RESEARCH DEPARTMENT REPORT SERIES no. 25-2009 ISSN 1749-8775

HIGHTOWN, CASTLEFORD, YORKSHIRE
AN ASSESSMENT OF GLASS WASTE

TECHNOLOGY REPORT

Carlotta Gardner

ARCHAEOLOGICAL SCIENCE

ENGLISH HERITAGE

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Research Department Report Series 25-2009

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NGR: SE 4198 2527

ISSN 1749-8775

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SUMMARY

The excavations in 2007 of the Hightown bottle-works, Castleford, produced substantial quantities of material. This report is an assessment of the glass-working waste recovered from the site. Chemical analysis of the glass waste identified two main phases of glass production. The glass produced in phase I (c1855 - 1872) is a high-lime low-alkali (HLLA) glass that is likely to have been made from cheap and basic ingredients, evident from the high iron and trace element content. The composition of this glass fits well with the description of ingredients used for bottle glass in the 19th century. Phase II glass (20th century) is soda lime silica glass that has a much purer composition suggesting that ingredients of better quality were used.

ARCHIVE LOCATION

Wakefield Museum, Wakefield, West Yorkshire

DATE OF RESEARCH

January 2009 - March 2009

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INTRODUCTION

The excavations in 2007 of the Hightown glass-works produced substantial quantities of material including complete and broken glass bottles, glass waste and bricks. Due to the size of the assemblage and variety of material recovered, a series of reports will examine different types of material. This report will focus on the analysis of the glass waste and what it can tell us about the development of the site and the development of the bottle glass industry in the 19th and 20th centuries. Future reports will examine the glass bottles and ceramic materials recovered. The glass bottles include numerous examples which bear marks and/or letters indicating the maker (eg J Lumb and UGB) or customer (eg Johnny Walker). The ceramic materials recovered include some materials associated with glass manufacture (ie fragments of furnaces) as well as bricks manufactured on site during the last quarter of the 19th century.

The Hightown Glass-works

The 19th century saw a number of glass-works built in Castleford; the earliest was founded in 1829 at Whitwood Mere. The first of these glass-works was built close to the river but in 1839 a railway line was built through the town, this resulted in the majority of glass-works being built close to it. The site of the Hightown glass-works, Castleford (SE 4198 2527) is shown on an 1852 Ordnance Survey map as open fields but the land was sold by auction in the same year and a glass-works established shortly after. In the following 20 years or so the ownership of the glass-works changed hands several times. By1874 the glass-works had been demolished and the site was used to quarry clay for brick making; by 1878 a Hoffman kiln had been built to fire the bricks (Figure 1a). In 1902 (Figure 1b) John Lumb and Co. bought the site and built a large gas-fired regenerative glass furnace and later the glass-works saw some of the first semi-automatic machines introduced for bottle making (Thorp and Thorp nd, 15). In 1937 United Glass (UGB) bought the glass-works and many others in the area and continued to make bottle glass at Hightown until 1985.

The site of the glass-works at Hightown was subjected to archaeological recording by Malton Archaeological Projects (directed by Anne Finney) in 2007 ahead of redevelopment and the construction of new housing. The excavation identified numerous structures as well as deposits containing glass and glass-working debris. This report on a selection of glass-working materials will contribute to the post-excavation report for this site. The initial assessment of the stratigraphy identified contexts containing glass-working materials which could be dated to, on the one hand, before the construction of the Hoffman kiln (ie c1855–1874) and, on the other, after glass working had resumed (ie 1902 onwards). The earlier phase is here referred to as Phase I and the later as Phase II.

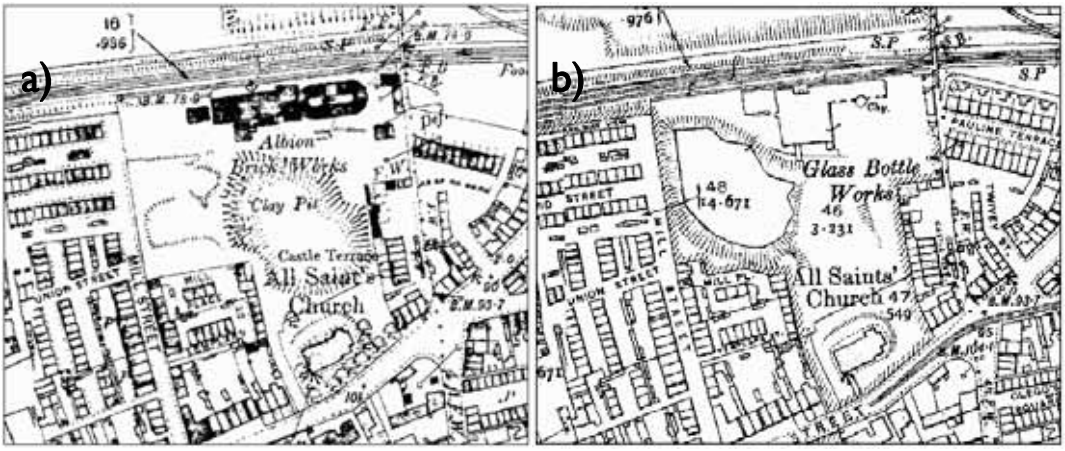

Figure 1: 1a) dates to 1893 (original scale 1:1500) shows the clay quarry and the brick-works 1b) dates to 1908 (original scale 1:1500) and shows the location of the glass house owned, at this time by John Lumb and Co.

