

SHORTLANDS LANE, CULLOMPTON, DEVON SCIENTIFIC EXAMINATION OF THE WINDOW GLASS

TECHNOLOGY REPORT

Brice Girbal and Dominic Ford



This report has been prepared for use on the internet and the images within it have been down-sampled to optimise downloading and printing speeds.

Please note that as a result of this down-sampling the images are not of the highest quality and some of the fine detail may be lost. Any person wishing to obtain a high resolution copy of this report should refer to the ordering information on the following page.

SHORTLANDS LANE, CULLOMPTON, DEVON

SCIENTIFIC EXAMINATION OF THE WINDOW GLASS

Brice Girbal and Dominic Ford

NGR: ST 019 071

© English Heritage

ISSN 1749-8775

The Research Department Report Series incorporates reports from all the specialist teams within the English Heritage Research Department: Archaeological Science; Archaeological Archives; Historic Interiors Research and Conservation; Archaeological Projects; Aerial Survey and Investigation; Archaeological Survey and Investigation; Architectural Investigation; Imaging, Graphics and Survey, and the Survey of London. It replaces the former Centre for Archaeology Reports Series, the Archaeological Investigation Report Series and the Architectural Investigation Report Series.

Many of these are interim reports which make available the results of specialist investigations in advance of full publication. They are not usually subject to external refereeing, and their conclusions may sometimes have to be modified in the light of information not available at the time of the investigation. Where no final project report is available, readers are advised to consult the author before citing these reports in any publication. Opinions expressed in Research Department reports are those of the author(s) and are not necessarily those of English Heritage.

Requests for further hard copies, after the initial print run, can be made by emailing:

Res.reports@english-heritage.org.uk

or by writing to:

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

Please note that a charge will be made to cover printing and postage.

SUMMARY

Twenty four fragments of window glass from an early to mid 18th-century pit at Shortlands Lane, Cullompton, Devon were analysed. A visual examination identified four different coloured glasses while the chemical compositions highlighted three major groups. Six of the fragments (mainly the darker greens) were HLLA glass probably produced between AD1570 and AD1700. Five fragments (pale blue-green in colour) were shown to be later kelp glass probably produced between AD1700 and AD1830 while the other thirteen fragments proved to be more of an anomaly with compositions in between the HLLA and kelp glass. The context (early to mid 18th-century pit) in which the glass was found would place the glass around the HLLA – kelp time boundary (circa AD1700) and combined with their compositions would suggest that these fragments represented the use of a mixture of seaweed and plant ash. Another possibility would be that they were not manufactured in Britain.

ACKNOWLEDGEMENTS

I would like to thank Bryn Morris for donating the glass fragments. I would also like to thank David Dungworth for his advice, help and patience. Sarah Paynter and Harriet White deserve special mention for their moral support and help with various aspects of this study.

ARCHIVE LOCATION

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

DATE OF RESEARCH

July/August 2010

CONTACT DETAILS

Technology Team, English Heritage, Fort Cumberland, Fort Cumberland Road, Eastney, Portsmouth, PO4 9LD

Brice Girbal, Tel: 023 9285 6785: brice.girbal@english-heritage.org.uk

INTRODUCTION

The analysis of fragments of window glass from Cullompton, Devon 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). Historic window glass often has a surface which is not smooth (see Figure 2 below) and usually has an unintentional tint or colour; both of these contribute to the character of the glass and the building as a whole.

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).

Nicolas 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 GLASS

The glass fragments analysed came from an early/mid 18th-century pit at Shortlands Lane, Cullompton, Devon. They represent a small selection of the fragments recovered but were the only ones made available for scientific analysis. The fragments were examined visually. The thickness (thickest part of the fragments) was recorded to 0.1mm using a Swiss Precision calliper. Some of the fragments had an edge which was thicker than the body of the glass; therefore, the thickest part of the body was also recorded. The colour of the glass was determined by placing them on a white piece of paper and comparing them to one another. Other descriptions or observations were noted such as the state of corrosion and flatness of the fragments (Table 1).

Table 1: Visual descriptions of the Cullompton glass fragments.

