy surfaces.

Table 3. Chemical composition of the Tower of London glass samples.

#	Group	Na_2O	MgO	Al_2O_3	SiO_2	SO_3	K_2O	CaO	MnO	Fe_2O_3	As_2O_3	SrO	ZrO_2
1	1	13.26	3.54	1.19	72.9	0.23	0.41	8.46	<0.02	0.147	<0.03	0.033	0.008
6	1	13.32	3.56	1.18	72.6	0.29	0.47	8.38	<0.02	0.145	<0.03	0.029	0.010
7	1	13.43	3.58	1.18	72.5	0.28	0.47	8.38	<0.02	0.161	<0.03	0.032	0.013
9	1	13.39	3.57	1.19	72.7	0.26	0.44	8.41	<0.02	0.147	<0.03	0.036	0.012
11	1	13.47	3.57	1.17	72.6	0.28	0.47	8.32	<0.02	0.150	<0.03	0.033	0.006
13	1	13.36	3.56	1.22	72.7	0.29	0.48	8.35	<0.02	0.148	<0.03	0.034	0.009
14	1	13.42	3.55	1.17	72.8	0.24	0.46	8.42	<0.02	0.154	<0.03	0.029	0.008
3	2	14.39	4.05	1.58	72.1	0.22	0.61	7.14	<0.02	0.220	<0.03	0.009	0.013
8	2	14.49	4.05	1.57	72.1	0.19	0.63	7.07	<0.02	0.207	<0.03	0.008	0.014
10	2	14.39	4.00	1.64	72.1	0.22	0.61	7.08	<0.02	0.203	<0.03	0.009	0.014
12	2	14.37	4.01	1.55	72.2	0.18	0.59	7.09	<0.02	0.201	<0.03	0.011	0.017
15	3	13.24	3.79	1.28	72.0	0.23	0.78	8.44	<0.02	0.197	<0.03	0.013	0.013
16	3	13.22	3.82	1.26	71.9	0.20	0.72	8.49	0.021	0.191	<0.03	0.014	0.007
17	3	13.16	3.78	1.36	72.1	0.26	0.63	8.52	<0.02	0.197	<0.03	0.010	0.010
2	4	11.91	0.25	0.49	71.6	0.41	0.12	14.6	0.057	0.179	0.05	0.038	<0.005
4	4	11.76	0.36	0.44	71.4	0.40	0.13	14.5	0.047	0.175	0.06	0.043	0.006
5	4	11.68	0.26	0.44	71.7	0.41	0.12	14.6	0.053	0.169	0.04	0.038	<0.005

