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LINCOLN
EVIDENCE FOR GLASS-WORKING ON FLAXENGATE AND OTHER SITES IN THE CITY

TECHNOLOGY REPORT

Justine Bayley

with contributions by Kate Foley and Paul Wilthew

ARCHAEOLOGICAL SCIENCE

ENGLISH HERITAGE

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SUMMARY

The evidence for high-lead glass-working from 9 sites is catalogued and discussed. Nearly 90% of the finds are from the Flaxengate site. Almost all the material is of Late Saxon or Saxo-Norman date (mainly 10th and 11th centuries) with a few finds re-deposited in later contexts. The collection comprises crucibles, scrap and waste glass. There are also beads and rings made of high-lead glass which may have been made in Lincoln. A few other glass finds, including coloured tesserae and smoothers, are also considered.

CONTRIBUTORS

Kate Foley, conservator for the then Lincoln Archaeological Trust, contributed to the project and included some of the work in her dissertation (Foley 1981). Assistance and advice was provided by staff of the Technology Section of the Ancient Monuments Laboratory, especially Leo Biek and Paul Wilthew, but also many of the students who worked there with me over the years.

ACKNOWLEDGEMENTS

Other staff of LAT and its successors (Trust for Lincolnshire Archaeology and City of Lincoln Archaeological Unit), Lauren Adams Gilmour, Jenny Mann, Jane Young, and later Jane Cowgill, were most helpful in finding objects and in providing context information. In 2007 Jenny Mann provided the updated phasing and context information which has allowed some conclusions to be drawn from the work that was previously undertaken; without her help it would not have been possible to produce this report.

ARCHIVE LOCATION

The archive of the scientific investigations is currently held by the Technology Section at Fort Cumberland. The excavation records and finds have been, or soon will be, deposited with 'The Collection' in Lincoln.

DATE OF RESEARCH

The work reported here was undertaken intermittently over a considerable number of years in the 1970s and 1980s by the author and the other contributors. The data was assembled into this report during 2007-08.

CONTACT DETAILS

Justine Bayley, English Heritage, Fort Cumberland, Fort Cumberland Road, Eastney, Portsmouth PO4 9LD.

Tel: 02392 856794. Email: justine.bayley@english-heritage.org.uk

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1 INTRODUCTION

The glass-working debris and glass finds reported on here (Table 1) come from 10 sites (Fig 1), mainly in the lower city at Lincoln, excavated between 1972 and 1984. Most of this material relates to the working of high-lead glass which was made into trinkets such as rings and beads. The majority of the glass-working finds are crucibles which were used to melt this glass, but objects and scrap made of high-lead glass were also investigated. A few fragments of other types of glass were also analysed to see if they could have been raw material for the glass-working industry. A small number of other glass objects, most notably coloured tesserae and glass slick stones (linen smoothers), were also studied.

The majority of the finds are from the Flaxengate site where all the high-lead glass-working dates to the 10th and 11th centuries. A few high-lead glass finds come from later contexts where they are residual.

Table 1: The glass-working finds and glass objects catalogued and discussed in this report

Site	Site code	high-lead glass					alkali glass					
		crucible sherds	scrap glass	mis-made objects	rings	beads	rings	beads	tesserae	other	Total finds	glass analyses
Flaxengate	F72	36	1	1	14+1?	9+?3	1	33	9	27	135	81
Danes Terrace II	DT74ii	1									1	1
Hungate	H83	1+1?									2	1
Saltergate	LIN73sa	1?									1	
Silver Street	LIN73si	1?									1	
Chestnut House, Michaelgate	MCH84	3+3?			2?						8	
Steep Hill	SH74	1									1	
West Parade	WP71	1?									1	
Lucy Tower	LT72	1?									1	
Waterside NW	WNW88				1					1	2	1
Waterside N	WF89				1						1	
Broadgate East	BE73	3-8?									8	
30-31 Broadgate	BB91	1?									1	
St Mark's Station	Z86	1?									1	
St Mark's Church	SM76				1						1	
St Mary's Guildhall	SMG82	1?									1	
Holmes Grain	HG72	1+1?	1			1		1		2	7	4
Total		63	2	1	20	13	1	34	9	30	173	88

When scientific study of the glass-working finds commenced in the 1970s they were far less well-understood than is now the case so initially the focus was on differentiating the finds relating to high-lead glass-working from those relating to metalworking, and specifically to precious metal assaying or refining (see Bayley 2008a). Most of the work

was undertaken in the Ancient Monuments Laboratory (AML) by Justine Bayley, either directly or by others working with her (see Acknowledgements). Kate Foley (1981) based part of her dissertation on the Flaxengate glass-working finds; some of the data she gathered has been incorporated into this report.

It had originally been planned to publish the evidence for metal- and glass-working on the Flaxengate site in the *Archaeology of Lincoln* series, and references to various forthcoming titles by Bayley *et al* occur in the published fascicules; however changing priorities meant this never happened. This report is therefore collating all the work carried out on the glass-working finds from Lincoln, mainly in the 1970s and 80s, so it can serve as an accessible archive that makes the information available by placing it in the public domain.

Because most of the work reported here was undertaken so long ago, it should be judged by the standards of its day rather than those of today. It is commendable that so many analyses were carried out, though most were qualitative analyses that identified the presence or absence of particular metals, rather than the fully quantitative analyses that are now common. X-ray fluorescence (XRF) spectrometry was chosen as the major method of analysis, partly because it was available in the AML but also because it is a rapid and non-destructive technique, at least in the way it was used on the Lincoln finds. The speed of analysis allowed most of the finds to be analysed, while its non-invasive nature preserved the finds so they are still available for further research in the future.

In addition Foley (1981, table 2) undertook thin section analysis of 12 of the crucibles, and R Keeley of the Metropolitan Police Laboratories carried out SEM/EDX analyses of 15 samples of glass for her (Appendix 4, Table 13). Details of all the scientific techniques used to study the finds are given in Section 6.

This report is divided into sections, each dealing with a specific group of finds. Within each section the general characteristics of the finds are discussed, and the assemblages for each site are briefly described. Full details of each object or fragment are given in the appendices. Section 1 comprises this introduction and Section 2 describes the properties and working of high-lead glass. Section 3 deals with the glass-melting crucibles and Section 4 the glass finds. Section 5 then compares the assemblages from different sites and sets them in a wider context, briefly summarising what is now known from other contemporary sites in the British Isles and northern Europe.

Most of the finds catalogued and reported on below were not given individual AML numbers when they arrived at the AML. Other finds were later given group AML Nos when they were moved. These AML Nos are listed with details of the relevant objects in the concordance in Appendix 1.