Technological Background

The first glass house was built at Hightown just after the repeal in 1845 of the last of the Glass Excise Acts. These acts, the first of which had been passed in 1745, set out rates of taxation to be made on the production of different types of glass and strict regulations regarding the sorts of materials which could be used (Pellatt 1844, 52, 67–68; Ure 1844, 583).

'The English laws, till lately, prohibited the use of fine materials for making ordinary bottles. Nothing but common river sand and soap boilers' waste was allowed.' (Muspratt 1860, 208)

A number of texts from the 19th century list and describe raw materials used to make the glass for bottles. Both Muspratt (1860, 208) and Powell and Harris (1883, 80) state that the main objective was to source materials that were cheap but still produced strong bottles; the appearance and colour was not important and thus not considered (the glass was usually heavily tinted green due to the presence of iron in the cheap sands used).

'The materials for common glass bottles are coarser and cheaper than for any other kinds of glass; and in consequence of this very coarseness or want of refining, the elements which enter the composition are more numerous . . .'
(Muspratt 1860, 208)

A number of materials were recycled from other industries and used to make the glass, for example; the residual alkaline and calcium-rich salts from gas-works, soap-works and alkali-works, the slag from iron blast furnaces, and ash from domestic fires (Powell and Harris 1883, 83). Most glass bottles produced in the 18th and 19th centuries contain relatively low proportions of silica and alkalis and are rich in lime (Cable and Smedley 1987; Dungworth 2005). When the last Glass Excise Act was repealed in 1845 glass-works *could* use purer materials, however, it is clear that many manufacturers continued to use the cheapest materials until the end of the 19th century (Turner 1926). The Hightown material provides the first opportunity to investigate 19th-century colourless (or pale green) bottle glass of the post-Excise period but prior to the introduction of mechanisation.

Significant changes took place in the technologies used to form bottles at the end of the 19th century which had an impact on the sorts of materials used in the industry (Cable 2001; Turner 1926). Manufacture of robust dark-coloured bottles had begun in the 17th century and initially the bottles were free blown without the aid of any mechanical devices (Fletcher 1976, 12). By the 18th century simple moulds were used for the manufacture of cylindrical bottles (Wills 1974, 48). More efficient moulding (using a mould with three parts) was patented by Henry Ricketts in 1822. The desire to increase profits through increasing the rate at which bottles could be produced led to the development of machines which used moulds and compressed air to form bottles and other containers (Cable 2001-02). The first decade of the 20th century saw the widespread adoption of the bottle forming machines developed by Owens and others (Cable 2001-02). It is likely that when John Lumb built the glassworks at Hightown in 1902 it was with such machines in mind, certainly in 1907 Hightown had 23 semi-automatic machines in use (Thorp and Thorp nd, 15). Turner's review shows that the change from hand to machine forming had an impact on glass composition (Turner 1926). The glass of the late 19th century which was hand blown generally had a high lime content which meant that the glass set rapidly, while the automatic machines required a comparatively slow-setting glass. The composition of the glass employed in early bottle forming machines was thus a soda lime silica glass with distinctly less lime than the glass employed previously.

METHOD

A sub-sample (10%) of the material removed from the site was visually examined (eg size, shape and colour). A total of 46 samples of glass-working waste were chosen to be analysed further using scientific techniques, discussed below. Each sample was assigned its own catalogue number and photographed to assist with the tracking of the sample through the analytical stage.

Small sections of the samples were removed and set in epoxy resin, ground flat and polished using diamond paste down to a 3µm grade. The material was quantitatively analysed using two different techniques. The first was energy dispersive X-ray fluorescence (EDXRF) and the second scanning electron microscopy with energy dispersive spectrometry (SEM-EDS). EDXRF (using an EDAX Eagle II) analysis provided the compositional data for the trace elements, such as strontium, lead and arsenic, and the SEM-EDS (FEI Inspect F with Oxford Instruments X-act SDD detector) for the major elements, such as silicon, sodium and calcium. Samples were analysed at 40kV, 1000µA for 500 live seconds with EDXRF and at 25kV, spot size 5, 1000x magnification and for 100 live seconds with SEM-EDS. Both machines were calibrated prior to use and the relevant standards were also analysed (the analytical error was equal to or less than 0.10wt %, except for sodium (0.19wt %) and silica (0.39wt %)). As the samples are homogenous and have no evident microstructures it was only necessary to analyse one area for each of the techniques. Many samples had corroded surfaces and the areas analysed were carefully selected to avoid such zones.

The compositional data from both techniques were placed into an Excel spreadsheet where it was studied for trends using a number of bi-plots. The phasing and contextual information was also combined with the analytical data for the interpretation of the results.

RESULTS

Visual examination

During visual examination it became apparent that it was possible to group the glass and glass waste into four groups based on their colour; very pale green (very pale green in reflected light and very pale blue-green in transmitted light), colourless, emerald green and finally a very dark green. The glass waste had been found in a number of different shapes and sizes, the majority were pieces that appear to be drips of glass and some are lumps of glass that are too large to be an object; examples are shown in Figure 2.