Sample	Context	Colour	Thickness (mm)	Comments
1	105	Pale Green	4.0	- Weathered surface - Wavy surface
2	105	Pale Green	3.0	- Edge is thicker – rest is 2mm - Weathered surface - Wavy surface
3	105	Pale Green	2.7	- Edge is thicker – rest is 2.2mm - Weathered surface - Wavy surface
4	105	Pale Green	2.6	- Edge is thicker – rest is 1.9mm - Weathered surface - Almost flat surface
5	105	Pale Green	2.8	- Edge is thicker – rest is 2mm - Weathered surface - Almost flat surface
6	105	Pale Green	3.2	- Edge is thicker – rest is 2.4mm - Weathered surface - Wavy surface
7	105	Pale Green	2.9	- Edge is thicker – rest is 2.4mm - Weathered surface - Almost flat surface
8	105	Pale Green	1.6	- Weathered surface - Almost flat surface
9	105	Pale Green	1.7	- Weathered surface - Almost flat surface
10	105	Pale Green	2.1	- Edge is thicker – rest is 1.8mm - Weathered surface - Wavy surface (curving on edge)
11	105	Pale Green	2.1	- Weathered surface - Flat surface
12	105	Pale Green	1.8	- Weathered surface - Almost flat surface
13	105	Pale Green	1.4	- Weathered surface - Flat surface

14	105	Pale Green	1.3	<ul style="list-style-type: none"> - Weathered surface - Almost flat surface
15	105	Pale Green	1.0	<ul style="list-style-type: none"> - Weathered surface - Almost flat surface
16	105	Green	1.9	<ul style="list-style-type: none"> - Weathered surface - Almost flat surface (wavy) - Two impressions about 4mm wide – tools?
17	105	Green	1.7	<ul style="list-style-type: none"> - Weathered surface - Almost flat surface
18	105	Green	1.2	<ul style="list-style-type: none"> - Weathered surface - Flat surface
19	105	Pale blue/green	3.1	<ul style="list-style-type: none"> - Edge is thicker – rest is 2.1mm - Weathered surface - Flat surface
20	105	Pale blue/green	5.0	<ul style="list-style-type: none"> - Edge is thicker – rest is 2.1mm - Weathered surface - Almost flat surface (curving on edge)
21	105	Pale blue/green	3.2	<ul style="list-style-type: none"> - Edge is thicker – rest is 2.1mm - Weathered surface - Flat surface (curving on edge)
22	105	Pale blue	3.5	<ul style="list-style-type: none"> - Edge is thicker – rest is 2.1mm - Weathered surface - Flat surface (curving on edge)
23	105	Colourless	1.1	<ul style="list-style-type: none"> - Weathered surface - Heavy corrosion on surfaces (mother of pearl) - Very flat surface and uniform
24	105	Very pale blue	1.6	<ul style="list-style-type: none"> - Weathered surface - Flat surface

The visual examination revealed three major groupings of material. These are mainly characterised by their colour (Fig 1). The first group comprises pale green (fragments 1 to 15) glass while the second group is of a darker green (16 to 18). The third group comprises of pale greenish blue, pale blue and very pale blue fragments (19 to 22 and 24). These also tend to be flatter and more uniform in thickness than the first two groups. A single outlier is a fragment of clear glass (23) which has heavy surface corrosion, very thin and almost perfectly flat. It is unlikely that any of the Cullompton glass was deliberately coloured. The raw materials employed would have naturally contained sufficient iron to give the glass the range of observed colours.



Fig 1: Cullompton glass fragments grouped by colour.

METHODS

All of the fragments of glass were sampled by breaking a small piece which was then 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. Most of the Cullompton samples exhibited 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 and strontium) due to improved peak to background ratios.

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 (Appendix 1) 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 of reference materials (NIST, DGG and Newton/Pilkington see Appendix 2). A number of elements were sought but not detected: vanadium, chromium, cobalt, nickel, copper, zinc, arsenic, 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 ₂ O	0.1	0.1	V ₂ O ₅	0.02	0.03
MgO	0.1	0.1	Cr ₂ O ₃	0.02	0.03
Al ₂ O ₃	0.1	0.1	MnO	0.02	0.03
SiO ₂	0.1	0.2	Fe ₂ O ₃	0.02	0.03
P ₂ O 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 ₂ O	0.1	0.1	ZnO	0.02	0.01
CaO	0.1	0.1	As ₂ O ₃	0.03	0.01
TiO ₂	0.1	0.1	SnO ₂	0.1	0.05
BaO	0.2	0.1	Sb ₂ O ₅	0.15	0.07
			Rb ₂ O	0.005	0.005
			SrO	0.005	0.005
			ZrO ₂	0.005	0.005
			PbO	0.03	0.02

RESULTS

All the glass analysed contains P₂O₅ above 0.3wt% suggesting (using Dungworth's 2009 glass classification) that none are post AD1830 in date when the Leblanc process was introduced to Britain. The chemical compositions of the samples reveal three distinct groupings of glass. The first grouping is comprised of all the darker green glasses and two

of the pale green glasses (samples 8, 15, 16, 17 and 18). These are all HLLA glasses and share a similar composition, with low levels of SrO (below 0.2wt%) and low MgO (below 5wt%). The colourless glass sample (23) falls in this group too as it shares the most similar compositions.

