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Summary

The glass working evidence all dates to the 10th and 11th centuries AD. Dark green or black high-lead glass was being made in Stamford ware crucibles on or near the adjacent sites. No quantitatively analysed objects had compositions that fully matched that of the glass on the crucibles so the products remain unknown. Blue soda glass of Roman-type composition was being remelted on small discs cut from sherds of Stamford ware and then made into beads.

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High-lead glassworking and alkali glass bead making at 16-22 Coppergate and 22 Piccadilly, York

Justine Bayley and Roger Doonan

Introduction

Around the 10th century AD a new type of glass came into use in Britain for beads, rings and other trinkets (eg, Bayley 1985); from the 9th-13th centuries it was commonly used for similar objects in eastern Europe (Ullrich 1989). Unlike most earlier glass whose main components were soda, lime and silica, it was a lead glass with up to about 70% by weight lead oxide and the rest mainly silica, with only low levels of other elements. Although some lead is found in opaque coloured glass and enamels at earlier periods, these have a maximum of up to 30% lead oxide. The new high-lead glass was a translucent yellow colour, though often copper was added to produce a translucent green or, when present in larger quantities, a much darker opaque green that can look almost black. Glass of this type was not used to make vessels in north-west Europe until the 13th-early 14th centuries (Baumgartner and Kreuger 1988, Tyson 1996).

York is one of only a few English towns that have so far produced evidence for working high-lead glass; the others include Gloucester (Bayley 1979) and Lincoln (Gilmour 1988, 70). This evidence is mainly in the form of crucibles in which the glass was melted, but there are also part-made and failed objects and glass waste.

High-lead glass-working in York

A number of York sites, all within 200m of each other, have produced evidence for the working of high-lead glass. Other sites in the same area have artefacts made of this type of glass, though no manufacturing waste has been identified on them (Henderson in Tweddle 1986, 226). Table 1 summarises these finds.

Table 1: High-lead glass and glassworking finds

Site	crucible sherds		waste	objects	date
	Stam.	other			
16-22 Coppergate	259	-	) yes	) beads, rings	M10 on
	-	47	)	) linen smothers	L10 on
22 Piccadilly	1362	1	yes	beads	10/11 on
34 Shambles	-	11	yes	beads	?12-E13
6-8 Pavement	-	-	-	beads, rings	A-S
7-13 Pavement	-	-	-	beads, rings	A-S
Clifford Street-	-	yes		beads	A-S

A number of different types of pottery were used as crucibles. From 34 Shambles were 11 sherds, one in a fine red fabric, three of a buff gritty fabric and seven of a red gritty fabric. The forms were probably fairly shallow bowls with a simple rim with a diameter of 105-150mm.

Nearly 85% of the Coppergate crucibles and all but one of the Piccadilly crucibles are Stamford ware. Most are bowls, twice as wide as they are deep, with a slightly flanged rim with a diameter of 120-150mm, sloping sides and a flatish base (Mainman 1990, Fig 205, 2345). The remainder of the Coppergate crucibles are in oxidised gritty fabrics, with similar forms but simple rims (Mainman 1990, Fig 205, 2357-66) like those from 34 Shambles (Brooks 1987, Fig 91, 845-50). A single sherd from Piccadilly was of this type and a further sherd from the site was a Stamford ware metal-melting crucible that had been used to melt high-lead glass.

The Coppergate and Piccadilly high lead glass

The Coppergate crucibles mainly contain dark green or almost black glass (Mainman 1990) as do 85% of the sherds from Piccadilly (see Table 2). About 10% of the Piccadilly sherds had blue alkali glass on them; they are discussed below. A sample of the main group of Piccadilly crucible sherds were analysed qualitatively by X-ray fluorescence (XRF). This showed the major element present in the glass was lead, together with some copper. Samples cut from nine sherds were examined and analysed quantitatively using an energy-dispersive analyser on a scanning electron microscope (SEM).