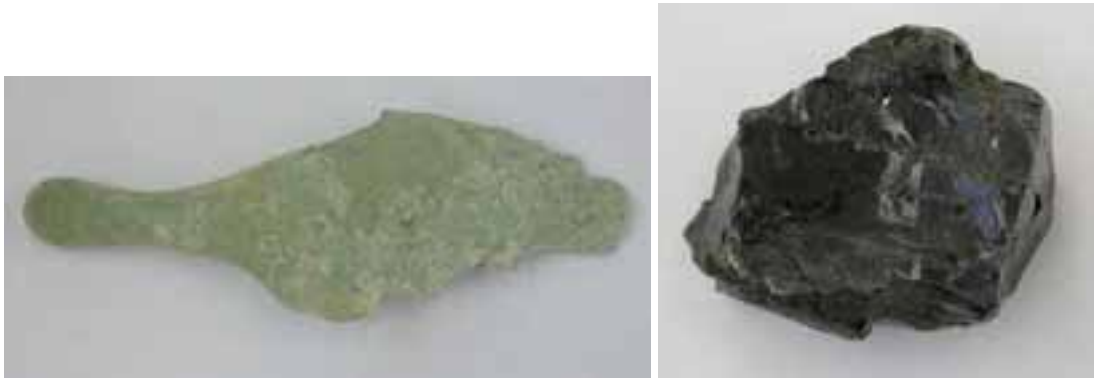

Figure 2: Examples of glass waste found at Hightown (left: (cat.124)a drip (90mm in length) of very pale green high-lime low-alkali glass, and right: (cat.175) a large lump (50mm in length) of dark green HLLA glass).

Compositional analysis

The compositional analysis of the glass waste (using quantitative EDXRF and SEM-EDS) has shown that there are two main compositional groups (Figure 3); a high-lime low-alkali glass (HLLA) with numerous impurities and a soda lime silica glass (SLS) with very few impurities. The SLS glasses have much higher quantities of silica (Figure 4), and many of the impurities (eg titanium and barium), that are present in the HLLA glasses, are absent from the SLS glass (Appendix Tables 3, 4, 5 and 6). The majority of the HLLA glass is found in contexts dating to phase I (c1850–1872) and the SLS glass only in unphased or phase II contexts (1902 onwards) (Table 1).

Table 1: The phasing of the different types of glass analysed in this report.

Type	Colour	Context	Samples	Phasing
HLLA	Dark green	3062	132, 133	I: Mid 19th century
HLLA	Dark green	5146	175	I: Late 19th century
HLLA	Dark green	3085	38, 40, 42, 43	Unphased
HLLA	Very pale green	5525	154, 155, 156	I: Pre Hoffman (<1874)
HLLA	Very pale green	5607	158	I: Pre Hoffman (<1874)
HLLA	Very pale green	5601	147, 148, 149, 150	I: c.1850-c.1880
HLLA	Very pale green	3062	140	I: Mid 19th century
HLLA	Very pale green	5146	173, 174, 175	I: Late 19th century
HLLA	Very pale green	5166	107	II: Late 19th century/early 20th century
HLLA	Very pale green	2035	124, 125	Unphased
SLS	Green	3013	27, 28, 29, 30, 31, 32	Unphased
SLS	Colourless	5166	73, 74, 75, 76, 77, 81, 110, 111	II: Late 19th century/early 20th century
SLS	Colourless	5168	119, 119a, 119b	II: Pre 1960s, post WWII
SLS	Colourless	3013	33, 34	Unphased

Within each of the major groups there are two different colours of glass: in phase I the very pale green glass and the dark green glass, and in phase II the emerald green glass and

the colourless glass. All four glasses types differ in composition and this is strongly linked to their colours. In most cases, the greener the glass the higher the iron content, for example the phase I dark green glasses have an average iron content of 3.2wt % and the phase II colourless glasses have an average iron content of 0.06wt % (Figure 4).

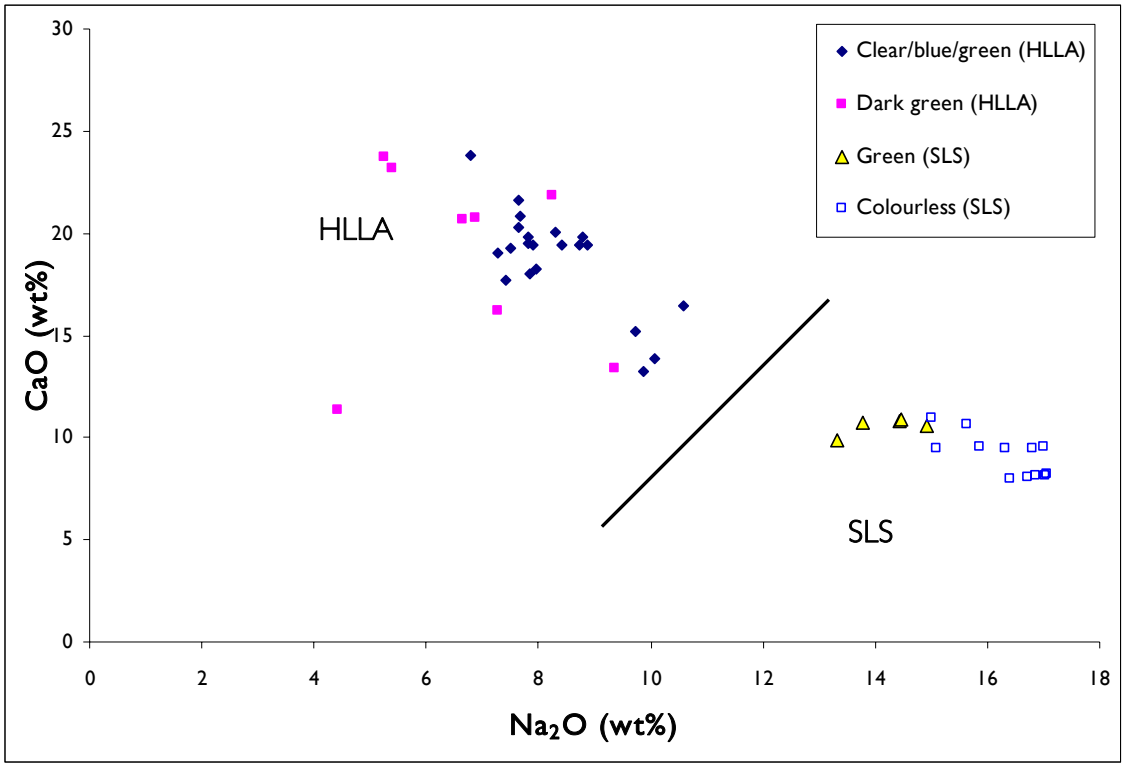

Figure 3: Soda (Na_2O) versus lime (CaO) contents in the glass waste from the Hightown glass-works, Castleford.