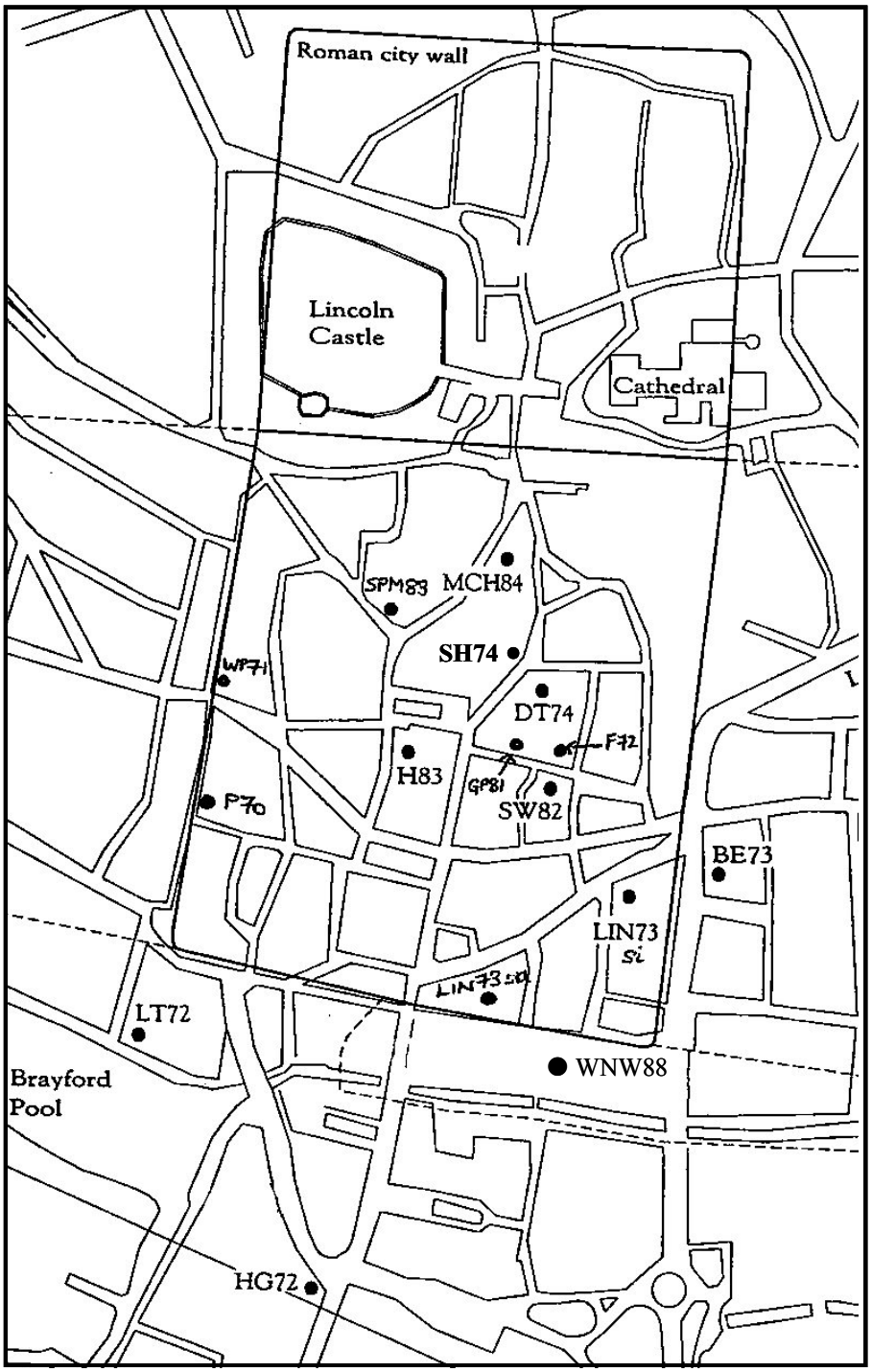


Fig1: Map showing the location of most of the sites mentioned in the text

2 HIGH-LEAD GLASS AND GLASS-WORKING

Analyses of the glass in the crucibles from the Flaxengate site demonstrated that it was high-lead glass, rather than alkali (soda or potash) glass, that was being worked (Appendix 2, Table 4). The difference in properties is most immediately evident in the specific gravity (density) of the high-lead glass which is roughly double that of ordinary alkali glass. Due to its high lead content the glass softens at a lower temperature and is therefore easier both to make and work than ordinary alkali glass. It also has a high refractive index which gives it an almost gem-like quality, making it well suited to the manufacture of trinkets such as rings and beads.

A recipe for making high lead glass is given in the 10th-12th century treatise *De artibus et coloribus Romanorum* ascribed to Heraclius (Merrifield 1867, 216). It describes 'How glass is made of lead, and how it is coloured'

> 'Take good and shining lead, and put it into a new jar, and burn it in the fire until it is reduced to powder. Then take it away from the fire to cool. Afterwards take sand and mix with that powder, but so that two parts may be of lead and the third of sand, and put it into an earthen ware vase ... But if you wish to make it appear green, take brass filings, and put as much as you think proper into the lead glass.'

The first stage turns metallic lead into lead oxide and the second reacts this with silica (sand) to produce a lead silicate glass which is about 65% lead oxide, a figure that corresponds well to analyses made of objects and glass deposits in crucibles (Table 13). Note that unlike post-medieval lead crystal, this high-lead glass contains virtually no alkalis. Heraclius' description also mirrors recent practice in glass-making where lead was introduced into the glass batch in the form of red lead (a lead oxide) which was produced by melting lead and passing a hot air blast over the surface of the melt (Rosenhain 1919, 45).

High-lead glass is normally translucent yellow or bright emerald green in colour. Sometimes 'opaque' black or, more rarely, blue or blue-green colours have been noted. The Lincoln finds are mainly yellow or green, though some were recorded as blue-green (Tables 4-7). The golden yellow is due to the natural colour of the lead silicate glass and not to the presence of impurities (Rosenhain 1919, 180). Chemical analyses have shown the green glass is coloured by small amounts of copper oxide (CuO), as Heraclius described (eg, Bayley in press, table 2).

Because no facilities for quantitative analysis of the high-lead glass were initially available, specific gravity measurements were made on most of the beads and rings. These showed a range of values running from 4.4 to 6.0, which correspond to lead oxide contents of 63-79% (see Section 7, Fig 19). In this report the term high-lead glass is used to mean glass with a specific gravity greater than 5; the glasses with specific gravities in the range 4-5 are described as lead-rich.

The finds

Apart from the crucibles (see Section 3) there is further evidence for high-lead glass-working in Lincoln. This is provided by finds of cullet (in the form of a block of high lead glass containing a lead droplet) from the Holmes Grainwarehouse site (HG72 G10), and from Flaxengate part of a rod with the impression of a gathering iron in the expanding end (F74 G232; Fig 2, centre top), a mis-made finger ring (F74 G21; Fig 3) and, of course, the rings and beads of high-lead glass that appear to correspond in lead content and colour to the glassy wastes on the crucibles.

Fig 2: Flaxengate: blobs of alkali glass with a mis-shaped bead (bottom centre) and the rod of green high-lead glass (top centre)

Fig 3: Flaxengate: mis-made ring of yellow high-lead glass (F74 G21)

In addition, fragments of Roman vessel and window glass were recovered from Flaxengate as well as a counter and waste, including blobs and a mis-shaped ?bead (Fig 2; Table 8). Although one blob (F74 G188) is stratigraphically associated with a glass working area, all of the blobs have significant amounts of manganese in them and none are high-lead glass (Tables 12-13). They probably derive from the Roman scrap vessel and window glass found on the site.

Some of these finds, including six pieces of colourless of lightly-tinted vessel or window glass, were analysed by SEM-EDX to provide quantitative data to compare with the composition of the high-lead glass (Table 13). Foley (1981, 31) had assumed that the high-lead glass included some alkali glass cullet and had conducted experiments, producing a high-lead glass by fusing lead metal with soda glass. She failed to fuse metallic lead and silica, not surprisingly perhaps as Heralius' recipe suggests it is necessary to use lead oxide to produce high-lead glass. The quantitative analytical data for the high-lead glass (Table 13) shows that its soda contents are far too low for most of the silica to have derived from a soda glass, and thus rules out any connection between the waste and scrap alkali glass and the production of high-lead glass.

3 GLASS-WORKING CRUCIBLES

Flaxengate

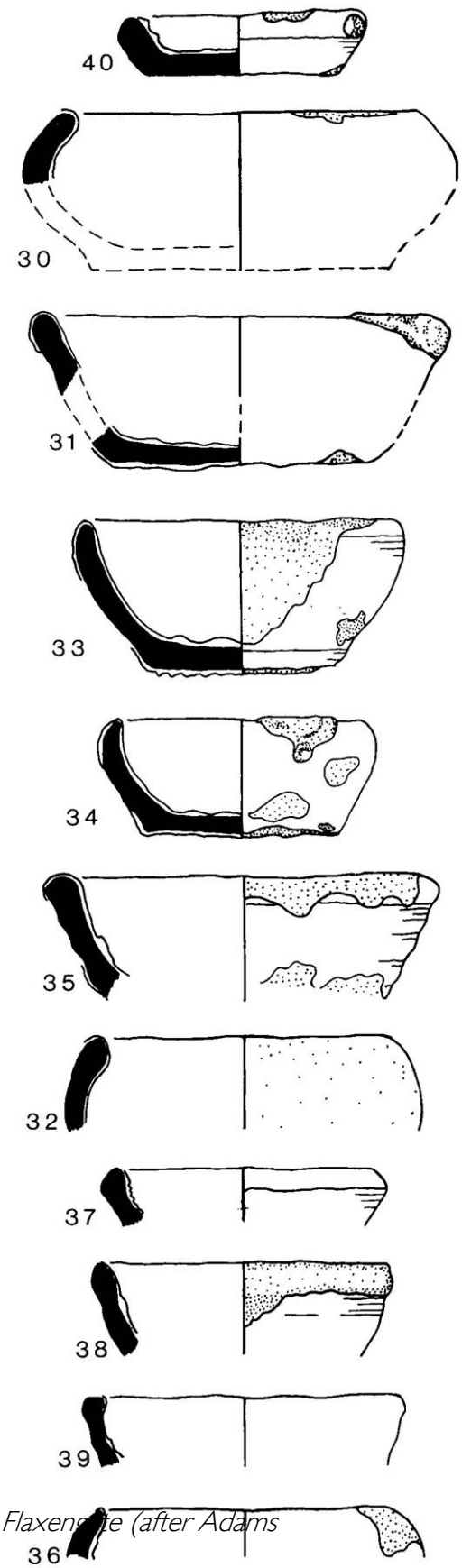
The glass-melting crucible fragments from Flaxengate are catalogued in Appendix 2. The 36 sherds represent 25 vessels (Figs 4-8), all of which contained high-lead glass. Unlike the metalworking crucibles they are oxidised-fired and include shell-tempered vessels and sandy wares. The shell-tempered wares are thought to have been made in the Silver Street kiln (Miles *et al* 1989) and are dish or bowl-shaped vessels whose form closely resembles the upper portion of pedestal lamps found at Lincoln. The other vessels, both sandy and shell-tempered, appear to be shallow, open dish- or bowl-shaped and are thought to be purpose-made crucibles (Adams Gilmour 1988, 70). The main concentrations of crucibles occur in contexts dating to the late10th to early 11th century, either associated with or close to structures 9, 14, 15, 17 and 18 (Perring 1981), with the occasional crucible found in earlier and later contexts.

The glassy deposits in the crucibles were up to 3mm thick and many also had glass adhering to the outer surface. Most of it was shades of yellow or green and more translucent than opaque, though often with more or less weathered surfaces. A network of fine cracks approximately perpendicular to the surface tended to be filled with what appeared to be fine-grained siliceous or calcitic material that is a post-burial contaminant.

Fig 4: Flaxengate: glass-working crucible containing translucent yellow glass (F74 P448), cf Figures 7, 31 and 21,4

Fig 5: Flaxengate: glass-working crucible containing translucent green glass (F76 P20), cf Figures 7, 33 and 21,5

X-radiography of selected sherds showed the varying thickness of the glass and the bubbles present in much of it. Thicker layers of glass appear brighter in Figure 8, though some of the visual differences may be due to inhomogeneity in the composition of the glass.