The second group comprises all the pale blue-green and blue fragments (19, 20, 21, 22 and 24). They are very distinct in composition from the second group with lower Fe₂O₃ content which explains their paler (less coloured) nature. They have high MgO (>6.0wt%), low TiO₂ (<0.14wt%), high Na₂O (>7.5wt%) and low Al₂O₃ (<3.1wt%) concentrations (Figs 2 to 5). However, the most useful element is the content of SrO which is sufficiently high (>0.53wt%) to suggest that they were made using seaweed ash (kelp glass) putting them in a date range of AD 1700 to 1830.

The third group is more complex. It comprises all of the pale green glass fragments (apart from samples 8 and 15). They have lower K₂O and P₂O₅ than the other groupings. Their SrO, MgO, Fe₂O₃ and Al₂O₃ levels fall in between the second and third groups (Figs 2 to 5). Strontium (SrO) in particular is higher than 0.2wt% which according to Dungworth (2009) is the barrier between kelp glass and forest or HLLA glass. This would put these fragments into the kelp category. As they were found in an early 18th-century pit around the HLLA – kelp time boundary (circa AD 1700) it is possible that they represent the use of a mixture of seaweed and wood/plant ash. However, on closer inspection it is clear that although the compositions fall in between the second and third groupings they share more characteristics with (compositions closer to) the second group (the HLLA glass). They also have similar contents of CaO, Na₂O and TiO₂. The similarly high levels of CaO in particular would suggest that it is unlikely that they were mixing kelp and wood/plant ash and that they are in fact HLLA glass.

It has been noted that some of the glass fragments (especially group 3 but also group 2) analysed in this study are on the extremities of 'normal' compositions associated with the different technological processes discussed by Dungworth (2009). Glasses in the second group, for example, seem to have higher SrO than usual for kelp glass while they have more MgO than any other glass analysed in Dungworth's studies. These small anomalies suggest that some of the glasses in the assemblage were perhaps not manufactured in Britain. Dungworth and Paynter (2010) have shown that some glass could be and was imported from mainland Europe. This possibility cannot be ruled out here.

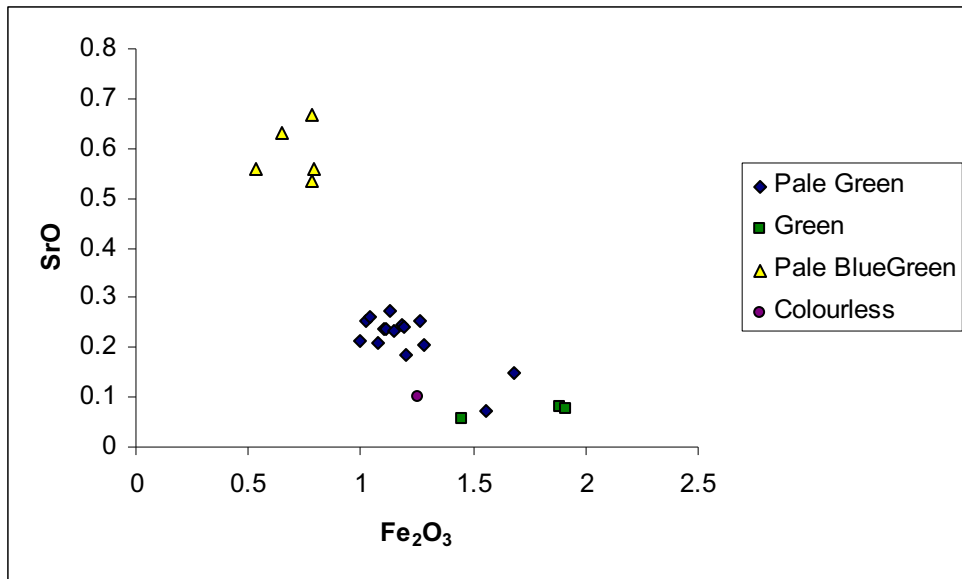


Fig 2: Plot of strontium and iron oxide content of the Cullompton glass. Note the higher concentrations of SrO and lower Fe₂O₃ in the pale blue-green glass and the opposite for the green glass.