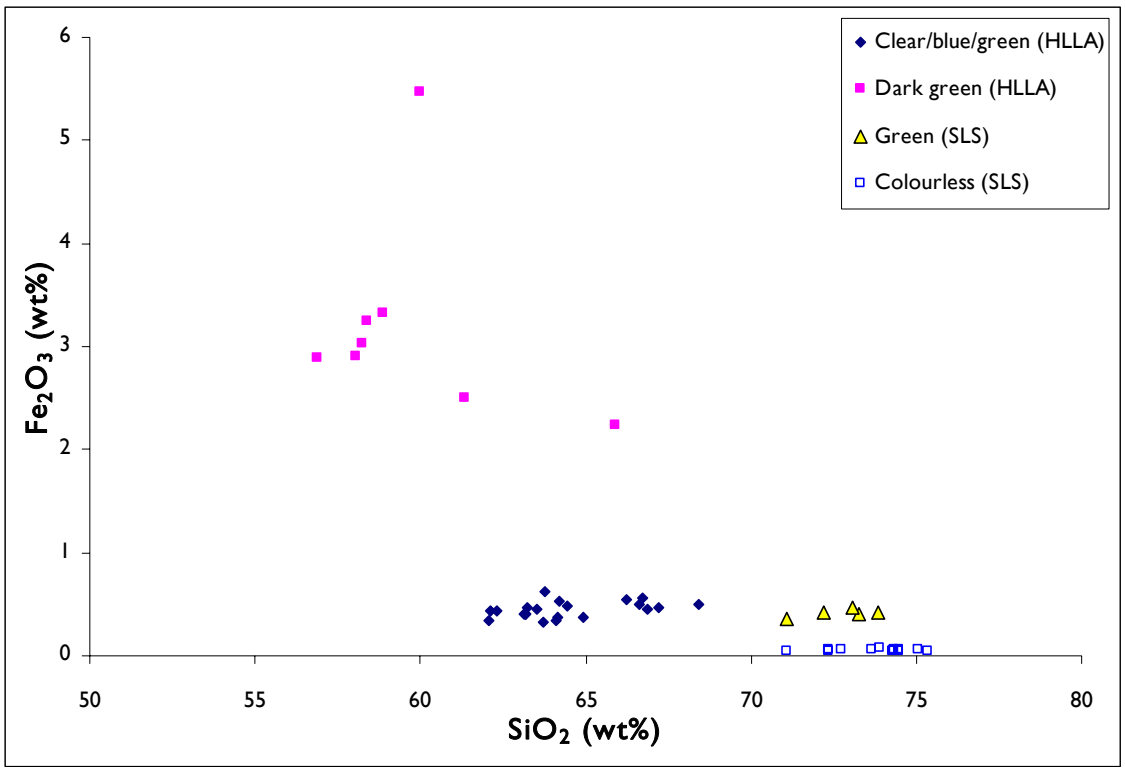

Figure 4: Silica (SiO_2) versus iron (FeO) contents in the glass waste from the Hightown glass-works, Castleford.

DISCUSSION

The glasses, as discussed above, fall into two main compositional groups HLLA and SLS. The stratigraphic evidence suggests that HLLA glass was produced in phase I and the SLS glass in phase II (Table 1).

Phase I

Both of the glass types made in the earliest phase are essentially high-lime low-alkali (HLLA) glasses but they are visually distinct; one is so dark green as to be almost opaque while the other is a very pale green. The visual difference reflects the differences in the chemical composition of the glass: the dark green glass contains high levels of iron while the pale green glass contains much lower amounts (Tables 3 and 4).

The pale green HLLA glass of phase 1 has a composition (Table 3) which is in many respects very similar to the dark green HLLA glass discussed below. Nevertheless, it contains greater concentrations of silica (on average 64.5wt %) and many (although not all) of the oxides that are abundant in the dark green HLLA glass are present at lower concentrations in the pale green HLLA glass. The iron oxide content of the pale green HLLA glass is low enough that it has had only a slight effect on its colour. The low levels

of iron oxide and alumina in this glass suggest the use of higher quality raw materials compared to the dark green glass discussed below.

The pale green glass contains no detectable phosphorous oxide and only low levels of potash suggesting that terrestrial plant ashes were not used as the flux. The principal flux was probably sodium-rich but the mixed nature of this glass makes any definitive identification of the flux difficult. The very pale green HLLA glass also has rather high concentrations of magnesium. It is possible that the magnesium entered the glass through the use of magnesian limestone (Castleford lies on an outcrop of magnesian limestone).