Flaxengate (after Adams

Fig 6: Flaxengate: glass-working crucible containing green glass. Diameter ~80mm (F74 P190), cf Figure 7, 40

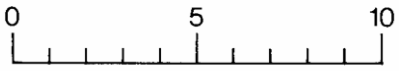


Fig 7: Glass-working crucibles from Gilmour 1988, fig 7). Scale bar 10cm

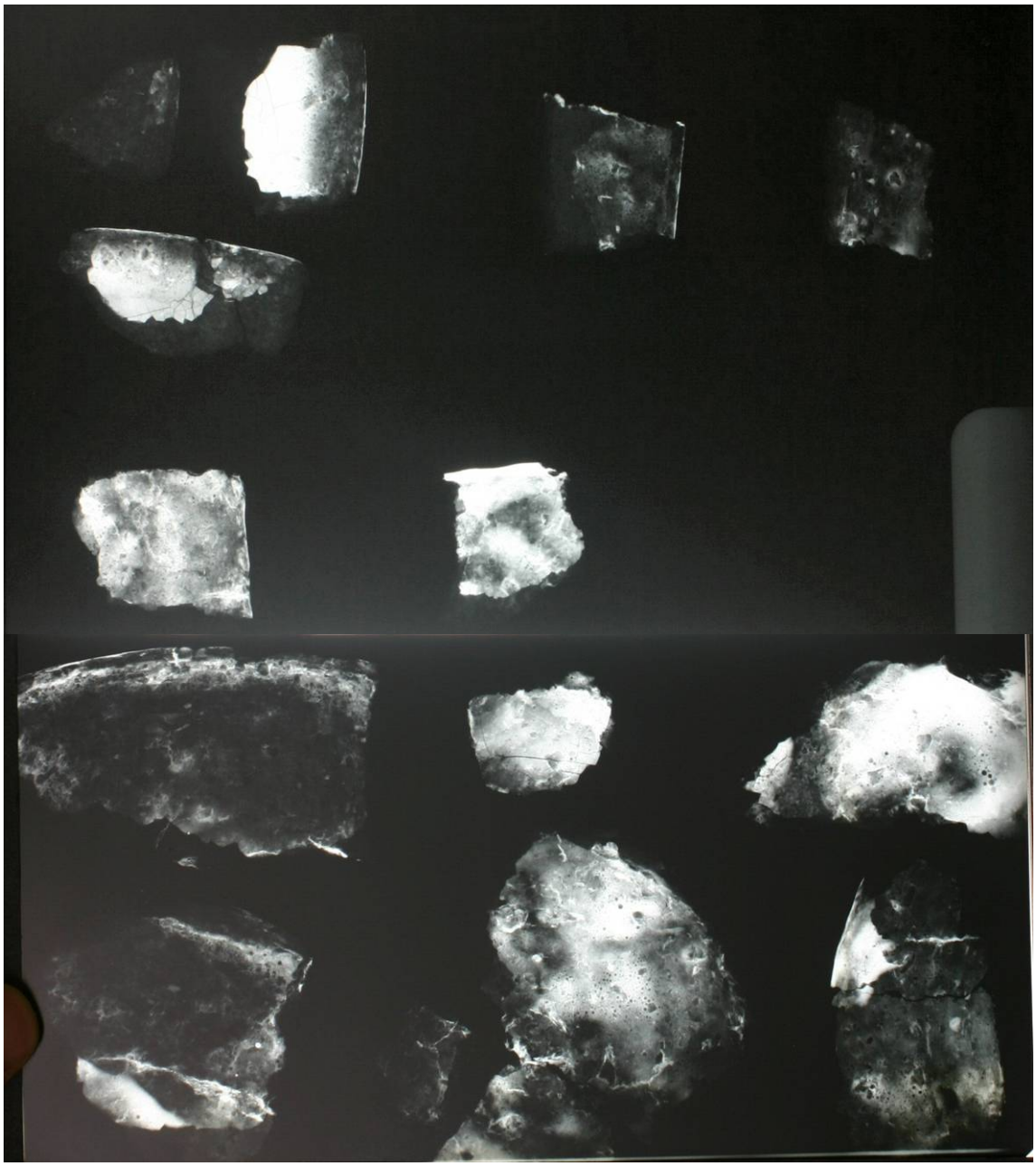


Fig 8: Flaxengate: X-radiograph of selected glass-working crucible sherds (LAT Plate 6 1980). Scale approximately 1:1
Top line (L to R): F76 P10 (3 sherds), F74 P194, F74 P97
Middle line (L to R): F74 P440, F74 P448
Bottom line (L to R): F74 P227 (2 sherds), F74 P189 (3 sherds), F74 P173 (2 sherds)

Crucible fabrics

Twelve of the crucible sherds were thin sectioned by Foley (1981) who identified four fabric groups:

A	sandy
BA	sandy with sparse shell additions

C shell tempered with dense silt-sized inclusions of sand and shell (Lincoln Saxo-Norman shelly ware)
DA shell tempered with a similar matrix to A (Lincoln kiln-type shelly ware)

The sandy wares from groups A and BA were rather higher-fired than the shelly crucibles and were thus probably more refractory. Calcium carbonate in the wares decomposes in the temperature range 650-898°C and reverts to a cryptocrystalline form. If the firing time is relatively short, or there is a high percentage of carbon dioxide in the kiln, little change may take place before about 750-800°C (Shepard 1965, 30). This is consistent with the degree of partial cryptocrystallinity seen in the shell of the wares under discussion and suggests that the temperature of use was fairly low, in the region of 800-900°C.

Unlike the sandy wares, the shell-tempered sherds were not uniformly oxidised but sometimes showed a reduced band of fabric. This probably related to the original firing and the way the wares were stacked in the kiln rather than to their reuse as crucibles, as the glassy wastes are indicative of oxidising conditions.

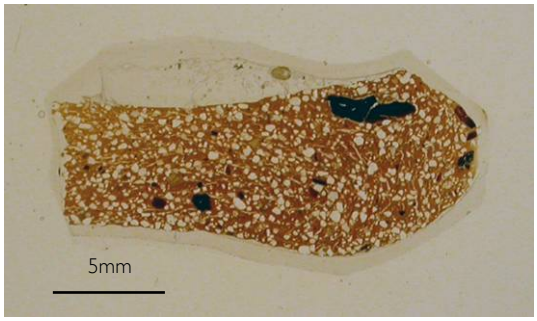


Fig 9: Flaxengate: Thin section of rim of sandy glass-working crucible (F76 P10), cf Figures 7, 38 and 11.

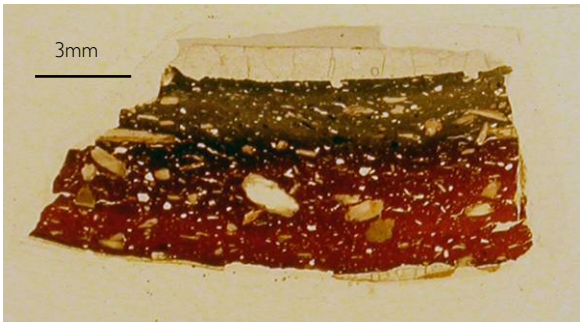


Fig 10: Thin section of sherd from a shelly glass-working crucible (F74 P210). Note the partly reduced-fired ceramic and glass on the outer as well as inner surface.

The shell-tempered crucibles showed varying degrees of erosion, caused by reaction of the fabric with the glass. Sometimes a relatively crisp boundary developed into an indistinct area surrounding a piece of shell or quartz or an 'island' of fabric in which the background minerals or inclusions could still be seen. The affected quartz grains all tended to be ovoid and of a slightly smaller size range than any quartz in the matrix, due to partial dissolution by the glass (Fig 11).

Analysis of glassy waste

It was hoped that analysis of the glassy waste on the glass working crucibles would show whether the glass had been made from primary raw materials or from recycled cullet. The only quartz particles found in the glass were those that had eroded out from the ceramic (Fig 11) so re-melting high-lead glass appears more likely than glass manufacture from sand and lead oxide, as described by Heraclius (see above). However, a good deal of

scrap lead was found in the vicinity of the crucibles (see Bayley 2008a, table 38) which could have been used as raw material if the high lead glass was made (rather than just re-melted) on the site.

The colour of the glass seen under crossed-polarizers in the petrological microscope varied from a faint yellow-green to an intense green. Under x400 magnification one glass-crucible interface which appeared fairly crisp at x100 was seen to be cloudy, with convectional swirls of brown colour arising from iron mottles in the clay body. Thus it seems clear that iron from the crucible fabric contributed to the colouration of the glass.

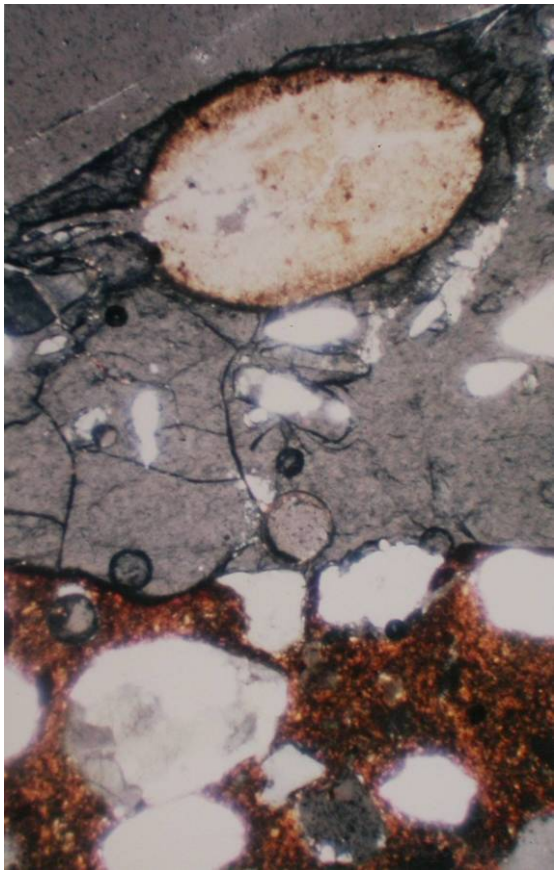


Fig 11: Thin section of glassy waste on crucible sherd (F76 P10). The quartz grains in the ceramic (below) are larger and more angular than those in the glass, suggesting the surface of the crucible has reacted with the glass, releasing the quartz grains which have been partly dissolved. Magnification ~x50.