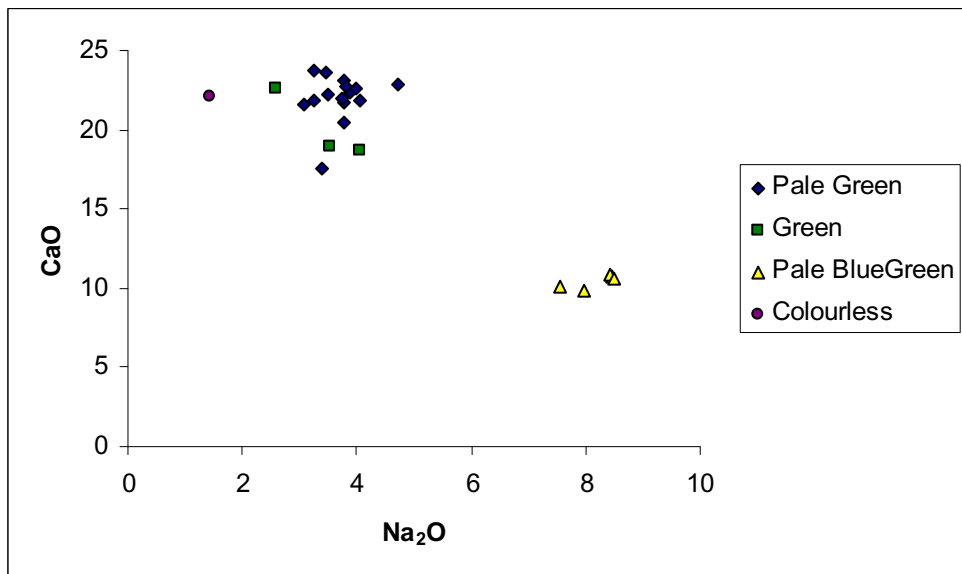


Fig 3: Plot of lime and soda content of the Cullompton glass. Note the low concentration of CaO and high Na₂O of the pale blue-green glass compared to the other coloured glass.

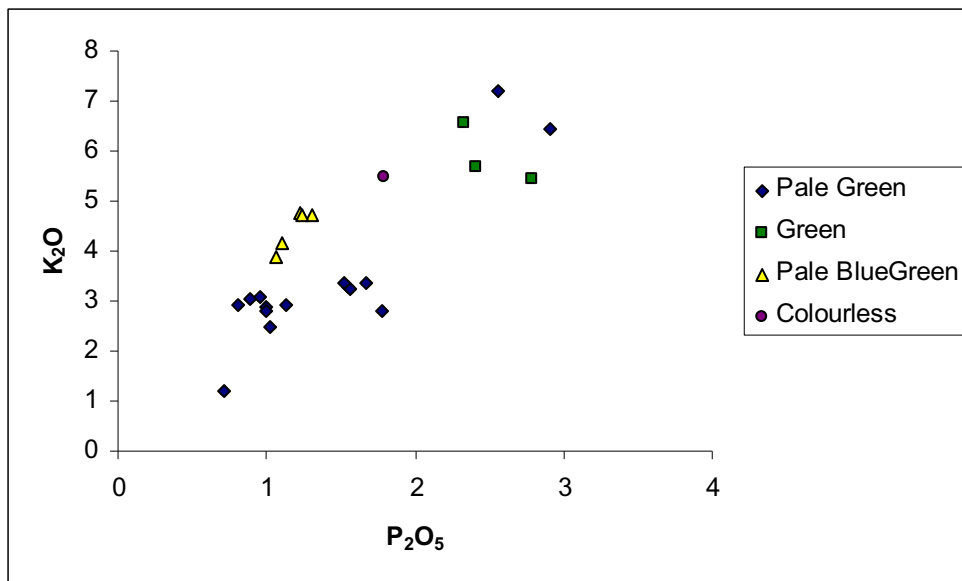


Fig 4: Plot of potash and phosphorous oxide of the Cullompton glass. Note the higher concentrations of both K₂O and P₂O₅ in the dark green glass.