The very pale green HLLA glass often contains minor amounts (0.2wt% on average) of arsenic oxide which is known to have been deliberately added to glass as either a fining agent or as a decolouriser. A fining agent releases lots of gas, creating large bubbles that will rise rapidly and carry the smaller bubbles to the surface leaving a bubble-free glass (Shelby 2005, 43). Arsenic oxide is a powerful oxidising agent and its ability to decolourise glass arises from the fact that it can increase the proportion of ferric iron, which gives a weak yellow colour, and decrease the amount of ferrous iron, which would give a stronger blue-green colour.

One sample of HLLA glass (sample 111) has a number of significant differences compared to the other samples pale green HLLA glass. This sample contains much less iron oxide than the other contemporary HLLA glasses and is virtually colourless. This sample is also distinguished by its low strontium content.

The dark green glass from phase I is, on average, a HLLA glass, although several samples (40, 43 and 175) contain much less lime (<15wt%) than is usual for this glass type. The dark green HLLA glasses have compositions similar to those reported in the 19th century for ordinary bottles (eg Muspratt 1860). This glass contains relatively low concentrations of silica (on average 59.7wt%) and substantial quantities of a wide range of other oxides. It is likely that this glass was made using poor quality sand which would contain appreciable concentrations of iron oxide, alumina and other impurities. Not all of the iron oxide and alumina present in the glass, however, will have come from the sand; some may have come from the addition of clay, rocks and slag to the glass batch as this was common practise at the time (Powell and Harris 1883). In one case (sample 40, Table 4) the alumina and iron oxide contents are very high suggesting the addition of substantial proportions of clay, rocks or possibly slag.

The dark green HLLA glass contains no detectable phosphorous oxide and low concentrations of potash suggesting that terrestrial plant ashes were not used as the flux. The principal flux was probably sodium-rich but the mixed nature of this glass make any definitive identification of the flux difficult.

The materials used to make the dark green bottle glass in this phase of glass-working at Hightown appear to be very similar to those that were used during the Glass Excise period; this confirms that cheap materials for bottle production were still desirable after

the last of the Excise laws had been lifted (1845). Among the samples analysed here only one context [5166] containing very pale green HLLA glass dates to the early 20th century (phase II) but it is likely that this material is residual.

The different samples of phase I dark green HLLA glass display more compositional variation than any of the other Hightown glasses. This variability may have arisen from the inherent heterogeneity of the cheap raw materials used in the manufacture of this glass. However, it is also possible that the variability reflects the changes in ownership of the site during this period.

It is not clear whether or not the dark green and pale green HLLA glasses were produced at the same or different times. It is possible that both were produced at the same time with different markets in mind, however, it is also possible that only one type of glass was produced at a time. The dating of phase I contexts is not yet (and may never be) sufficiently precise to allow this problem to be solved.

Phase II

Two types of soda lime silica (SLS) glass appear to have been made in phase II: one of them is colourless and the other is an emerald green colour. The stratigraphic evidence shows that the colourless SLS glass was produced in phase II, however, the emerald green SLS glass was only recovered from unphased contexts. The colourless and emerald green SLS glasses show many compositional similarities with each other and with the sorts of glass used in the glass container industry in the 20th century (Turner 1926).

Most of the glass from phase II contexts is a SLS glass and none of this glass was recovered from phase I contexts. The SLS glass from phase II contexts has a composition which is strikingly different to that produced in phase I. The colourless glass from this period (Appendix Table 5) has relatively high silica content (on average 73.7wt %) compared to the phase 1 glasses. The SLS glass contains very few impurities and appears to have been made from relatively pure materials. The glass contains (on average) only 0.06wt% iron oxide suggesting the use of sand with less than 0.1wt% iron oxide. Arsenic oxide is present in most samples of colourless SLS glass and probably served as both fining agent and a decolouriser by oxidising the FeO to Fe_2O_3.

The phase II colourless SLS glass has an average composition which is very close to the early 20th-century glasses reported by Turner (1926; see Table 2). Turner contrasts the rather high lime (CaO) and low soda (Na_2O) content of the glass used up to the end of the First World War with the glass in use in the middle of the 1920s. The Hightown colourless SLS glass shares the low lime and high soda content of the latter glass and was thus probably made after the end of the First World War.

Table 2: The average composition (shown in weight %) of early 20th-century bottle glass (Turner 1926) compared with phase II colourless SLS glass.

	1900–1917	c1926	Hightown
Na_2O	11.2	16.5	16.3
MgO	0.5	0.1	0.6
Al_2O_3	0.5	0.6	0.8
SiO_2	69.7	74.1	73.7
CaO	17.4	8.8	9.1
Fe_2O_3	0.25	0.07	0.06

Phase II covers over 80 years of bottle and other container production at Castleford, during which there were changes in ownership and types of vessel produced. It is to be expected therefore that there would be some variation in glass composition during this period. The phase II glasses (Table 5) can be divided into three sub-groups based on the concentrations of minor elements. The largest group (samples 73, 74, 76, 77, 81 and 110) is distinguished by its slightly greater concentrations of sulphur, while the second group (samples 75, 119, 119a and 119b) contains elevated concentrations of magnesia and the third group (samples 33 and 34) contains elevated concentrations of alumina. Each of these groups displays low levels of compositional variability (often comparable to the analytical precision). This suggests that considerable attention was paid to using consistent raw materials and to the accurate weighing of these. It is possible that the different colourless SLS glass groups have some chronological significance. The future analysis of further samples of phase II glass waste from phased contexts, in conjunction with the analysis of dated vessels, will allow the construction of a detailed chronology for changes in SLS glass technology at Hightown.