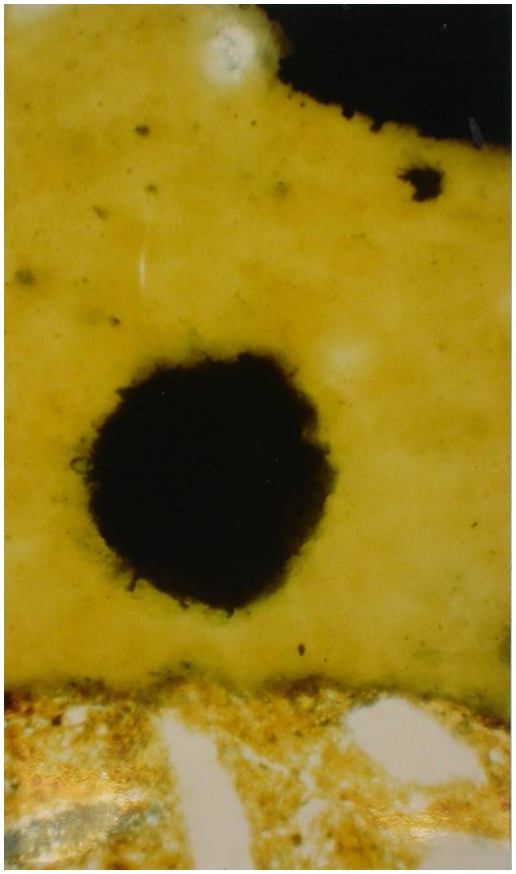


Fig 12: Thin section of yellow glass waste on a crucible (?F74 P478) which contains a lead droplet (black spot) that has probably been reduced from the melt. Magnification ~x50.

Two thin sectioned sherds showed inclusions of what is almost certainly lead in an opaque yellow-green glass matrix (Fig 12). It is possible that they represent a glassmaking process in which the lead was not completely oxidised and dissolved, but it is more likely that the lead had been accidentally reduced from the melt when the furnace atmosphere became insufficiently oxidising.

XRF analysis was carried out on almost all of the glass residues on the crucible sherds. It revealed substantial variations in composition, although all the residues were rich in lead. This can be seen as variations between the results for different crucibles, but also as variations between different sherds from the same crucible. The calcium and iron that were detected came mainly from the clay body or the shell temper in it, and the lead from the glass. The other metallic elements reflect the deliberate addition of opacifiers or colorants, perhaps added in the form of bronze or brass filings, as Heraclius describes. The elements detected by XRF are listed in Table 4.

If one ignores lead, 14 of the sherds have iron as their strongest peak, although copper and zinc were universally detected in low amounts. The glass tends to be yellow or yellow-brown with the colour due to lead silicates (Rosenhain 1919, 180), perhaps darkened by small amounts of iron. Three vessels have an opaque yellow glassy waste but there is little difference in these XRF spectra except for a slightly enhanced tin peak for one sherd*. In this case it is possible that a small amount of lead-tin oxide, an opaque yellow pigment, may be present but it is more likely that the opacity is due to time/temperature conditions in the furnace, bubbles in the glass or post-depositional weathering rather than composition.

Three of the six fragments that show a fairly strong signal for copper have greenish glass on them, confirming the presence of a copper colorant. The amount of copper in the contexts producing the glass-working crucibles was probably quite high as the main metalworking activities were nearby. This relatively high 'background' may have masked some of the quite low levels of copper that could have produced a good green colour in the glass. The XRF analyses were not quantitative so no assessment of either the lead content or the levels of other elements present could be made from them.

For this reason two crucible sherds (F74 P189 and F74 P210) and several of the glass rings were analysed quantitatively using SEM-EDX (Table 13). The percentage of lead oxide in the glass on the crucibles is given as 81% and 75% respectively, although the two sherds were later found to come from the same vessel. This difference may be due to inhomogeneity of the glass in the crucibles but could also be due, at least in part, to imprecision in the analyses (see Section 7 for discussion of the SEM-EDX data). This lead content is similar to that of the glass rings, and by comparing the amounts of all the oxides present, it is clear that the glass being melted in the crucibles is of the same composition as that of the rings. The SEM samples are polished sections and can be used to illustrate the way the high-lead glass reacts with the crucible fabric, penetrating deeply into it, eventually leading to the failure of the vessels (Fig 13).

* The small tin peaks recorded in many of the XRF spectra may be artefacts of the analytical method as the position of the tin K_α XRF peak overlaps with the lead L_α coincidence peak which is often seen when there are very high levels of lead present in the sample being analysed.

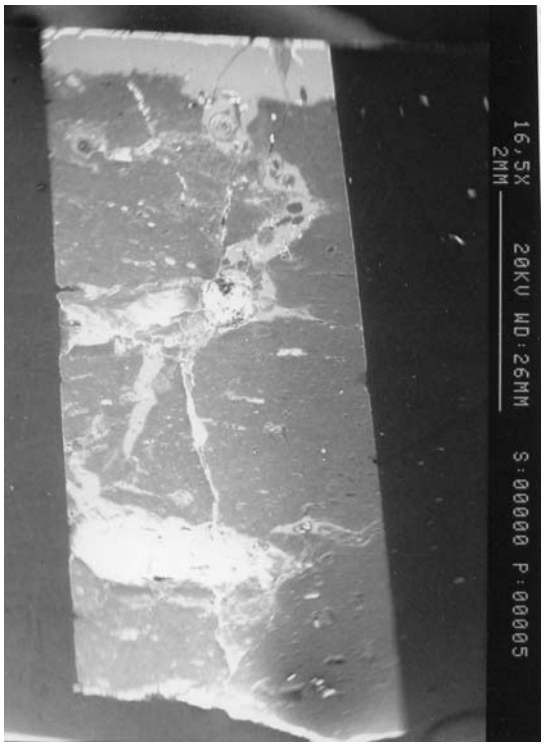


Fig 13: Flaxengate: Backscattered SEM image of sample cut from glass-working crucible (F74 P189). The brighter areas have higher average atomic number and are the lead-rich zones. The glass can be seen eroding the surface of the ceramic and penetrating deep into it.. At the top the original surface of the glass has been removed. Scale bar 2mm

Crucibles from other sites in Lincoln

A further thirteen fragments of definite or possible glass working crucibles were recovered from other sites in Lincoln (Tables 1 and 5). In addition there are at least three and possibly as many as eight from Broadgate East (BE73); one from 30-31 Broadgate (BB91); two more additional examples from Chestnut House, Michaelgate (MCH84); one from St Mark's Station (Z86); and possible examples from Silver Street (LIN73si) and St Mary's Guildhall (SMG82) (Jenny Mann, pers comm). These other glass working crucibles were made in a range of fabrics, most of them represented in the Flaxengate assemblage. The Stamford ware examples shown in Table 5 are probably not glass working crucibles. This is because Stamford ware is heavily tempered with silica which makes it liable to react with the high-lead glass and hence an unsuitable fabric for high-lead glass working.

Only two of these pieces have been analysed by XRF but their visual appearance strongly suggests that most are further evidence for high-lead glass-working in 10th or 11th-century Lincoln. Many of the pieces were redeposited in later contexts but their period of use is unlikely to extend later into the medieval period.

4 GLASS FINDS

Rings and beads

There are a total of forty-five beads of a wide range of different shapes and sizes (Table 6) and one mis-made bead (Table 8) distributed throughout the Flaxengate excavations. Many examples are either yellow or green (blue-green) glass whose translucency varied with the colour density; other colours are also represented (Fig 14). Although most of those listed in Table 6 come from post-Roman contexts, about half have been identified as Roman types and are therefore residual in the contexts in which they were found. There are however a number of Late Saxon beads which XRF analyses have shown to have an elevated lead content, or whose specific gravity is sufficiently high to suggest they too are made from high-lead glass (Table 6). Typical examples are the translucent yellow beads about 10mm in diameter shown in Figure 15. Several of the lead-rich beads are recorded as blue-green in colour, but these are generally smaller in size.

Fig 14: Flaxengate: miscellaneous glass beads

Fig 15: Flaxengate: translucent high-lead glass rings

Fig 16: Flaxengate: two yellow high-lead glass rings

Fig 17: Flaxengate: two green high-lead glass rings

The rings may have been worn as beads or hair ornaments, or as finger rings, although their internal diameters are only about 15-20mm. There are 10 translucent yellow and 5 translucent green high-lead examples from Flaxengate as well as one amber-coloured alkali glass example (Table 7; Figs 3, 16 and 17). Part of another ring (F74 M98) was originally identified as jet (Mann 1982, 11) but is probably black glass (Jenny Mann, pers comm). High-lead glass rings have also been found in other more recent excavations in Lincoln. Mann (1990) notes part of a yellow glass ring from a 10th and 11th century dump at Waterside North: Saltergate (WF89), and a virtually complete green glass ring in

a mid 10th century context at Waterside North West (WNW88), 20m to the south); there is another green fragment (SM76 G248) from the site of St Mark's Church and two thin opaque blue-black examples from Chestnut House, Michaelgate (MCH84).