The SEM images showed the glass all contained sub-rounded silica particles. These were larger than the silica temper in the crucible fabric and so could not have eroded out from the crucible surface. They must therefore be a deliberate component of the glass melt. This suggests that the glass had been made, rather than just melted, in the crucibles. Heraclius, probably writing in the 12th century (Merrifield 1967, 216), gives a recipe which involved heating together equal volumes of lead oxide and sand (silica) and colouring the resulting glass by adding copper. Heraclius' recipe gives a composition similar to that found by analysis.

The analyses (which were made of areas without unreacted quartz grains) show that the glass in most of the crucibles has a consistent composition, typically 60-70% lead oxide (PbO), 25-30% silica (SiO_2) and 5-10% copper oxide (CuO), though there is some variation between different areas on the same sherd (Table 3). The levels of alkalis (Na_2O, K_2O) and alkali earths (MgO, CaO) are very low compared with most glasses, suggesting they are accidental contaminants rather than deliberate additions. The other elements shown in Table 3 are also at too low a level to be deliberate.

On about 3% of the Piccadilly sherds some or all of the glass is opaque red, orange or ginger-brown rather than green/black but its chemical composition is no different. This colour change was caused by melting conditions becoming more reducing so some of the copper was present as finely divided metal or as Cu_2O rather than as CuO (note however that the copper content shown in Table 3 is still calculated as CuO). In several crucibles droplets of metallic lead were also found in the glass, another indicator of insufficiently oxidising conditions. No tin or zinc were detected in any of the quantitatively analysed glass, though traces of both metals were found on some sherds that were analysed by XRF. This suggests that both pure copper and a range of copper alloys were used as colourants; all these metals were present on the Coppergate site (Bayley 1992, Fig 357), as were *c*30kg of scrap and waste lead (*ibid*, 810).

Table 2: The glass-containing crucibles from 22 Piccadilly

Context		per	Dark green			Red/orange			Blue			Other	Pot
	SRS		rim	body	base	rim	body	base	rim	body	base		
2042	119 52	6	29 30 111	21 21 116	11 14 40	2 1 3	2 5			2 4 10	1	3 hl 1 *	25 4 2
2049		6	1										
2079		6	1	1									
2083		6	2	1	5					1			
2086		4/1	11	4	3	1							
2087		4/1	2	1									
2089		4/1	32	32	14		4	1		13	1	2	
2095		4/1	1	1									
2098		4/1	1										
2112		4/1	12	10	5					5	2	1	4
2113		4/1	49	46	19	2	2	1		23		5	
2142		4/1	3	8	5		1			1			1
2143		4/1	5	2	1					1			3
2146		4/1	16	9	3		1			5		1	1
2160		4/1			2								
2162		4/1	118	75	31	1	2		1	39	12	1	4
2166		4/1	1	1	2								
2169		4/1	1										
2170		4/1		5	1								
2183		4/1	1										
2184		4/1	4		1								1
2187	238	4/1	16 18	17 15	3 6	1	1	1				1	21 1
2188		4/1		1									
2206		4/1		1						1		1	
2213		4/1	4	2				1		2			
2214	248	4/1	2										1
2216		4/1	19	11	3			1		1			
2219		4/1	1	1	2								1c+ 1

Table 2 (cont)

Context		Per	Dark green			Red/orange			Blue			Other	Pot
	SRS		rim	body	base	rim	body	base	rim	body	base		
2229		4/1	5	2	1								1
2230		4/1	1										
2232		4/1	2	1	1								2
2243		4/1	15	30	8		2	1					1
2252		4/1	2							1			
2253		4/1	1		1								
2263		4/1		1									
2267		4/1		1									1c
2269		4/1	2	1									
2270		4/1	6	1									
2277		4/1	1										
2278		4/1	7				1						
2280	335	4/1	6	7	6		2						3
3053		4/3		1									
3084		4/2											1c
3088	214	4/1	1 1										
3116		4/1			1								
3129		3			1								
3130	256	3			1		1						7c
Total			541	447	191	11	24	6	1	109	16	16	76+10c

Key: hl = hearth lining with glass on it
c = metal-melting crucible
* = lump of high-lead glass

Table 3: Composition of high-lead glass on crucibles from context 2113 at 22 Piccadilly