The emerald green glass is a SLS glass (Table 6) and so is likely to have been manufactured during the 20th century (phase II) though examples of it have unfortunately only been recovered from unphased contexts. The emerald green SLS glass contains just as much iron oxide as the phase I pale green glass but its strong emerald green colour is due largely to the presence of chromium oxide (on average 0.25wt%). According to Muspratt chromium 'yields the purest and most brilliant grass-green hue, but is too costly for common use' (Muspratt 1860, 240) which suggests that the Hightown chromium green glass was probably produced in the 20th rather than the 19th century. This is confirmed by Rosenhain (1919, 186) who states that chromium is a relatively cheap material. A residue, dark green in colour, was found in a context [5244] dated to the first half of the 20th century. The qualitative EDXRF analysis of this residue showed that it contained large proportions of chromium with traces of arsenic, potassium, sulphur, iron, vanadium, nickel and manganese. This is likely to be the material that was used as a colourant in this green glass. Weyl reports that arsenic was commonly added to chromium green glasses as it prevents the colour of the glass from having a yellow tint (Weyl 1976). It is not clear if the chromium-rich material from context [5244] is a naturally occurring material or a deliberate amalgam like a smalt.

CONCLUSION

The glass waste examined for this report derives from two main phases: phase I (c.1855-1872) and phase II (20th century). The first phase saw the production of two HLLA glasses; one of which was dark green and the other pale green. The dark green HLLA belongs to a family of HLLA glasses that was used for the manufacture of bottles from the mid 17th century until the end of the 19th century. The analyses of well-stratified samples of dark green HLLA glass from Hightown confirm the reports of contemporary written sources (such as Muspratt 1860). By the mid 19th century dark green HLLA glass used for the manufacture of bottles was made using very cheap ingredients which no longer contained any appreciable proportion of plant ashes. Instead the poor quality sands were largely fluxed with waste materials from other industries and as much slag, clay or brick was added as possible. The pale green HLLA appears to be contemporary with the dark green glass and while it belongs to the same technical category (HLLA) there are several significant differences in the chemical composition. The most important of these differences is the much lower iron content of the pale green glass. The low iron content can only have been achieved by using much better quality sand and avoiding the use of other materials which might contain significant quantities of iron. The pale green HLLA glass would therefore have been more expensive to produce. There was clearly a strong demand, however, for less strongly coloured glass containers in the second half of the 19th century. The soft drinks market became increasingly popular from the mid to late 19th century, for example the mineral water market expanded in the 1840s (Douglas and Frank 1972, 169; Wills 1974, 52), and these drinks tended to be bottled in a colourless or only slightly coloured glass so that the contents, which were sometimes brightly coloured, could be seen.

The second phase of glass working at Hightown (phase II) started around 1902 and is of a substantially different character to that of the earlier phase. The later, 20th-century phase was characterised (at least during the early part of the century) by the use of the latest technology. For the manufacture of bottles and other containers this meant the adoption of automatic bottling machines which enabled the production of huge numbers of bottles. Turner (1926) showed that the HLLA glass of the 19th-century hand-blown industry was not well suited to such machines and that it was replaced by SLS glass (with a composition not dissimilar to that which had been used for the previous 60 years for the production of windows). While most of the 20th-century glass was colourless, at least some glass was produced with an emerald green colour. While the cheap HLLA of the 19th century was naturally a dark green colour, the 20th century glass was made using more expensive and better quality ingredients suitable for the mechanised industry and the emerald green colour had to be achieved by adding chromium.

RECOMMENDATIONS

This assessment of the glass waste provides a framework for future research into glass production at Hightown. The research so far has identified the main periods and groups. As mentioned in the introduction, future research should include samples of bottles and other containers produced at Hightown. This will help to establish the reasons why different glass types were produced, and for the 20th-century glass-working will provide considerable chronological detail. Nevertheless, the composition of the glass types discussed above are still quite varied and further research should be undertaken using more samples of glass working waste to better characterise these groups and sub-groups. Further research should also be conducted into the origins of the chromium and uses to which this 20th-century emerald green glass was put.

BIBLIOGRAPHY

Cable, M 2001-2002 'The mechanisation of glass container production'. *Transactions of the Newcomen Society* **73**, 1-31.

Cable, M and Smedley, J W 1987 'Liquidus temperatures and melting characteristics of some early container glasses'. *Glass Technology* 28, 94–98

Douglas, R W and Frank, S 1972 *A history of glassmaking*. Henley: G T Foulis and Co

Dungworth, D 2005 *Investigation of 18th-Century Glass and Glassworking Waste from Limekiln Lane, Bristol*. Centre for Archaeology Report 7/2005. Portsmouth: English Heritage

Fletcher, E 1976 *Antique bottles in colour*. Poole: Blandford Press

Muspratt, S 1860 *Chemistry theoretical, practical and analytical, as applied and relating to the arts and manufacture,* Volume **II**. Glasgow: William Mackenzie

Pellatt, A 1844 *Curiosities of Glass Making*. London: Bogue

Powell, H J and Harris, H G 1883 *The Principles of Glass-Making and Plate Glass*. London: George Bells and Sons

Rosenhain, W 1919 *Glass manufacture*. London: Constable and Company

Shelby, J E 2005 *Introduction to glass sciences and technology*, 2nd edition. Cambridge: Royal Society of Chemistry

Thorp, C and Thorp, L nd *The development and dissolution of the hand-made bottle industry of Castleford.* Unpublished

Turner, W E S 1926 'The composition of glass suitable for use with automatic machines' *Journal of the Society of Glass Technology* **10**, 80-94

Ure, A 1844 *A dictionary of arts, manufactures and mines; containing a clear exposition of their principles and practice*, Volume **I**. New York: D. Appleton and Company

Weyl, W A 1976 *Coloured glasses*. Sheffield: Society of Glass Technology

Wills, G 1974 *English glass bottles for the collector*: Edinburgh: John Bartholomew and Son.