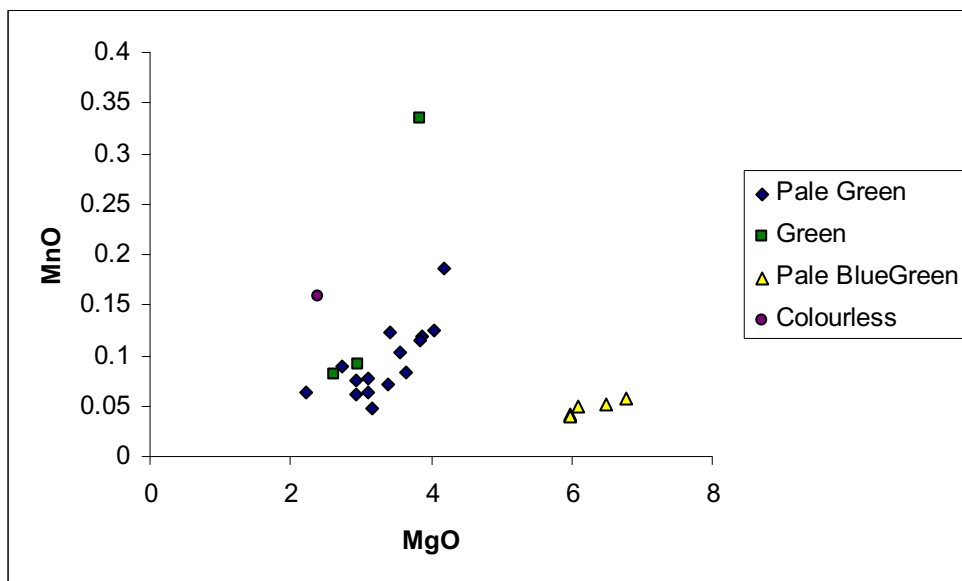


Fig 5: Plot of magnesia and manganese oxide of the Cullompton glass. Note the higher MgO content of the pale blue-green glass.

CONCLUSION

The visual examination of the Collumpton glass identified four colours of glass which correspond to three distinct groupings based on the chemical composition. One exception is the colourless glass. The clarity of this glass would suggest a much later date, however, the fact that it was very corroded may have had an effect on the surface colouration. The chemical analysis confirmed that six of the fragments (mainly the darker greens) were HLLA glass dating between AD 1570 and 1700. Five fragments (pale blue-green in colour) were shown to be later kelp glass produced between AD 1700 and 1830. The other thirteen fragments proved to be more of an anomaly with compositions in some respects between the HLLA and kelp glass. The glass was found in an early to mid 18th century pit which would place them around the HLLA – kelp time boundary (circa AD 1700) perhaps suggesting that these fragments represented the use of a mixture of seaweed and plant ash.

The use of kelp in the production of glass began in the late 17th century and it is possible that it was mixed with the older recipes as part of a gradual transition. Another possibility is that older glass (HLLA) was recycled when the use of kelp became the norm leaving the distinct traces of the older glass with higher levels of SrO due to the inclusion of kelp. On the other hand, the high concentration of CaO (comparable to HLLA glass) suggests that the mixing of kelp and wood/plant ash was unlikely. The glass may therefore not have been mixed with kelp ash and just represents HLLA glass with higher SrO levels in which case Dungworth's classification would have to be adjusted. The levels of SrO which indicate the boundary between Forest/HLLA and kelp glass may have to be increased from 0.2wt% to 0.3wt%. Supporting this is the knowledge that chemical compositions vary in plants and trees growing on different soils and substrata (Stern and Gerber 2004). This glass is an HLLA glass but may have been manufactured or used resources of a different region to the ones already analysed by Dungworth. It is possible that none of the glass analysed in this study was manufactured in Britain which would explain the compositional differences/anomalies. All the glass analysed fitted with the early to mid 18th-century date of the pit they were found in but the lack of context limits further interpretation.

REFERENCES

Cable, M 2004 'The development of flat glass manufacturing processes'. *Transactions of the Newcomen Society* 74, 19–43

Clark, K 2001 *Informed Conservation. Understanding historic buildings and their landscapes for conservation*. London: English Heritage

Cooper, W 1835 *The Crown Glass Cutter and Glazier's Manual*. Edinburgh: Oliver and Boyd

Dungworth, D 2009 *Chatsworth House Greenhouse, Chatsworth, Derbyshire. An investigation of the flat glass*. Research Department Report 90/2009. Portsmouth: English Heritage

Dungworth, D and Clark, C 2004 *SEM-EDS Analysis of Wealden Glass*. Centre for Archaeology Report 54/2004. Portsmouth: English Heritage

Dungworth, D, Degryse, P and Schneider, J 2009 'Kelp in historic glass: the application of strontium isotope analysis', in P Degryse, J Henderson and G Hodgins (eds) *Isotopes in Vitreous Materials*. Leuven: Leuven University Press, 113–130

Dungworth, D and Paynter, S 2010 *Blunden's Wood Glasshouse, Hambledon, Surrey. Scientific examination of the glassworking materials*. Research Department Report 38/2010. Portsmouth: English Heritage

McGrath, R and Frost, A C 1937 *Architectural Glass*. London: Architectural Press

Muspratt, S 1860 *Chemistry. Theoretical, Practical and Analytical*. Glasgow: Mackenzie

Parkes, S 1823 *Chemical Essays*. Two volumes. Second edition. London: Baldwin, Craddock and Joy

Smrcek, A 2005 'Evolution of the compositions of commercial glasses 1830 to 1990. Part I. Flat glass'. *Glass Science Technology* 78, 173–184

Stern, W B and Gerber, Y 2004 'Potassium-calcium glass: new data and experiments'. *Archaeometry* 46, 137–156

Ure, A 1844 *A Dictionary of Arts, Manufactures and Mines*. Third Edition. New York: Appleton

Watson, R 1782 *Chemical Essays*. London: Dodsley and Cadell

APPENDIX I: CHEMICAL COMPOSITIONS OF THE GLASS

All data retrieved by SEM apart from MnO, SrO and PbO which were from XRF.