Spectrum Label	colour	Na2O	MgO	Al2O3	SiO2	P2O3	K2O	CaO	TiO2	FeO	CuO	PbO
rs/1/97 a anal 1 inside	green/black	nd	nd	0.14	21.26	0.47	nd	0.09	nd	0.18	0.35	78.05
rs/1/97 a anal 2 inside	green/black	nd	nd	1.16	30.76	0.06	0.12	0.39	0.17	0.22	nd	67.28
rs/1/97 a anal 3 inside (nr pot)	green/black	0.14	0.06	1.86	29.82	0.52	0.08	0.19	0.03	0.75	0.11	66.43
rs/1/97 a anal 4 inside (away pot)	green/black	nd	nd	0.51	14.96	0.31	nd	0.15	nd	0.31	0.21	83.94
rs/1/97 a anal 5 inside (away pot)	green/black	0.16	0.12	0.30	16.05	nd	0.19	0.11	0.02	nd	nd	83.43
rs/1/97 a anal 1 outside	green/black	nd	nd	4.09	25.16	nd	0.10	0.29	0.47	0.49	0.09	69.66
rs/1/97 a anal 2 outside	green/black	0.06	0.11	3.55	25.74	0.28	0.02	0.16	0.41	0.83	0.43	68.41
rs/1/97 b anal 1 near pot o/side	green/black	nd	0.01	0.60	26.49	nd	nd	0.33	0.11	0.59	nd	72.60
rs/1/97 b anal 2 away pot o/side	green/black	0.08	0.02	0.01	26.34	nd	nd	0.27	0.31	0.45	0.85	71.93
rs/1/97 b anal 3 away pot	green/black	0.28	0.16	0.27	27.75	0.27	0.38	0.34	0.09	nd	nd	70.73
rs/1/97 c anal 1	green/black	0.01	0.05	0.61	28.36	0.47	0.26	0.36	0.12	0.22	9.47	60.37
rs/1/97c anal 3	green/black	0.71	0.04	0.71	28.01	0.06	0.12	0.39	0.13	0.13	9.78	59.90
rs/1/97 d anal 1	green/black	0.35	0.13	0.72	27.86	0.13	0.71	1.14	0.52	0.53	6.93	61.00
rs/1/97 d anal 2	green/black	0.47	nd	0.59	27.10	0.37	0.06	0.37	0.23	0.61	8.60	61.80
rs/1/97 e anal 1	green/black	0.14	0.22	1.03	25.96	0.19	0.15	0.25	nd	0.18	4.81	67.11
rs/1/97 e anal 3	green/black	0.21	0.30	0.62	23.25	0.24	0.11	0.05	0.04	nd	7.50	67.74
rs/3/97 b anal 2	dull red	1.98	0.43	0.88	33.00	nd	0.50	0.28	0.02	0.43	5.11	57.44
rs/3/97 b anal 3	dull red	1.73	0.38	1.04	33.08	0.07	0.65	0.02	0.34	0.25	4.03	58.43
rs/3/97 c anal 1	black	nd	nd	0.58	28.85	0.28	0.21	0.46	0.10	0.16	11.54	57.87
rs/2/97 c anal 3	black	0.41	0.08	0.69	29.21	0.26	0.17	0.29	0.06	0.02	8.61	60.20
rs/3/97 a anal 1	orange	0.55	0.14	1.15	30.34	0.28	0.40	0.25	0.04	0.47	6.75	59.62
rs/3/97 a anal 2	orange	0.06	0.01	1.24	30.65	0.08	0.43	0.01	nd	0.66	6.90	60.00
rs/4/97 a anal 1	yellow	nd	nd	6.25	16.58	0.29	0.38	0.95	0.81	1.80	0.48	72.66
rs/4/97 a anal 2	yellow	0.22	0.09	6.94	16.53	0.41	nd	0.92	0.79	2.10	0.81	71.22
rs/4/97 a anal 3	yellow	0.15	nd	7.02	16.83	0.43	0.25	0.74	0.81	2.22	nd	72.01

Detection limits are c.0.1% elemental. nd = not detected.