APPENDIX

Table 3: Results (shown in weight %) from the compositional analysis (SEM-EDS and EDXRF) of twenty-one samples of phase I very pale green glass waste from the Hightown glass-works, Castleford.

Cat#	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	Cl	K_2O	CaO	TiO_2	Cr_2O_3	MnO_2	Fe_2O_3	BaO	As_2O_3	PbO	SrO	ZrO_2
51	7.6	7.24	1.03	63.2	<0.1	0.69	<0.10	0.21	20.3	<0.05	<0.05	<0.05	0.40	0.87	0.22	<0.05	0.03	<0.01
52	8.9	7.13	0.99	63.2	<0.1	0.68	<0.10	0.24	19.4	<0.05	<0.05	<0.05	0.47	0.86	0.19	<0.05	0.03	<0.01
53	7.7	7.63	1.05	62.1	<0.1	0.81	<0.10	0.20	21.6	<0.05	<0.05	<0.05	0.43	0.83	0.25	<0.05	0.02	<0.01
54	7.8	7.92	1.02	64.2	<0.1	0.67	0.14	0.21	19.5	0.13	<0.05	<0.05	0.37	0.83	0.19	<0.05	0.03	<0.01
55	7.8	6.65	0.83	66.7	<0.1	0.53	0.22	0.12	18.0	0.07	<0.05	<0.05	0.56	0.14	<0.05	<0.05	<0.01	<0.01
56	7.7	7.64	1.03	63.2	<0.1	0.85	0.13	0.22	20.8	<0.05	<0.05	<0.05	0.40	0.91	0.24	<0.05	0.03	<0.01
107	8.7	7.10	1.37	66.6	<0.1	0.63	0.17	0.29	19.4	0.12	<0.05	<0.05	0.49	<0.10	0.33	<0.05	<0.01	<0.01
111	8.3	7.15	0.89	63.7	<0.1	0.86	0.18	0.14	20.1	0.09	<0.05	<0.05	0.32	1.09	0.08	<0.05	<0.01	<0.01
124	7.4	8.38	1.30	64.9	<0.1	0.51	0.19	0.17	17.7	<0.05	<0.05	<0.05	0.38	1.37	<0.05	<0.05	0.03	<0.01
125	8.4	6.41	0.99	64.1	<0.1	0.85	0.17	0.16	19.4	0.09	<0.05	0.09	0.34	0.90	<0.05	<0.05	0.03	<0.01
140	6.8	4.87	1.15	63.1	<0.1	0.81	0.11	0.18	23.8	0.09	<0.05	<0.05	0.41	0.33	0.12	<0.05	0.02	<0.01
147	7.8	6.93	0.93	62.1	<0.1	0.85	0.18	0.13	19.8	<0.05	<0.05	<0.05	0.34	1.07	0.07	<0.05	0.03	<0.01
148	7.9	6.70	0.85	66.8	<0.1	0.88	0.15	0.22	18.3	0.10	<0.05	<0.05	0.44	0.86	0.10	<0.05	0.02	<0.01
149	8.8	7.66	1.02	62.3	<0.1	0.58	0.40	0.14	19.8	0.08	<0.05	0.06	0.43	1.18	0.10	<0.05	0.03	<0.01
150	7.5	8.93	1.29	63.8	<0.1	0.40	0.25	0.26	19.3	<0.05	<0.05	<0.05	0.61	0.16	0.88	<0.05	<0.01	<0.01
154	7.9	6.86	1.30	64.4	<0.1	0.74	0.23	0.21	19.4	0.12	<0.05	<0.05	0.48	0.13	<0.05	<0.05	0.02	<0.01
155	7.3	6.50	1.23	63.5	<0.1	0.74	<0.10	0.25	19.0	<0.05	<0.05	<0.05	0.46	0.92	0.07	<0.05	0.03	<0.01
156	10.6	7.11	1.37	64.2	<0.1	0.70	0.16	0.07	16.4	0.12	<0.05	<0.05	0.52	1.18	0.13	<0.05	0.03	<0.01
158	9.7	7.22	1.41	66.2	<0.1	0.40	0.24	0.12	15.2	0.11	<0.05	<0.05	0.55	0.58	0.78	<0.05	0.02	<0.01
173	10.1	6.62	1.77	68.4	<0.1	0.42	<0.10	0.27	13.8	0.08	<0.05	0.13	0.49	<0.10	<0.05	0.07	<0.01	<0.01
174	9.9	6.12	1.91	67.2	<0.1	0.30	<0.10	0.32	13.2	0.08	<0.05	0.12	0.47	<0.10	<0.05	0.06	<0.01	<0.01

Table 4: Results (shown in weight %) from the compositional analysis (SEM-EDS and EDXRF) of eight samples of phase I dark green glass waste from the Hightown glass-works, Castleford.