It is these high-lead glass rings and beads that are the sort of objects that were being made on Flaxengate from the glass melted in the crucibles; the mis-made ring (F74 G21) is one example and at least some of the other rings and beads found on the site are also likely to have been made there. The one alkali glass ring (F72 G179) has a relatively high manganese content which is probably responsible for its pale amber colour.

Theophilus, who was writing in the early 12th century, describes how to make glass finger rings (Hawthorne and Smith 1979, 73-4). He specifies a lead-rich glass, though the chapters describing its manufacture have been lost from surviving manuscripts. He explains how to make the necessary tool - a fine iron spike hafted onto a wooden handle, but separated from it by a wooden disc (Hawthorne and Smith 1979, fig 7). The iron tip was dipped into a crucible of molten glass to pick up a small amount. The spike was then driven into a wooden post to perforate the glass, then removed and spun on its axis to stretch the glass into a ring. This would naturally produce a D-sectioned ring, the shape of most of those found. There is evidence for the use of an iron spike or former in the pattern of marks, filled with iron oxide, which are visible inside some of the rings at x100 magnification. They demonstrate contact with a heated iron surface which would have been covered with a thin layer of oxide scale. If there had been little or no rotation, the product of this method of manufacture would have been a bead, and the slightly conical perforations seen in some of those from Flaxengate support this suggestion. Foley (1981) put forward an alternative hypothesis, suggesting the rings were made from a rod of glass that was softened and wound round a former, then cut into lengths that were re-heated to fuse the ends. None of the surviving objects show evidence of joins so the method described by Theophilus is more likely to have been used.

Foley's observations of beads show they '… appear to have been formed initially by a blob of glass being dropped on a flat surface and then pierced. The entrance hole on the more rounded surface is always wider than that which exits in the flattened, rather scarred base. The scars are, however, indistinct as if cooling had been delayed …' (*ibid*, 36); this fits well with Theophilus' description. One high-lead opaque yellow bead (F74 E27 G218) had parallel flow lines which eventually fold into each other. This could be interpreted as a sign of it being wound, but Theophilus' method would produce this effect if the glass was inhomogeneous. Similar parallel flow lines have been noted on a translucent high-lead glass bead from Coppergate, York (Mainman and Rogers 2000).

Tesserae

Nine tesserae from Flaxengate were examined, both microscopically and by XRF. Most were opaque blue, but some were of greener shades (Table 9; Fig 18). The XRF analyses showed that the tesserae were alkali glasses containing significant amounts of antimony, the normal opacifier in Roman glass. However, all come from post-Roman contexts, or

contexts with intrusive post-Roman finds, so although they could perhaps have come from the Roman building that underlies the western end of the Flaxengate site, it is more likely that they were brought to the site later, as raw material to be used in small-scale glass working; Theophilus describes removing tesserae from Roman buildings and suggests this re-use was not unusual in the early medieval period (Hawthorne and Smith 1979, 59).

It is thus likely that the tesserae were brought to Lincoln as a raw material, maybe for enamelling metalwork (Bayley forthcoming) or for post-Roman bead making as at Paviken, on Gotland (Lundström 1968). Glass with this sort of composition was used to make blue beads on the Coppergate site in York in the 10th century (Bayley and Doonan 2000, 2525-2528) but there is no evidence, except the presence of the tesserae, for similar activity in Lincoln. There is certainly no compositional similarity between the tesserae and the high-lead glass, so the former cannot have been incorporated into the latter.

A blue glass tessera was also found at Broadgate East and a translucent emerald green one at Brayford Wharf East (Price *et al* forthcoming). A few glass tesserae also came from the 1947 Flaxengate excavations, just to the NE of the excavations reported on here. An initial report (Webster 1948) describes them as coming from a late 2nd-3rd century context associated with marble wall veneers, which suggests that in this case they were intended for decorating a substantial Roman building. Further work (Coppack 1973) showed this context was from levelling the site during the construction of Roman Building B in the late 3rd century; two (unstratified) gold-glass tesserae and also a group of thirteen unstratified tesserae are recorded (*ibid*, 81).

Fig 18: Flaxengate: blue and green glass tesserae

Smoothers

Work by Mortimer (1995) has shown that some linen smoothers (slick stones) were made from lead-rich glasses, and more recently Gratuze *et al* (2003) have shown the glass was almost certainly the by-product of lead smelting. Examples have been identified from several sites in the British Isles (Bayley in press, table 3) so some of the smoothers found in Lincoln were analysed to see if they too had this unusual composition (Tables 10-11). Disappointingly, the Lincoln smoothers all proved to be made from alkali glasses, most probably potash glass.

5 DISCUSSION

The evidence for high-lead glass-working in Lincoln has been set out above. It is apparent that the vast majority of the finds come from the Flaxengate site, though there are small numbers of related finds from other sites in the city. Whether these sites represent further areas where this type of glass-working was carried out in the 10th-11th centuries is less certain as many of the finds are from later contexts where they are residual or re-deposited, as at Lucy Tower (LT72).

High-lead glass elsewhere

High-lead glass suddenly appears in the British Isles in the 10th century. Its origins almost certainly lie in the Slav lands of eastern Europe where trinkets like those found on Flaxengate are known from the 9th century onwards, with finds most common in the 11th and 12th centuries (Ullrich 1989). Smaller numbers of similar finds are known from Scandinavia, as at Haithabu (Steppuhn 1998), although in general high-lead glass appears to be rare in Scandinavia at this time (Callmer 1997). Occasional finds of high-lead glass have also been identified from Carolingian contexts in north-western Europe (Danielle Calluwe, pers comm).

It is not unexpected to find relatively small numbers of high-lead glass trinkets which have close parallels in eastern Europe in the British Isles in the 10th and 11th centuries as this was the period of the Viking settlements, and Vikings were renowned for their long-distance trading connections which reached from the Atlantic to the Black Sea. Parallels to the rings and beads from Lincoln can be found in York (eg Henderson and Warren 1986, Mainman and Rogers 2000), at Meols (Tyson 2007) and also in Dublin. What is more surprising perhaps is that high-lead glass objects have also been found at a number of English sites outside the area of the Danelaw such as Hereford (Bayley 1985), Oxford and Winchester (Bayley 1990) (Bayley in press).

High-lead glass-working elsewhere in the British Isles

There is a variety of evidence for the working of high-lead glass in three other cities in the British Isles – Gloucester (Bayley 1979), York (Bayley 1986 and 1987; Bayley and Doonan 2000) and Dublin; in York the finds come from several separate excavations.

The glass-working crucibles from Gloucester are hand-made, of local oxidised-fired fabrics, and have similar shapes to those from Lincoln – flat-bottomed, shallow bowls with the maximum diameter at or near the rim of 110-140mm (Heighway *et al* 1979, Fig 7, nos 59-66). All the glass in them is yellow, though often with a weathered surface. In addition there are irregular lumps of glass (?cullet) and two pieces of glassy waste which are vesicular and inhomogeneous and may represent partly-made high-lead glass.

From York there are a few oxidised-fired glass-melting crucibles (Bayley 1986; Mainman 1990, fig 205 nos 2357-66) where the glass varies in colour from golden to olive green,

dark brown and black, with more than one colour visible on many sherds; where there is an added colorant, it is iron. The composition of this glass can be paralleled in some of the beads from York (Henderson and Warren 1986). However the majority of the c.1600 crucible sherds from York are rather different. They are from wheel-thrown grey-fired Stamford-ware bowls, most of which have a slightly flanged rim with a diameter of 120-150mm, sloping sides and a slightly convex base (Bayley 1987, figs 4-5; Mainman 1990, fig 205 nos 2345-56). The glassy deposits are mainly dark green to black (with 'opacity' due to depth of colour), though one was translucent yellow and about 3% of them are opaque ginger-brown, orange or red (due to reduced copper, present as Cu_2O, produced by less strongly oxidising atmospheres) – often with a range of colours on a single fragment. None of the analysed samples have the high iron levels found in 'black' glass samples, three have copper oxide contents under 1 wt%, probably similar to that in the green glass objects and crucible wastes from Lincoln, while six contain larger amounts of copper (4-10 wt% when calculated as CuO) (Bayley and Doonan 1999, table 3). There are also finds of glass dribbles and glass with adhering ceramic (Bayley and Doonan 2000). These are likely to be the result of spilling molten glass or glass that had solidified in a crucible breaking away from the vessel once it had cooled.

The crucible sherds from Dublin are white-firing ceramics containing high-lead glass that looks olive green to black and is coloured by iron (Bayley in press). Polished sections of these crucible sherds show how the glass has attacked the ceramic and penetrated into cracks in the crucible, as was seen in Lincoln (Fig 13).

High-lead glass-working outside the British Isles

Glass-working crucibles have recently been identified from Sigtuna, in central Sweden, dating to around AD 1000 (Söderberg 2008). The fragments are small but the vessels appear to have similar sizes and shapes to the Flaxengate examples; both yellow and green high-lead glasses were being worked.

Most of the previously published evidence for high-lead glass-working comes from eastern Europe and has been summarised by Ullrich (1989, Abb 14). It is interesting to note that the proportion of towns with manufacturing evidence compared to those with only finished objects appears lower than in the British Isles by a factor of about two (Bayley in press). Whether this is a real difference or one due to varied publication policies or interest in past technologies is difficult to determine.

Ullrich (1989) has suggested that migrant workers transported the raw glass westwards from its heartlands in Russia, Ukraine and middle Poland. He thus sees the manufacture of high-lead glass objects in the west, as at Hoxter in Germany, as not only imported technology, but as the work of immigrant craftsmen. While high-lead glass definitely appears to be an import into the British Isles, there is nothing to show whether it was the raw glass, the idea of making high-lead glass, or the craftsmen themselves who came here in the 10th century. Lead isotope analysis of high-lead glass from a number of countries might provide the answer.