Cobalt and manganese were not detected in any of the samples. Because of the high lead contents sulphur could not be determined.

The glass on two of the analysed sherds (rs/1/97 a and b) were lead silicates, like the rest, but had atypical copper contents of well under 1%. Visually they are indistinguishable from the other green/black samples analysed. A clear yellow glassy coating on a crucible rim (rs/4/97 a) had a similar low copper content. This suggests that the high copper contents were not necessary to produce the desired green colour.

Table 7 lists a group of finds from 16-22 Coppergate which provide additional evidence of high-lead glass working. There are pieces of fired clay interleaved with high-lead glass and lumps of glass of this type. They probably represent glass that was spilt from the crucibles and soaked into the hearth lining. Most of the glass is green/black and contains appreciable amounts of copper, like the glass on most of the crucibles, but a few pieces have far lower copper levels or are effectively copper-free. These are mainly yellow to golden brown in colour. Sf 5784, is green high-lead glass on an iron wire; it is probably a bead in the making.

With all this evidence for glass making and working, it is necessary to consider what objects were being made from it. Glass finds from the Coppergate and Piccadilly sites include beads of a range of forms and colours, rings, and slick stones and a selection of them have been analysed so their compositions can be compared with those of the glassworking debris.

Some of beads from Coppergate had their density determined. The values (Table 4: measurements carried out in the YAT conservation laboratory?) show that most of these beads have lead oxide contents of around 70-75%; they are made of high-lead glass.

Table 4: Measured density of some beads from 16-22 Coppergate

SF No	Density	Colour	Comments
5354	5.72	yellow	
5374	5.92		
5454	6.75?	yellow	very small bead. glass looks opaque density measurement unreliable
5457	5.74	yellow	
5542	5.75	yellow	
5544	5.62	yellow	
5712	2.26		antimony opacified glass; not high-lead
5853	5.59	yellow	
5938	5.74	yellow	
5973	6.80?	yellow	density measurement unreliable
6463	4.45	yellow	tapering hole does not fully perforate bead
7036	5.51	yellow	

A second group of beads were analysed by XRF; the results (see Table 5) show that the yellow, green and black beads all had the same high-lead composition. The yellow colour appears to be due to traces of iron while the black beads have higher iron contents; the green beads are coloured by small amounts of copper. The opaque red and orange beads were both coloured by copper but contained no detectable lead.

Samples were removed from four beads and analysed in the SEM (see Table 6). These results confirm the interpretation of the XRF data. The yellows contain less iron than the black bead (sf 6949) but one of them (sf 4457) had copper levels similar to that in the green bead (sf 3156). These results are comparable to those obtained by Henderson (in Tweddle 1986). None of the beads contain nearly as much copper as the glass on most of the crucibles, and two of them have far more iron. It is therefore most unlikely that any of the analysed beads were made from glass from the crucibles found on the Piccadilly site, though the green

Table 5: Selected glass beads from 16-22 Coppergate

context	sf no	colour	SEM (see Table 6)	elements detected by XRF
7782	3131	green		Pb Cu Fe
12412	3156	green	yes	Pb Cu Fe ?Mn
9801	3299	green		Pb Cu Fe
3543	3333	yellow		Pb Fe ?Cu
15432	4361	yellow	yes	Pb Fe ?Cu
16733	4420	green		Pb Cu Fe
16734	4457	yellow	yes	
15592	4673	yellow		Pb Fe ?Cu
18489	5047	yellow		Pb Fe ?Cu
6927	6949	black	yes	Pb Fe ?Cu
25350	8550	op red		Cu Zn Sn Fe
31389	11345	op orange		Cu Sn Fe
6866	11484	black		Pb Fe ?Cu
15311	11519	black?		Pb Fe

The elements are listed in order of decreasing abundance; question marks denote uncertainty. Silica was not detectable using XRF.