Sample	Na ₂ O	MgO	Al ₂ O ₃	SiO ₂	P ₂ O ₅	SO ₃	Cl	K ₂ O	CaO	TiO ₂	MnO	Fe ₂ O ₃	SrO	PbO
1	3.50	3.09	4.01	60.96	0.81	0.57	0.34	2.94	22.20	0.20	0.077	1.02	0.253	<0.05
2	3.45	2.94	3.75	60.10	1.03	0.50	0.35	2.47	23.67	0.23	0.062	1.00	0.213	<0.05
3	3.79	3.17	4.12	59.27	1.00	0.57	0.35	2.89	23.12	0.21	0.048	1.10	0.238	<0.05
4	3.87	4.18	4.33	57.41	1.78	0.49	0.53	2.80	22.37	0.29	0.186	1.26	0.253	<0.05
5	4.05	3.40	4.16	59.74	0.96	0.49	0.36	3.07	21.84	0.24	0.071	1.28	0.204	<0.05
6	3.80	2.23	4.46	61.94	0.71	0.34	0.83	1.19	22.69	0.21	0.063	1.20	0.184	<0.05
7	3.79	3.87	4.25	58.44	1.55	0.70	0.36	3.28	21.78	0.28	0.118	1.18	0.247	<0.05
8	3.40	3.63	4.05	58.39	2.56	0.29	0.52	7.22	17.55	0.32	0.083	1.68	0.150	<0.05
9	4.72	4.04	3.90	56.26	1.67	0.63	0.49	3.38	22.90	0.25	0.124	1.13	0.272	<0.05
10	3.78	3.11	3.97	62.40	1.00	0.33	0.35	2.79	20.50	0.24	0.063	1.11	0.239	<0.05
11	3.97	3.57	4.08	59.04	1.13	0.62	0.41	2.91	22.54	0.26	0.103	1.04	0.262	<0.05
12	3.24	2.93	4.52	60.91	0.89	0.48	0.28	3.05	21.82	0.20	0.075	1.15	0.234	<0.05
13	3.26	3.41	3.86	58.04	1.56	0.62	0.42	3.25	23.80	0.28	0.123	1.08	0.208	<0.05
14	3.75	3.85	4.29	58.18	1.52	0.66	0.39	3.35	21.93	0.31	0.114	1.19	0.243	<0.05
15	3.08	2.72	4.06	56.23	2.91	0.18	0.69	6.44	21.62	0.23	0.090	1.56	0.073	<0.05
16	3.52	3.85	5.16	56.76	2.79	BDL	0.97	5.44	18.93	0.27	0.334	1.45	0.057	0.165
17	4.04	2.97	5.06	57.44	2.41	0.10	0.97	5.70	18.68	0.26	0.092	1.89	0.082	<0.05
18	2.57	2.63	4.81	55.19	2.33	<0.10	0.64	6.58	22.62	0.30	0.082	1.91	0.078	<0.05
19	8.46	5.97	3.04	63.49	1.22	0.38	0.42	4.77	10.75	0.11	0.042	0.79	0.559	<0.05
20	8.41	6.09	2.92	63.17	1.30	0.40	0.46	4.74	10.91	0.14	0.049	0.78	0.667	<0.05
21	8.49	5.97	3.06	63.62	1.24	0.36	0.43	4.72	10.62	0.12	0.040	0.78	0.535	<0.05
22	7.54	6.78	2.18	65.95	1.11	0.37	0.33	4.15	10.13	0.12	0.058	0.65	0.633	<0.05
23	1.45	2.40	2.10	61.99	1.79	0.55	0.31	5.47	22.11	0.20	0.159	1.25	0.102	<0.05
24	7.97	6.50	1.92	66.90	1.06	0.41	0.45	3.89	9.80	0.12	0.051	0.53	0.559	<0.05

APPENDIX 2: STANDARD DATA

All data below was retrieved by scanning electron microscope.