6 SCIENTIFIC TECHNIQUES USED TO STUDY THE FINDS

All of the objects included in this report were examined using a low power binocular microscope (x10 and x30) and many were also analysed chemically. The techniques used are described below.

Radiography

Some of the glass-working crucibles sherds were radiographed in a Faxitron cabinet type X-ray machine (see Fig 8). The results showed patches of relatively high density on the crucibles due to the presence of lead-rich and high-lead glasses. Bubbles within the glass can also be seen. The variation in brightness of the radiograph was due to variations in both the lead content and thickness of the glassy layer.

Thin sections

In order to look more closely at the vitreous wastes and to observe their interaction with the clay body of the crucible, several sherds were subjected to thin section analysis by Kate Foley. Samples were mounted on slides, ground to an approximate 30 microns thickness and examined under a petrological microscope in plane-polarized light and with crossed polarizers. Most of the samples were from glass working crucibles. For further discussion of the thin sections see Foley (1981). The reference numbers of the thin sections are included in Tables 4, 5 and 7.

X-ray fluorescence spectrometry

Most of the analyses were carried out completely non-destructively by X-ray fluorescence (XRF). The XRF spectrometer used was a Link Systems MECA 10-42 energy dispersive system fitted with a rhodium X-ray tube and a lithium drifted silicon detector. Typical analytical conditions were a tube voltage of 35 kV and current of 0.03mA, an air path for the X-rays and a detector live time of 10 or 20 seconds. The range of the detector was 0-40keV with a channel width of 20eV.

The system was set up to analyse a large area (about 1cm^2). This is an advantage when dealing with heterogeneous materials as an 'average' analysis over a relatively large area is more representative than a small spot analysis. When analysing a particular object many factors such as its shape, size and surface texture, the concentration and distribution of the elements of interest, its major element composition, and the analytical conditions used can all affect the strength of the signal (peak height) produced by each element.

The elements detected are listed in the catalogues, usually in descending order of peak heights (Tables 4 and 9) which, it should be noted, are not directly related to the amount of that element present. Peak heights for some glass analyses are given in Table 12.

SEM/EDX

The imaging using the scanning electron microscope (SEM) and analysis using the attached energy-dispersive X-ray spectrometer (EDX) was carried out at the Metropolitan Police Laboratories by R Keeley. The outputs were a few Polaroid images (eg, Fig 13) and the quantitative data that is presented here as Table 13. Nowadays it is normal to analyse

several areas on each sample and average the results to obtain a more representative result; it is not known if this procedure was followed for the Lincoln samples. For optimum results, the system must be calibrated using standards of known composition that are similar to the unknown samples. It is not known what if any standards were used, and how similar their compositions were to the high-lead glasses and/or the alkali glasses.

Looking at the results, the totals for the high-lead glasses are a little on the high side but those for the alkali glasses are very low. This suggests that a single calibration may have been used for all the samples, and the enormous differences in their major element content meant that it could not give accurate results across the whole range of compositions. Problems with the high-lead glass data show up when they are compared with the lead oxide content calculated from the specific gravity measurements (see below). The soda glass would be expected to have a composition similar to that of Roman and earlier Saxon glass, ie 10-20% Na_2O, 60-70% SiO_2 and 5-10% CaO; only two of the samples fall within these limits for all three oxides.

It is certain that samples of two types of glass were analysed, but the percentages given in Table 13 must be treated with caution and should perhaps be considered as semi-quantitative at best.

Specific gravity (density) measurements

The percentage of lead oxide in glass can be estimated by measuring its specific gravity (SG). Figure 19 shows the calibration that converts SG to weight% lead oxide.

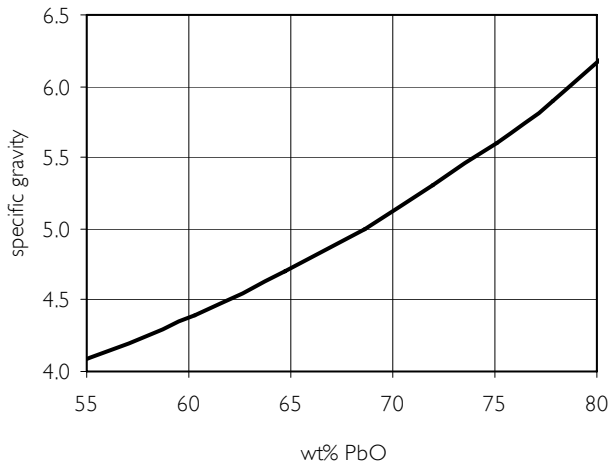


Fig 19: Calibration graph allowing lead oxide content to be estimated from the specific gravity of lead silicate glasses (after Eggert 1991, 248)

The specific gravities of the beads and rings were measured by weighing them in air and again submerged in water and then calculating the value from the formula:

SG = weight in air / (weight in air – weight in water)

The results are included in Tables 6, 7 and 11 and are plotted in Figure 20. It appears that values below 5 are outliers to the main distribution so these glasses with lower SGs are described as lead-rich while the term high-lead glass is only used for those objects with a SG above 5. At least two of the lead-rich beads (F74 G1 and F74 G339) are of colours

that normally contain significant amounts of lead (cf Bayley and Wilthew 1986) but certainly not at the levels found in high-lead glass; it is possible the other lead-rich beads were similar, but insufficiently detailed records were available when writing this report.

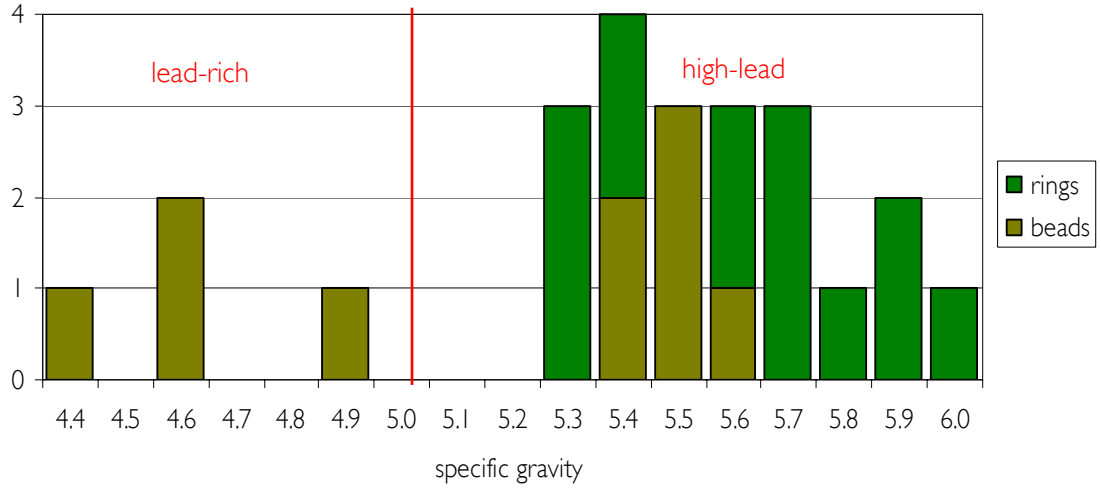


Fig 20: Bar chart showing the numbers of rings and beads of each specific gravity

Table 2: Comparison of quantitative data for high-lead glass composition

Sample	SG	PbO% from SG	PbO% by EDX	PbO% by EDX normalised	Total by EDX
F72 G25	5.4	73.06	83.60	81.51	102.56
F74 G192	5.6	75.06	82.60	80.02	103.22
F74 G281	5.7	76.01	83.65	80.06	104.49
F74 G237	5.7	76.01	84.04	80.08	104.95
F74 G291	5.9	77.81	83.58	80.23	104.18
F74 G191	6.0	78.67	81.39	77.28	105.32

The lead oxide contents of the glass calculated from the SG measurements are lower than those determined by SEM/EDX analysis (see Table 2). Inspection of the data shows the difference is not large but it is the lack of correlation between the values calculated from the SG measurements and those derived from the EDX analysis that is more worrying. This points to random errors in either or both of the data sets. There can be weighing errors leading to inaccuracies in the SG measurements. There may also be inaccuracies in the EDX values, usually originating in the calibration of the system (see above). If the EDX results are normalised, the figures are in slightly better agreement, but there is now a negative correlation with the SG-derived values! As all the measurements were done over 25 years ago it is not now possible to say why the two data sets do not agree, though accuracy in determining the lead content of high-lead glass is still a problem to analysts (Bayley in press).

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APPENDIX 1 DEFINITIONS AND ABBREVIATIONS

In Appendices 2 and 3 the column headings have the following meanings:

Finds no: site code followed by finds number
RN: unique number given to all finds (including bulk material like pottery) from Silver Street (LIN73si) and Saltergate (LIN73sa); only selected finds were also given a finds number, with each trench having its own sequence.
Cxt: alphanumeric context code assigned during excavation
cg: context group assigned during post excavation work, combining a number of individual contexts
LUB: Land use block assigned during post excavation work, combining a number of context groups
Period: most LUBs are assigned to a period or range of periods. The abbreviations used (after Steane *et al* 2001, Fig 1.5) are:

LR	late Roman	mid 3rd - late 4th century
VLR	very late Roman	late 4th - very late 4th century
LS	late Saxon	late 9th - late 10th century
SN	Saxo-Norman	early 11th - early/mid 12th century
EM	early medieval	early/mid 12th - early/mid 13th century
HM	high medieval	early/mid 13th - mid 14th century
LM	late medieval	mid 14th - end 15th century
PM	post medieval	beginning 16th - early 18th century
MOD	modern	mid 18th - 20th century

In Appendix 3, where no cg or LUB is given the Period information is taken from an earlier, less precise version of the phasing and is designated as ROM (Roman), SAX (Saxon) or MED (medieval)
Date: most LUBs have a date range (in centuries AD) which may be further qualified as early/mid/late (E/M/L)
In Appendix 3, where no cg or LUB is given the Date information is taken from an earlier version of the phasing and may no longer be correct
Context description: summary description of the context
For Flaxengate finds the Roman numerals are the phase number used by Perring (1981). Feature numbers (eg, for pits) for the 'early medieval' (late 9th to late 11th centuries) are those used by Perring (1981), and for the medieval those used by Jones (1980).