Table 6: Composition of some high-lead glass beads from 16-22 Coppergate

Spectrum Label	sf no	colour	Na2O	MgO	Al2O3	SiO2	P2O3	K2O	CaO	TiO2	FeO	CuO	PbO
rs/2/97 c anal 3	3156	green	0.17	0.05	0.63	24.09	0.16	0.07	0.08	0.09	0.17	0.64	73.83
rs/2/97 c anal 4			0.06	nd	0.64	24.85	0.20	0.15	nd	nd	0.27	0.46	73.60
rs/2/97 d anal 1	6949	black	nd	0.10	0.17	15.28	0.11	0.08	0.21	0.15	3.10	0.12	80.87
rs/2/97 d anal 3			0.52	nd	0.35	21.04	0.15	0.04	nd	0.12	3.17	0.13	74.53
rs/2/97 d anal 4			0.53	nd	0.43	21.07	0.24	0.05	0.15	nd	3.06	0.01	74.47
rs/2/97 d anal 5			0.49	nd	0.41	21.37	0.05	0.29	0.03	nd	3.20	0.04	74.23
rs/2/97 e anal 1	4361	yellow	0.15	0.08	0.47	18.11	0.29	0.20	nd	0.02	0.24	nd	80.55
rs/4/97 b anal 1	4457	yellow	0.10	nd	0.32	18.75	0.17	0.11	0.12	0.06	0.59	0.43	79.40
rs/4/97 b anal 2			nd	nd	0.38	19.50	0.39	0.03	0.25	0.01	0.04	nd	80.00

Detection limits are c.0.1% elemental. nd = not detected

Table 7: Other high-lead glass finds from 16-22 Coppergate

Context	SF No	Description	Elements detected by XRF	Period	Date (century)
5348		hearth lining with Pb/Cu-rich vitrified surface layer	Pb Cu Fe Zn ?Sn	C6e1/D6a16	12/13
5781		fired clay interleaved with green high-lead glass	Pb Fe Cu Zn	C6e6	early 13
6284		fired clay interleaved with green high-lead glass		5b	late 10-mid 11
6774	5784	green glass on iron wire	Pb Fe Cu Zn	5cr	mid-late 11
6774		fired clay interleaved with green high-lead glass		5cr	mid-late 11
6785		fired clay interleaved with green/yellow high-lead glass	Pb Fe Cu Zn	5b	late 10-mid 11
9224		lump of golden-brown high-lead glass (35x33x20mm)		C6e9	mid 13
9305		fired clay interleaved with green high-lead glass	Pb Cu Fe Zn	D6a24	12/13
9801		high-lead brown glass lump (15x12x10mm)	Pb Fe Zn Cu	D6y1	late 12-13
15311	5815	high-lead green glass waste on fired clay	Pb Fe Cu	5cr	mid-late 11
16525		fired and vitrified clay with green high-lead glass		D6a13-14	mid 12
16882	6466	green high-lead glass lump (24x18x8mm)		5b	late 10-mid 11
27017	11710	fired clay with golden-brown high-lead glass	Pb Fe Cu ?Zn	4b	mid 10
27819	10643	black glass fragment (?high-lead glass)		3	mid 9-early 10
27819	10863	green high-lead melted glass		3	mid 9-early 10
30189	11650	`black' high-lead glass on fired clay		3	mid 9-early 10
Some of the Coppergate crucibles with high-lead glass (cf Mainman 1990, Table 51 and *2345-2366*)					
4000		yellow high-lead glass in pot		u/s	-
6085		high-lead glass on sherd		D6a6	11/12
6782	6428	lead glass in pot base		5b	late 10-mid 11
13886	6310	pot rim with dark high-lead glass		B6a3	11/12
17890	5741	sherd with high-lead green/black glass showing scrape marks		B6a1/C6a1	late 11
17890		24 sherds with high-lead glass, some yellow and red, mainly green/black	B6a1/C6a1	late 11	

The elements are listed in order of decreasing abundance; question marks denote uncertainty.

glass stuck on an iron wire is probably of similar composition to that of the translucent green beads and so is probably a part-made bead. Some of the glassy waste listed in Table 7 has only traces of copper and may therefore be of a similar composition to the yellow beads.