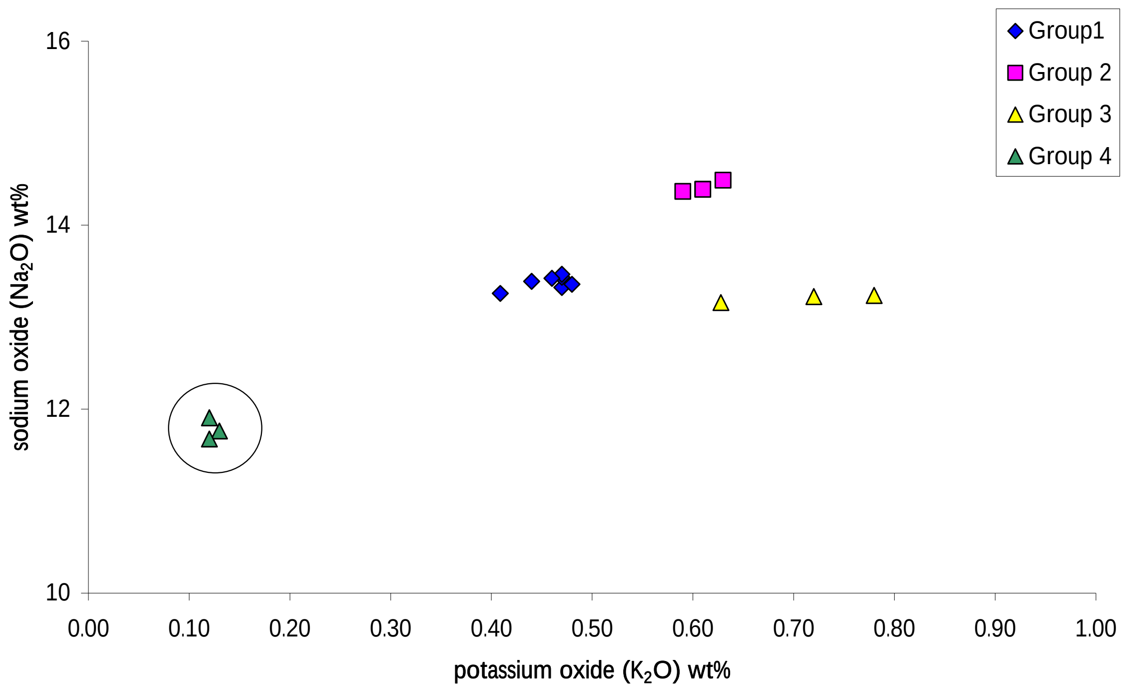

Figure 3. Potassium oxide and sodium oxide plot, Group 4 circled

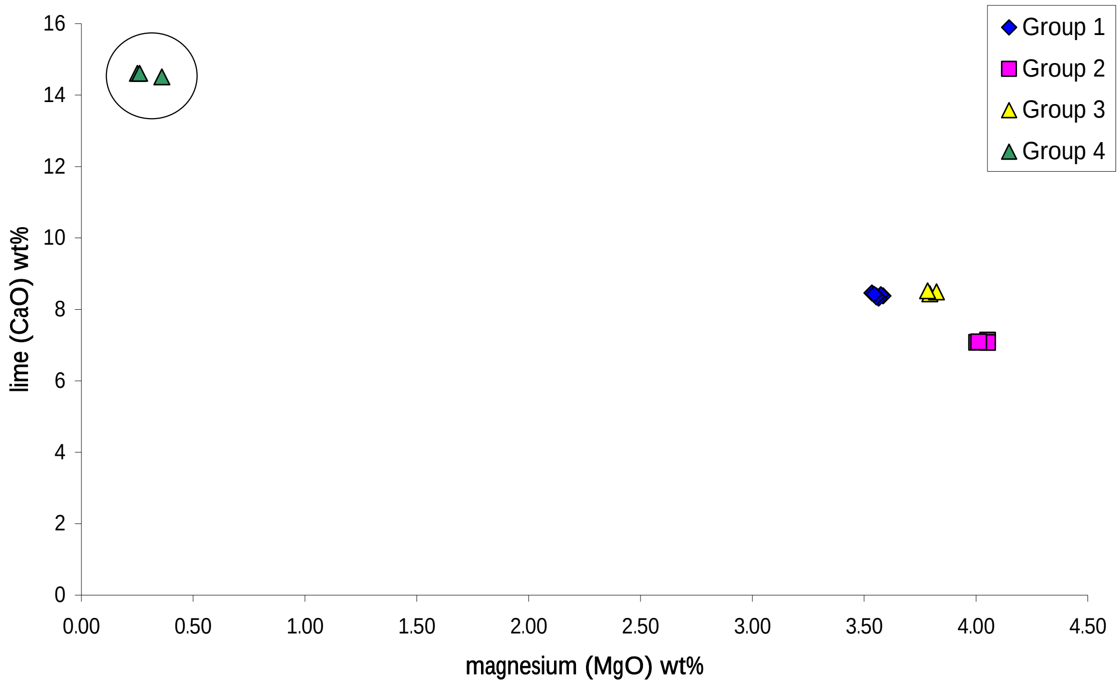

Figure 4. Magnesium and lime plot, Group 4 circled.

DISCUSSION

All of the window glass from the Royal Fusiliers Regimental Museum is soda-lime glass low levels of impurities. The absence of phosphorus indicates that all of the glass was manufactured using a synthetic soda, such as Leblanc soda, and must post-date c1830. Almost all window glass manufactured before c1830 was made using alkali derived from plant ash and so containing significant proportion of phosphorus. The samples have been divided into four compositional groups and each group comprises glass of a slightly different physical character (thickness, colour, surface finish). Groups 1–3 show only minor differences in their chemical compositions but all are clearly distinct from Group 4 (Figure 3). In particular the Group 4 samples contain high levels of calcium and very low levels of magnesium (Figure 4). The analysis of other samples of 19th- and 20th-century window glass (eg Dungworth and Wilkes 2010c; Smrcek 2005) suggests that samples with low levels of magnesium (cf our Group 4 glass) were manufactured prior to the introduction of mechanised drawing of flat glass c1930. The Group 4 glass also contains traces of arsenic (Table 4) and resembles mid 19th-century glass from Chatsworth (Dungworth 2009) and Nailsea (Hatton 2004). Group 4 glass is likely to represent that glass originally installed in 1845.