Standard Pilkington CL324

Spectrum	Na ₂ O	MgO	Al ₂ O ₃	SiO ₂	K ₂ O	CaO	TiO ₂	CuO
1	0.00	0.03	3.93	48.20	15.19	29.90	0.60	1.91
2	0.00	0.02	3.98	48.25	15.10	30.02	0.54	1.84
3	0.00	0.02	3.96	48.27	15.07	29.99	0.47	1.85
4	0.00	0.07	3.95	48.10	15.05	30.08	0.55	1.91
5	0.00	0.02	4.00	47.96	15.16	30.00	0.55	1.89
Mean	0.00	0.03	3.96	48.15	15.12	30.00	0.54	1.88
Std.dev	0.00	0.02	0.02	0.13	0.06	0.07	0.05	0.03
Reported	0.10	0.05	3.80	48.70	14.60	30.10	0.50	1.80

Standard Pilkington CL325

Spectrum	Al ₂ O ₃	SiO ₂	K ₂ O	CaO	TiO ₂	MnO	Fe ₂ O ₃	CuO	PbO
1	4.04	43.38	14.92	34.94	0.50	0.99	0.11	0.40	0.43
2	4.05	43.39	14.97	34.81	0.53	0.96	0.10	0.54	0.48
3	3.95	43.41	14.94	35.02	0.39	1.03	0.18	0.51	0.54
4	4.02	43.44	14.94	34.90	0.50	1.01	0.05	0.44	0.45
5	4.18	43.47	14.84	34.99	0.52	0.99	0.09	0.50	0.44
Mean	4.05	43.42	14.92	34.93	0.49	1.00	0.11	0.47	0.47
Std. dev	0.08	0.03	0.05	0.08	0.06	0.02	0.05	0.06	0.04
Reported	3.90	44.00	14.50	34.90	0.50	1.00	0.11	0.50	0.50

Standard Pilkington CL326

Spectrum	MgO	Al ₂ O ₃	SiO ₂	K ₂ O	CaO	TiO ₂	Fe ₂ O ₃
1	0.09	3.70	43.35	29.79	20.43	0.11	2.02
2	0.13	3.70	43.19	29.91	20.34	0.13	2.02
3	0.00	3.77	43.29	30.02	20.29	0.11	1.93
4	0.04	3.79	43.45	29.88	20.29	0.16	2.04
5	0.07	3.75	43.45	29.87	20.32	0.06	2.08
Mean	0.07	3.74	43.35	29.89	20.33	0.11	2.02
Std. dev	0.05	0.04	0.11	0.08	0.06	0.03	0.05
Reported	0.04	3.90	43.60	29.50	20.60	0.10	2.10

Standard Pilkington CL327

Spectrum	Al ₂ O ₃	SiO ₂	K ₂ O	CaO	MnO	Fe ₂ O ₃	PbO
1	4.09	52.87	15.17	25.98	0.17	0.35	1.00
2	4.01	52.82	15.23	25.83	0.25	0.38	1.03
3	4.03	52.90	15.21	25.93	0.18	0.33	1.04
4	4.08	52.83	15.31	25.91	0.16	0.34	1.13
5	3.99	52.59	15.36	26.04	0.19	0.31	1.00
Mean	4.04	52.80	15.26	25.94	0.19	0.34	1.04
Std. dev	0.04	0.12	0.08	0.08	0.04	0.02	0.05
Reported	3.90	53.80	14.60	25.90	0.20	0.40	0.90

Standard Pilkington CL328

Spectrum	Na ₂ O	MgO	Al ₂ O ₃	SiO ₂	P ₂ O ₅	K ₂ O	CaO	TiO ₂	MnO	Fe ₂ O ₃	PbO
1	4.95	3.08	3.79	54.92	4.18	7.52	19.16	0.27	0.50	0.27	0.94
2	4.84	3.02	3.75	55.20	4.10	7.61	19.22	0.22	0.49	0.25	0.86
3	4.93	3.07	3.84	54.97	4.17	7.62	19.16	0.22	0.53	0.27	0.93
4	4.89	3.02	3.72	55.17	4.13	7.57	19.11	0.18	0.47	0.28	0.84
5	4.99	2.99	3.88	54.99	4.24	7.56	19.18	0.16	0.43	0.24	0.68
Mean	4.92	3.04	3.80	55.05	4.16	7.58	19.17	0.21	0.48	0.26	0.85
Std. dev	0.06	0.04	0.07	0.13	0.05	0.04	0.04	0.04	0.04	0.02	0.10
Reported	5.00	3.20	3.90	56.00	3.90	7.20	19.00	0.20	0.50	0.31	0.70

Standard Pilkington CL329

Spectrum	Al ₂ O ₃	SiO ₂	K ₂ O	CaO	TiO ₂	MnO	CoO	CuO
1	4.01	56.46	14.93	21.15	0.22	1.85	0.26	1.02
2	3.99	56.51	14.97	21.20	0.26	1.86	0.20	0.86
3	3.96	56.31	14.93	21.16	0.34	1.86	0.25	1.01
4	3.95	56.38	14.99	21.03	0.33	1.92	0.23	0.93
5	4.09	56.43	14.91	21.03	0.24	1.89	0.23	0.97
Mean	4.00	56.42	14.94	21.11	0.28	1.88	0.23	0.96
Std. dev	0.05	0.08	0.03	0.08	0.05	0.03	0.02	0.07
Reported	4.20	56.80	14.30	21.50	0.22	1.80	0.24	0.90