Table 3: Concordance of AML Nos with Finds Nos

AML No (part of …)	Finds No	Context	Description
801510	F72-F76	various	all the crucibles
891513	DT74II P21	KG	crucible
891515	SH74 P9	TC	crucible
891517	MCH84 184	83	crucible
891517	MCH84 191	61	crucible
891517	MCH84 580	137	crucible
891517	MCH84 525	366	crucible
891521	H83 452	513	crucible
891521	H83 829	907	crucible
891525	LT72 P12	BU	crucible
891527	LIN73 DI 329	92	crucible

APPENDIX 2 CATALOGUE OF CRUCIBLES

In Appendix 2 the additional columns are:

Fabric: of crucible

LKT	Lincoln Kiln-type shelly ware
ELSW	Early Lincoln glazed ware
STAM	Stamford ware
MS	Miscellaneous

Sherd:

B	body
Ba	base
R	rim

Glass colour: All except some of the yellow glass is translucent/transparent. Colour names were assigned by several people whose nomenclature appears to differ slightly. The colour recorded may have been affected by seeing the crucible fabric through the glass, by the thickness of the glass, and/or by post-deposition weathering.

B	brown
Bl	blue
T	turquoise
G	green
(op)Y	(opaque) yellow

Elements detected by XRF: Elements are listed in decreasing order of the height of their major XRF peak. ( ) = trace only

Pb	lead
Fe	iron
Ca	calcium
Cu	copper
Zn	zinc
Sn	tin

KF: Data taken from Foley (1981). The numbers are those on the thin sections she made, which will be deposited with the site archive. The letter codes are the fabric groups to which she assigned the sherd (see Section 3, Crucible fabrics).

Fig: References to illustrations in this report

Comments: other notes

Table 4: Catalogue of glass-working crucible sherds from Flaxengate

Finds No	Cxt	cg	LUB	Period	Date	Context Description	Fabric	Sherd	Glass colour	Elements detected by XRF	KF	Figs	Comments
F76 P10	BDT	r97	31	LS	M/L9-E10	Pit	ELSW	R	Y-G	Pb Fe Cu Ca Zn (Sn)	19 BA	21,1	
F76 P10	D29	sp60	45	LS-SN	L10-M/L11	v Spit Occupation near Str T17	ELSW					7,38	
F76 P10	E9	sp72	45	LS-SN	E-M/L11	v-vi Spit Loam dump near Str T17	ELSW		Y			8; 9; 11	previously P151
F74 P262	B96	sp52	35	LS-SN	M10-E/M11	iii-vi Spit Road & dump	LKT	B	Y	Pb Fe Ca Cu Zn (Sn)	DA	21,2	
F74 P194	E13	sp113	36	LS-SN	E/M-M/L11	vi-vii Spit Pit F13	ELSW	R	B-G	Pb Fe Cu Ca Zn (Sn)	24 39 44 A	7,30; 8; 21,3	
F74 P515	E13	sp113	36	LS-SN	E/M-M/L11	vi-vii Spit Pit F13	LKT						
F76 P11	BHX	t36	36	LS-SN	E/M-M10	iii Pit F669	LKT					5; 8; 10	
F76 P12	BHX	t36	36	LS-SN	E/M-M10	iii Pit F669	LKT					7,33	
F76 P20	BHX	t36	36	LS-SN	E/M-M10	iii Pit F669	LKT	Ba	Y	Pb Fe Ca Cu Zn (Sn)	31	21,5	
F74 P189	G35	sp62	44	LS-SN	E-E/M11	iv-v Spit Occupation	LKT	R, Ba	Y/opY	Pb Ca Fe Cu (Sn)	DA	13; 21,4	SEM analysis
F74 P210	G35	sp62	44	LS-SN	E-E/M11	iv-v Spit Occupation	LKT	R, B	G-B	Pb Ca Fe Cu Zn (Sn)	10 42	7,36	SEM analysis
F74 P190	G72	sp36	38	LS	M10-E/M11	iii Spit Dump & occupation			G			6; 7,40	diam ~80mm, ht ~10mm
F74 P173	F72	sp56	38	LS	L10	iv-v Spit Occupation & dump	LKT	R, Ba	Y	Pb Fe Ca Cu Zn (Sn)	21 46 DA	22,1	
F74 P173	E72	sp66	45	LS-SN	E-E/M11	iv-v Spit Occupation & dump	LKT		Y			7,34	previously P118
F74 P173	E71	sp66	45	LS-SN	E-E/M11	iv-v Spit Occupation & dump	LKT					8	
F74 P173	E29	sp71	45	LS-SN	L10-M/L11	iv-v Spit Dump nr Str T17	LKT						
F74 P550	J29	sp8	38	LS	E/M-M10	ii-iii Spit Dump	LKT						
F74 P137	B100	sp44	44	LS-SN	L10	iii-v Spit Occupation	ELSW		Y-B	Pb Fe Cu Ca (Zn)	26 A	22,2	
F74 P270	H15	sp62	44	LS-SN	E-E/M11	iv-v Spit Occupation	LKT	B	Y?	Pb Fe Ca Cu (Sn)		22,3	
F74 P440	F75	sp80	44	LS-SN	E-E/M11	iv-vi Spit Occupation	LKT		Y	Pb Fe Ca Zn Cu (Sn)	40? 45 DA	7,39; 8; 22,4	

Table 4: Catalogue of glass-working crucible sherds from Flaxengate (cont)

Finds No	Cxt	cg	LUB	Period	Date	Context Description	Fabric	Sherd	Glass colour	Elements detected by XRF	KF	Figs	Comments
F74 P149	A104	sp82	44	LS-SN	L10-M/L11	iv-vi Spit Occupation & dump	ELSW	B	T-G	Pb Fe Cu Ca Zn (Sn)	35 A	22,5	
F74 P478	B98	sp83	44	LS-SN	L10-M/L11	iii-vi Spit Occupation & dump	LKT	R	opY	Pb Fe Zn Ca Cu Sn	33 DA	12?; 22,6	lead metal present
F74 P158	E6	sp20	45	LS-SN	E/M10-M/L11	ii-vi Spit Dump	LKT	R	opY	Pb Fe Ca Cu Zn		7,37; 22,7	
F74 P97	B98	sp83	44	LS-SN	L10-M/L11	iii-vi Spit Occupation & dump	LKT	R		Pb		7,32; 8	rim diam 60mm
F74 P501	B93	sp84	44	LS-SN	L10-M/L11	iv-vi Spit Occupation	LKT	Ba	opY	Pb Fe Ca Zn Cu Sn		22,8	
F74 P448	D30	sp109	45	LS-SN	E-M/L11	v Spit Occn Str T17	LKT	R	opY	Pb Ca Fe Cu Zn Sn	22 34 37 DA	4; 8; 23,1	
F74 P448	G71											7,31	
F74 P548	G49	sp13	45	LS-SN	L10	iii-iv Spit Dump	LKT						
F74 P368	G31	sp58	45	LS-SN	L10-E/M11	iii-iv Spit Dump & occupation	LKT	?	G	Pb Fe Ca Cu (Sn)		23,2	previously P199?
F74 P566	G31	sp58	45	LS-SN	E-E/M11	iii-iv Spit Dump & occupation							
F74 P235	AZX	t68	58	SN	L11-E12	vi Levelling dump							
F74 P227	ARO	t80	61	SN	E/M-M/L11	vi Pit F676	LSH	R	Y-B	Pb Fe Ca Cu Zn (Sn)	36 C	7,35; 8; 23,3	2 sherds
F74 P514	AQQ	t81	63	SN	L11-E12	vii Levelling dump	MS						
F72 P82	ABU	t121	82	EM	M/L12-E/M13	x Levelling dump	LKT						
F72 P30	ABN	t242	95	EM	E/M-M/L12	xi Pit F731	STAM	B		Pb Cu Zn			metalworking
F74 P434	+	-	-	LS-SN	-	Unstratified	LKT	B	Bl	Pb Sn Fe Zn Ca Cu	14 18 C		

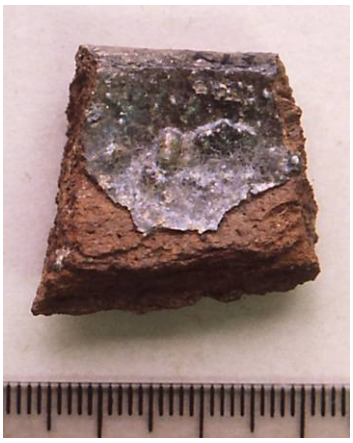
Multiple sherds enclosed by boxes come from the same crucible. Figure numbers within the boxes refer to one or more of the sherds.