Five of the slick stones from 16-22 Coppergate have been shown to be high-lead glass (sf 5238, 12577, 14787, 14925 and 34663) and lower lead levels were detected in several more (Mortimer 1995). They are all dark green/black in colour and are reported as containing no copper; the colour was due to significant amounts of iron. These pieces probably have a similar composition to that of the black bead (sf6949) but no quantitative analyses have been carried out.

There are problems in interpreting most of the glass artefacts from Coppergate and Piccadilly as products of the local glass industry because of the mismatchs in composition and appearance. The lead content of the glass on the crucibles is on average a little lower than that of the glass beads from both Coppergate and Shambles. In general, glass that looks similar has different copper and iron contents, while some pieces where the analyses are in good agreement appear different colours. A larger programme of analyses might help resolve these difficulties, but as high-lead glass is only used in England and eastern Europe for a limited period (Ullrich 1989, Bayley forthcoming), it is most unlikely that all the artefacts are imports to the site.

Alkali glass melting

About 10% of the sherds from Piccadilly had glass of a different type, with only traces of lead present. On most of these pieces the glass was a transparent or translucent blue, though some were so pale they appeared colourless. The blue is normally produced by low concentrations of cobalt, and XRF analyses detected cobalt in most of this glass, along with small amounts of manganese, iron, copper, lead and antimony. On two pieces the glass was turquoise rather than blue, a colour produced by copper in a low-lead or lead-free glass. In this case tracs of tin and zinc were also present. On a few pieces the glass appeared an opaque buff or white, but in the majority of cases closer examination showed these to be devitrified glass; their appearance was similar to that of decayed potash glass.

The fabric of the sherds with the low-lead glass were similar to Stamford ware in texture, but had a pale buff rather than pale grey colour. This may be due to the glass being melted under more strongly oxidising conditions. These sherds were not parts of complete vessels that had contained molten glass, like the crucibles described above. Instead they were sherds from larger pots that had been cut into rough circles 30-40mm across and then had a small amount of glass placed on their concave side which was melted and scraped off, apparently to make a bead (see below). Not all the sherds are complete discs, but they were all parts of pieces of this size and shape. The glass on them usually does not reach the curved edge, or if it does it flows over the broken edge. A total of 21 similar sherds, used in the same way, are known from the Coppergate site, although on five of them the glass appears colourless rather than blue (see Table 8).

From Piccadilly there were mis-formed blue beads (eg sf 382) and also a number of irregularly-shaped pieces of blue glass-working waste, some of which had pincer marks (eg sf 380); Table 9 provides a full list. Some of these pieces were also analysed by XRF and four samples in the SEM. The results (Tables 9 and 10) show the blue glasses are soda glass, coloured by traces of copper and cobalt and containing some antimony; the composition is very consistent. Varying redox conditions mean that some of the glass was decolourised by the antimony, while in other cases it is opaque, or contains opaque white swirls; under the SEM

Table 8: Sherds with translucent blue glass from 16-22 Coppergate

Context	SF No	Comments	Date (century)
1604		clear scrape marks	13/14
3366		glass appears colourless	13/14
3407			early 13
3493			12
4620/A		glass includes other vitrified material	mid 13
6245			11/12
6284			late 10-mid 11
8023	1965	colourless glass on potsherd	late 10
9276			early 13
9453			mid 12
12363			early 13
12674		clear scrape mark	early 13
16130			mid 12
16612	4661	glass appears `colourless'	late 11
16612/2B			late 11
17890/B3			late 11
18331/B		pale blue	11/12
18668			mid 12
19270			mid/late 11
26732	11244	glass appears `colourless'	mid 9-early 10