Standard Pilkington CL330

Spectrum	Na ₂ O	MgO	Al ₂ O ₃	SiO ₂	K ₂ O	CaO	Fe ₂ O ₃
1	9.65	6.53	4.45	54.79	1.64	22.43	0.27
2	9.62	6.49	4.31	54.80	1.62	22.45	0.25
3	9.46	6.51	4.43	55.21	1.58	22.50	0.25
4	9.58	6.42	4.38	55.06	1.53	22.37	0.26
5	9.75	6.51	4.45	54.83	1.56	22.29	0.25
Mean	9.61	6.49	4.40	54.94	1.59	22.41	0.26
Std. dev	0.10	0.04	0.06	0.19	0.04	0.08	0.01
Reported	9.50	6.60	4.30	55.40	1.50	21.90	0.30

Standard Pilkington CL331

Spectrum	Al ₂ O ₃	SiO ₂	K ₂ O	CaO	MnO	ZnO
1	3.88	40.41	25.45	29.19	0.14	0.43
2	3.83	40.49	25.41	29.17	0.09	0.51
3	3.80	40.37	25.52	29.11	0.13	0.59
4	3.86	40.50	25.67	29.06	0.10	0.53
5	3.85	40.45	25.51	29.10	0.09	0.53
Mean	3.84	40.44	25.51	29.13	0.11	0.52
Std. dev	0.03	0.05	0.10	0.05	0.02	0.06
Reported	3.80	40.70	24.90	29.40	0.10	0.50

Standard Pilkington CL332

Spectrum	Al ₂ O ₃	SiO ₂	K ₂ O	CaO	ZnO
1	3.82	42.07	24.87	28.26	0.48
2	3.84	42.07	24.70	28.24	0.54
3	3.84	42.01	24.71	28.07	0.54
4	3.80	42.19	24.72	28.04	0.60
5	3.82	41.92	24.89	28.07	0.52
Mean	3.82	42.05	24.78	28.14	0.54
Std. dev	0.02	0.10	0.09	0.10	0.04
Reported	3.80	42.60	24.20	28.40	0.50

Standard Pilkington CL333

Spectrum	Na ₂ O	Al ₂ O ₃	SiO ₂	CaO	Fe ₂ O ₃
1	21.06	4.34	48.74	23.24	2.32
2	21.11	4.27	48.69	23.20	2.33
3	21.01	4.32	48.68	23.25	2.28
4	21.15	4.18	48.57	23.25	2.35
5	21.18	4.19	48.34	23.30	2.35
Mean	21.10	4.26	48.61	23.25	2.33
Std. dev	0.07	0.07	0.16	0.04	0.03
Reported	21.70	4.10	48.70	22.60	2.50

Standard NIST 620

Spectrum	Na ₂ O	MgO	Al ₂ O ₃	SiO ₂	SO ₃	K ₂ O	CaO
1	14.31	3.60	1.88	71.93	0.31	0.41	7.38
2	14.09	3.68	1.86	72.01	0.35	0.42	7.46
3	14.04	3.58	1.92	72.10	0.30	0.43	7.51
4	14.11	3.70	1.90	71.95	0.31	0.40	7.45
5	14.06	3.63	1.92	72.17	0.19	0.43	7.49
Mean	14.12	3.64	1.89	72.03	0.29	0.42	7.46
Std. dev	0.11	0.05	0.02	0.10	0.06	0.01	0.05
Reported	14.39	3.69	1.80	72.08	0.28	0.41	7.11

Standard NIST 1834

Spectrum	Na ₂ O	MgO	Al ₂ O ₃	SiO ₂	P ₂ O ₅	K ₂ O	CaO	TiO ₂	Fe ₂ O ₃
1	0.22	0.16	39.30	42.71	0.37	0.53	0.13	1.98	0.44
2	0.19	0.16	38.99	43.07	0.43	0.54	0.13	2.03	0.41
3	0.19	0.18	39.25	42.72	0.42	0.56	0.16	2.03	0.40
4	0.18	0.16	39.09	43.04	0.48	0.54	0.12	1.96	0.37
5	0.19	0.18	39.21	42.81	0.36	0.57	0.14	1.96	0.42
Mean	0.19	0.17	39.17	42.87	0.41	0.55	0.14	2.00	0.41
Std. dev	0.01	0.01	0.13	0.17	0.05	0.02	0.02	0.04	0.03
Reported	0.26	0.15	39.13	43.19	0.35	0.51	0.13	1.85	0.46



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