Cat#	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	Cl	K_2O	CaO	TiO_2	Cr_2O_3	MnO_2	Fe_2O_3	BaO	As_2O_3	PbO	SrO	ZrO_2
28	8.2	3.33	4.98	56.9	<0.1	0.64	<0.10	0.90	21.8	0.16	<0.05	1.24	2.89	0.26	0.20	<0.05	0.02	<0.01
38	6.9	2.75	5.92	58.2	<0.1	0.52	<0.10	1.05	20.8	0.19	<0.05	1.70	3.02	0.22	0.06	<0.05	0.02	<0.01
40	4.4	2.97	14.46	60.0	<0.1	<0.15	<0.10	1.31	11.4	0.66	<0.05	0.45	5.47	0.43	0.06	<0.05	0.02	<0.01
42	6.6	3.36	5.20	58.0	<0.1	0.50	<0.10	0.88	20.6	0.20	<0.05	1.65	2.91	0.31	<0.05	<0.05	<0.01	<0.01
43	7.3	6.27	4.85	61.3	<0.1	<0.15	<0.10	0.43	16.2	0.16	<0.05	0.04	2.50	1.13	0.15	<0.05	0.03	<0.01
132	5.2	3.22	5.85	58.8	<0.1	0.42	<0.10	1.15	23.7	0.24	<0.05	0.75	3.32	<0.10	<0.05	<0.05	<0.01	<0.01
133	5.4	3.28	5.84	58.4	<0.1	0.41	<0.10	1.12	23.2	0.21	<0.05	0.77	3.25	0.12	<0.05	<0.05	<0.01	<0.01
175	9.4	4.56	5.51	65.9	<0.1	0.22	<0.10	0.53	13.4	0.24	<0.05	0.06	2.24	<0.10	0.11	<0.05	<0.01	<0.01

Table 5: Results (shown in weight %) from the compositional analysis (SEM-EDS and EDXRF) of twelve samples of phase II colourless glass waste from the Hightown glass-works, Castleford.

Cat#	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	Cl	K_2O	CaO	TiO_2	Cr_2O_3	MnO_2	Fe_2O_3	BaO	As_2O_3	PbO	SrO	ZrO_2
33	15.6	0.14	1.47	74.5	<0.1	0.26	<0.10	0.17	10.6	0.08	<0.05	<0.05	0.06	<0.10	<0.05	<0.05	<0.01	0.02
34	15.0	0.10	1.36	75.0	<0.1	0.22	<0.10	0.03	10.9	<0.05	<0.05	<0.05	0.07	<0.10	<0.05	<0.05	<0.01	<0.01
73	15.1	0.12	0.76	72.7	<0.1	0.34	<0.10	0.04	9.5	<0.05	<0.05	<0.05	0.06	<0.10	0.17	<0.05	<0.01	<0.01
74	16.3	0.15	0.77	74.4	<0.1	0.33	<0.10	0.08	9.5	0.08	<0.05	<0.05	0.05	<0.10	0.08	<0.05	<0.01	<0.01
75	16.7	1.37	0.62	72.3	<0.1	0.21	<0.10	0.20	8.1	<0.05	<0.05	<0.05	0.05	<0.10	0.08	<0.05	<0.01	<0.01
76	17.0	0.19	0.84	75.3	<0.1	0.30	<0.10	0.09	9.6	0.09	<0.05	<0.05	0.05	<0.10	0.08	<0.05	<0.01	<0.01
77	16.8	0.15	0.77	74.3	<0.1	0.30	<0.10	0.06	9.5	<0.05	<0.05	<0.05	0.06	<0.10	0.09	<0.05	<0.01	<0.01
81	15.9	0.14	0.87	74.3	<0.1	0.29	0.13	0.07	9.5	<0.05	<0.05	<0.05	0.05	<0.10	0.08	<0.05	<0.01	<0.01
110	17.0	0.22	0.80	71.1	<0.1	0.27	<0.10	0.06	8.1	<0.05	<0.05	<0.05	0.05	<0.10	0.08	<0.05	<0.01	<0.01
119	16.4	1.45	0.62	72.3	<0.1	0.21	<0.10	0.14	8.0	<0.05	<0.05	<0.05	0.07	<0.10	0.17	<0.05	<0.01	<0.01
119a	17.0	1.36	0.67	73.6	<0.1	0.23	<0.10	0.17	8.2	<0.05	0.05	<0.05	0.06	<0.10	0.17	<0.05	<0.01	<0.01
119b	16.9	1.40	0.68	73.9	<0.1	0.19	<0.10	0.22	8.2	<0.05	<0.05	<0.05	0.07	<0.10	0.17	<0.05	<0.01	<0.01

Table 6: Results (shown in weight %) from the compositional analysis (SEM-EDS and EDXRF) of five samples of phase II emerald green glass waste from the Hightown glass-works, Castleford.

Cat#	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	Cl	K_2O	CaO	TiO_2	Cr_2O_3	MnO_2	Fe_2O_3	BaO	As_2O_3	PbO	SrO	ZrO_2
27	14.92	0.41	2.10	73.3	<0.1	<0.15	<0.10	0.82	10.5	0.10	0.25	<0.05	0.41	<0.10	<0.05	<0.05	<0.01	0.04
29	14.47	0.42	2.11	73.8	<0.1	<0.15	<0.10	0.85	10.9	0.06	0.27	<0.05	0.42	<0.10	<0.05	<0.05	<0.01	0.03
30	13.33	0.33	2.01	72.2	<0.1	<0.15	<0.10	0.80	9.9	<0.05	0.20	<0.05	0.42	<0.10	<0.05	<0.05	<0.01	0.02
31	13.78	0.38	2.06	71.1	<0.1	0.16	<0.10	0.81	10.7	<0.05	0.26	<0.05	0.35	<0.10	<0.05	<0.05	<0.01	0.04
32	14.43	0.35	2.15	73.1	<0.1	0.18	<0.10	0.87	10.8	<0.05	0.26	<0.05	0.47	<0.10	<0.05	<0.05	<0.01	0.05






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