Table 9: XRF analyses of blue glass beads and waste from 22 Piccadilly

context	sf no	object	XRF	Comments
2042	269	misformed bead	yes	bubbles in glass make it looks opaque
2042	294	6 glass chunks + ceramic/stone inclusions		SEM analysis (Table 10)
2042	937	bead + `core'		
2089	187	bead fragment glass + pincer marks		glass waste attached to Stamford ware fragment
2089	194	bead		
2112	257	bead fragment		glass not hot enough so imperfectly shaped; joins visible
2162	375	misformed bead	yes	bubbles and ?sand in the glass
2162	376	bead		
2162	380	chip and 2 ?rod ends + pincer marks	yes	SEM analysis (Table 10)
2162	381	3 beads + 1 misformed		
2162	382	6 bead fragments + 1 misformed	yes	SEM analysis (Table 10)
2162	400	6 beads	yes	
2162	614	waste/trail + pincer marks	yes	
2162	871	2 bead fragments		
2186	439	bead fragment	yes	
2186	504	bead fragment	yes	
2187	555	misformed bead		bubbles and ?sand in the glass
2187	1261	2 glass fragments + ceramic inclusions		
2243	645	bead fragment	yes	
2254	698	bead fragment		
3035	317	bead	yes	

XRF detected the following elements at low levels in almost all the analysed pieces: Mn, Fe, Co, Cu, Pb, Sb (Co was not detected in sf269 and Ni was also probably present in on rod end in sf380.

Table 10: Composition of blue glass from 22 Piccadilly

Spectrum Label		Na2O	MgO	Al2O3	SiO2	P2O3	SO3	K2O	CaO	TiO2	MnO	FeO	CoO	CuO	Sb2O3
rs/2/97 a anal 1	sf 382 bead	15.69	0.81	1.94	68.77	0.28	0.69	0.71	6.69	0.27	0.45	0.98	0.19	0.24	2.30
rs/2/97 a anal 2		15.23	0.73	1.94	69.09	0.12	0.65	0.63	6.77	0.22	0.51	0.80	0.03	0.43	2.84
rs/2/97 a anal 3		9.11	0.65	4.29	77.33	0.27	0.24	1.81	2.09	0.79	nd	2.93	nd	0.23	0.25
rs/2/97 b anal 1	sf 380 pincer-mark	16.72	0.96	2.16	67.63	0.18	0.64	0.61	6.48	0.04	0.51	1.01	0.19	0.64	2.24
rs/2/97 b anal 3		15.70	0.90	2.07	69.16	0.10	0.74	0.63	6.34	0.27	0.54	1.09	nd	0.54	1.94
rs/2/97 b anal 4		15.41	0.91	2.03	68.60	0.10	0.71	0.65	6.81	0.03	0.41	0.93	0.07	0.78	2.54
rs/2/97 f anal 1	'crucible' from c2162	12.50	0.78	2.04	70.72	0.07	0.67	1.04	7.20	0.09	0.72	0.94	0.17	0.29	2.77
rs/97/2 f anal 2		10.85	0.73	2.26	71.98	0.18	0.63	0.80	7.66	0.12	0.51	0.95	0.04	0.44	2.85
rs/2/97 f anal 3		11.28	1.02	2.08	70.51	0.21	0.72	0.76	7.33	0.17	0.26	0.42	0.04	0.43	4.76
rs/2/97 f anal4		0.19	0.11	nd	55.70	51.24	nd	0.12	nd	0.10	nd	0.30	0.23	nd	nd
rs/2/97 f anal a		12.76	0.88	2.37	69.52	0.28	0.39	1.31	7.52	0.28	0.57	1.15	0.12	0.54	2.31
rs/2/97 f anal b		15.03	0.93	1.88	68.05	0.13	0.90	0.89	7.06	0.09	0.55	0.89	0.29	0.46	2.85
rs/2/97 f anal c		13.66	0.80	2.24	69.74	0.10	0.61	0.96	7.05	0.10	0.72	1.13	0.07	0.44	2.38
rs/2/97 f anal d		10.88	0.75	2.37	69.72	0.29	0.62	1.22	6.96	nd	0.28	0.41	0.10	0.11	6.30
rs/2/97 f anal e		8.50	0.70	2.15	72.23	nd	0.63	1.12	6.90	0.15	0.26	0.39	0.03	0.17	6.77
rs/2/97 g anal 1	sf 294 glass lump	15.10	0.89	1.84	69.17	0.06	0.55	0.98	6.72	0.13	0.50	1.14	nd	0.58	2.35
rs/2/97 g anal 2		15.29	0.77	2.34	68.84	0.18	0.69	1.06	6.53	0.13	0.39	0.93	0.38	0.32	2.14