19th-century sources frequently mention the addition of small quantities of arsenic to the glass batch (eg Cable 2008, 44; Chance 1856; Muspratt 1860, 213). The addition of arsenic to the glass is likely to have been undertaken to help refine the molten glass, that is remove small bubbles. Although a range of later sources continue to mention the addition of arsenic (eg Powell *et al* 1883, 107; Rosenhain 1919, 83) to the glass batch, arsenic has not been detected in any later 19th-century glass (Table 4). Theses later glasses do, however, contain small amounts of potassium. Potassium nitrate has been used as a refining agent in glass making (Rosenhain 1919, 83) and it is possible that the health hazards posed by arsenic encouraged glassmakers to switch to potassium nitrate.

Groups 1–3 contain significant proportions of magnesium (and low levels of calcium), characteristic of glass made after c1930. Mechanically drawn glass was found to suffer from devitrification and the solution was to replace some calcium with magnesium (Cable 2004). The magnesium content of mechanically drawn glass falls into two groups; the first with 2.8–3.0wt% MgO and the second with 3.5–4.1wt% MgO. It has been suggested (Dungworth and Wilkes 2010c) that the former group was made between c1930 and c1960 (ie between the introduction of mechanically drawn glass and the introduction of the float process) and that the latter group is typical of float glass. Thus it is considered that Groups 1–3 are 20th-century glass and they were probably manufactured after 1960.

Table 4. Chemical composition of some 19th- and 20th-century window glass (nr = not reported). (Sources: 1 = Dungworth 2009; 2 = Hatton 2004; 3 = this report; 4 = Dungworth and Wilkes 2010b; 5 = Dungworth and Wilkes 2010c, 6 = Dungworth 2010a; 7 = Dungworth and Wilkes 2010a; 8 = Dungworth 2010b; 9 = Smrcek 2005)

Source	Source	Date	Na_2O	MgO	Al_2O_3	SiO_2	K_2O	CaO	Fe_2O_3	As_2O_3
Chatsworth	1	1837–40	14.0	<0.1	0.7	70.3	<0.1	14.1	0.20	0.41
Nailsea	2	1830–70	13.1	0.2	0.8	68.9	0.1	13.5	0.33	0.22
RFRM 19 Century	3	1845	11.8	0.3	0.5	71.6	0.1	14.6	0.14	0.05
Flint Lodge	4	1851	11.6	0.1	0.5	71.5	<0.1	14.9	0.16	0.02
Wentworth	5	1877	11.9	0.4	0.7	71.5	0.3	14.3	0.28	<0.02
Welch Road	6	1894–95	11.6	0.1	1.5	72.5	0.6	13.1	0.20	<0.02
Highland House	7	1880	12.1	<0.11	1.5	72.0	0.6	13.2	0.22	<0.02
Fort Cumberland GH	8	1940	14.5	2.9	0.2	72.7	<0.1	9.3	0.10	<0.02
Drawn	9	1930–60	14.6	2.1	1.0	72.0	0.1	9.8	0.12	nr
Highland House	7	1930–60	14.7	3.3	0.7	72.3	0.2	8.5	0.15	<0.02
RFRM 20 Century	3	1930–60	13.6	3.7	1.3	72.4	0.6	8.0	0.12	<0.02
Float	9	1960–99	13.8	4.1	1.1	71.9	0.6	8.1	0.19	nr

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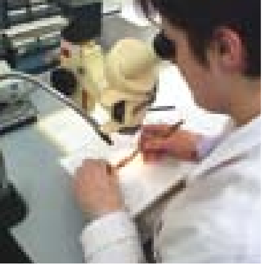
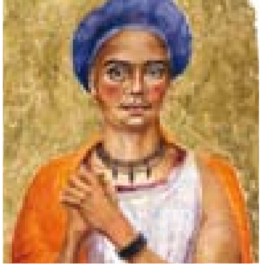



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