Detection limits are c.0.1% elemental. nd = not detected
Lead was below the level of detection in all these samples, although it was universally detected by XRF which is more sensitive to it.

these can be seen to be due to calcium antimonate particles in the transparent glass. The composition of the blue glass is comparable to that of Roman blue glass. It therefore appears that Anglo-Scandinavian bead makers either collected Roman blue glass locally or imported glass that was probably still being made to this recipe in the eastern Mediterranean. The glass was remelted on the makeshift ceramic discs, scraped up when soft, and manipulated to make segmented beads, and possible other shapes as well.

There are a few further finds from Coppergate which appear to be related to this blue glass working (see Table 11). There is some blue glass on a lump of fired clay as well as a droplet and piece of waste (sf 6585, 8635 and 11242). A blue tessera (sf 3579) is possible raw material for this small-scale remelting industry, Theophilus mentions tesserae as a good source of coloured glass (Hawthorne and Smith 1979, 59), though vessel fragments or cullet would have been equally suitable.

Dating the glassworking

On Coppergate the earliest Stamford ware crucibles with high-lead glass date from the mid 10th century but nearly three-quarters are from Period 6 (later 11th century onwards). Three sherds from Piccadilly are from Period 3 (10th/11th century) but 68% are from Period 4/1 (early/mid 11th century) with almost all the rest from 14th/15th century contexts where they are presumably residual as Stamford ware had stopped being made by the mid 13th century. It appears that the main period of high lead glass manuafacture was in the 11th century, and probably earlier rather than later. It has been suggested that the effectively unstratified material from 34 Shambles was probably of 12th or early 13th century date. If this is correct, it suggests that high-lead glass continued to be used to make beads after its original floruit in the 11th century.

The chronological distribution for the crucibles with blue, Roman-type glass is very similar to that of the high lead glass (see Table 12); the two glass working traditions appear to be contemporary.

Most of the post 11th-century contexts containing glassworking finds are build-up or levelling dumps so it is likely that the finds are residual in them, reinforcing the suggestion that the main floruit for the industry on 16-22 Coppergate and 22 Piccadilly was in the 11th century.

Conclusions

High lead glass was being made in Stamford ware crucibles, and used to make objects, on or near the 16-22 Coppergate and 22 Piccadilly sites. No quantitatively analysed objects had compositions that fully matched the glass on the crucibles so we cannot demonstrate what types of objects were being made.

Blue soda glass of Roman-type composition was being remelted on small discs cut from sherds of Stamford ware and turned into beads.

Both these industries appear to have started in the 10th century but their main production was in the 11th century.

Table 11: Other glass-working finds from 16-22 Coppergate

Context	SF No	Comments		Period	Date (century)
1346	294	part-melted half opaque orange glass bead (XRF: Pb Cu Fe)		C6z1	late 14-early 15
6284	6585	blue glass on fired clay lump		5b	late 10-mid 11
11886	3579	blue glass tessera (XRF: Pb Fe Sb Cu Co)		B6f4	early 14
15177	4058	potash-glass lump/flow	5b	late 10-mid 11	
15688	4565	melted colourless glass	4b	mid 10	
18366	4921	melted colourless glass	B6a5	11/12	
22633		metalworking crucible with black glass		4b	mid 10
22797	11242	blue glass waste fragment		4b	mid 10
24556	8635	blue glass droplet		4b	mid 10

Table 12: Glass melting crucibles (after Mainman 1990, Table 51 with additions)

Coppergate	Piccadilly	High-lead glass		Non-lead glass	
period	period	Stamford ware	other	Stamford ware	other/unknown*
3		-	-	-	1
4A		-	-	-	-
4B		7	-	-	-
4/5		2	1	-	-
5A		2	2	-	1
	3	3	-	-	-
5B		24	22	-	1
	4/1	918	1	120	-
5C		33	11	-	1
	4/2	-	-	-	-
6		191	11	-	17
	4/3	1	-	-	-
	6	438	-	21	-

* most of these are probably Stamford ware; my notes do not make this clear

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