Table 5: Catalogue of definite and possible glass-working crucible sherds from other sites in the city

Finds No	Cxt	cg	LUB	Period	Date	Description	Fabric	Glass colour	XRF	Comments
Saltergate										
LIN73 DI 329	92	28	19	LS-SN	L9-10	Str 2 wall	LKT			?glass
Lucy Tower										
LT72 P12	BU	18	7	HM-LM	L13-L14	Dump	LOC SANDY			?glass
Danes Terrace										
DT74II P21	KG	286	71	PM	E-M16	Cess-pit	EMED		Pb	
Steep Hill										
SH74 P9	TC	32	18	HM-LM	12-13 (15?)	Dump (terrace make-up?)	ELSW EMED			KF: TS4
Chestnut House, Michaelgate										
MCH84 184	83	16	10	LS-SN	12	Pit	ELSW			
MCH84 191	61	22	10	LS-SN	12	Pit	LKT			
MCH84 580	137	149	42	EM-HM	E/M13-M14	Dump (terrace make-up)	LKT			
MCH84 525	366	184	17	LS-SN	11	Pit	STAM			?metalworking
Hungate										
H83 452	513	250	52	PM	16	Str 12 demolition	LS/SNLS			
H83 829	907	113	24	LS-SN	E10-E/M11	Dump	ELSW		Pb	
Homes Grainwarehouse										
HG72 P1	BC	130	29	VLR-LS	VL4-L10	Demolition Str6		Y		buff deposit outside
HG72 P17	CU	140	36	LS	L10-M/L11	Str 8.2	STAM			
West Parade										
WP71 P40	1 AN	-	P6b	EM	M-L12	Dump	STAM			

1

2



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4

5

Fig 21: Flaxengate glass-working crucibles. 1: F76 P10, 2: F74 P262, 3: F74 P194, 4: F74 P448 (cf Figure 4) and ?F74 P189 (bottom right), 5: F76 P20/P11/P12 (cf Figure 5) and ?F74 P210 (lower centre).
Scale divisions are mm.

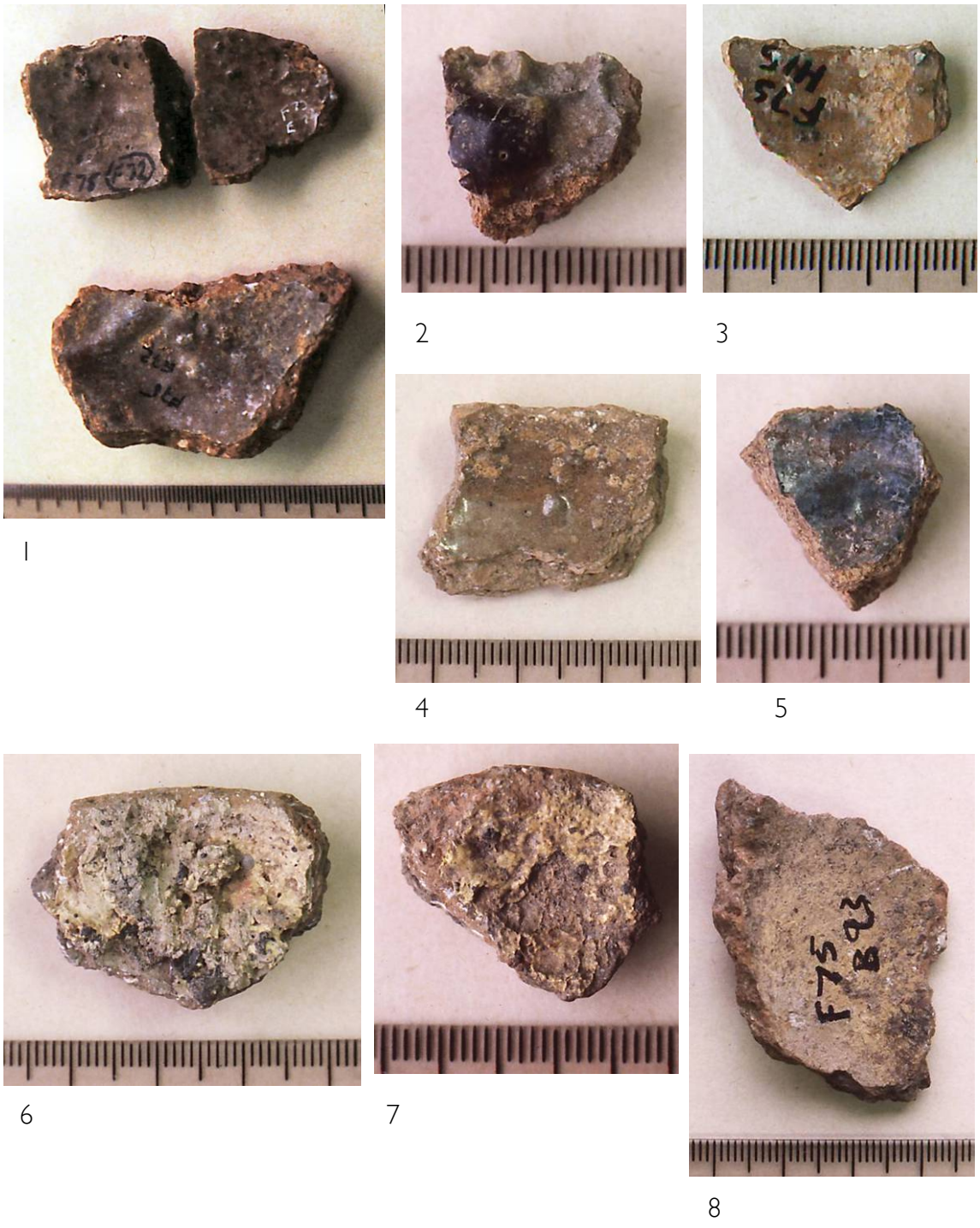
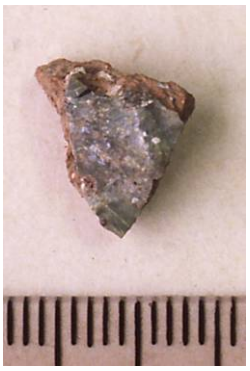


Fig 22: Flaxengate glass-working crucibles. 1: F74 P173, 2: F74 P137, 3: F74 P270, 4: F74 P440, 5: F74 P149, 6: F74 P478, 7: F74 P158, 8: F74 P501. Note Nos 6 and 7 are from the same crucible. Scale divisions are mm.

1



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3

Fig 23: Flaxengate glass-working crucibles. 1: F74 P448, 2: F74 P368, 3: F74 P227. Scale divisions are mm.

APPENDIX 3 CATALOGUE OF GLASS FINDS

In Appendix 3 the additional columns are:

Diam (int/ext): internal or external diameter in mm

Size: dimensions in mm

Description: of the object

- R Roman
- LS Late Saxon

Colour: of the glass

- B blue
- T turquoise
- B-G bluish-green
- G green (varies from apple green to emerald green)
- Bk black
- Y/Br yellow/brown
- Y yellow
- O orange
- X nearly colourless

SG: specific gravity (density)

Analyses: Type(s) of analysis undertaken.

Data from XRF analyses is presented in Table 12 and that for SEM/EDX analyses in Table 13

Elements detected by XRF: Elements are listed in decreasing order of height of their major XRF peak. ( ) = trace only

- Mn manganese
- Fe iron
- Ni nickel
- Cu copper
- Zn zinc
- Pb lead
- Sn tin
- Sb antimony

Glass type:

- High-lead: Lead silicate glass with a measured SG above 5.0 (see Section 7)
- Lead-rich: Usually a lead silicate glass with a measured SG below 5.0 (see Section 7). Most but not all of these objects are most probably high-lead glasses
- Alkali: Probably soda lime silica glass (on the basis of the lack of weathering) but in most cases the levels of soda and potash were not determined so the exact type of glass remains unknown
- SLS: Soda lime silica glass, often known as soda glass
- + Sb: Antimony detected in significant amounts. Antimony was often added to Roman glass to decolorize it so these glasses as almost certainly Roman in origin

Comments: other notes

- KF Nos = reference numbers of glass samples mounted in resin blocks for SEM/EDX analysis
- TS Nos = reference numbers on thin sections

Table 6: Catalogue of glass beads from Flaxengate

Finds No	Cxt	cg	LUB	Period	Date	Context description	Diam (ext)	Colour	Description	SG	Analyses	Glass type
F76 G486	CAS	r24	7	LR	L3	Destruction debris Str R2		T	R square			
F76 G307	BVD	r80	16	VLR-LS	L/VL4-L9	Large pit		T	R segmented fragment			
F76 G121	BDQ	r90	25	LS	L9-E10	Levelling dump		T	R annular			
F76 G160	BDQ	r90	25	LS	L9-E10	Levelling dump		'Bk'	LS cylindrical segmented iridescent			
F76 G116	BDS	r90	25	LS	L9-E10	Levelling dump		X	R annular			
F76 G495	BHV	r101	17	VLR-LS	L/VL4-L9	Dump		B-G	R cylindrical			
F76 G294	BRL	r90	25	LS	L9-E10	Levelling dump		B	R cylindrical			
F76 G444	CAH	r101	17	VLR-LS	L/VL4-L9	Dump		T	R cylindrical segmented			
F76 G378	CAI	r101	17	VLR-LS	L/VL4-L9	Dump		T	R cylindrical segmented			
F76 G94	BDM	r100	32	LS	L9-E10	Dump		B-G	R cylindrical			
F76 G417	BHU	r105	17	VLR-LS	L/VL4-L9	Turf		T	R segmented			
F74 G70	APN	t19	32	LS	E/M-M10	ii Levelling dump		G	R cylindrical			
F76 G30	BCU	t19	32	LS	E/M-M10	ii Levelling dump		G	R cylindrical			
F76 G153	BEU	t19	32	LS	E/M-M10	ii Levelling dump		G	R cylindrical segmented			
F76 G194	BEU	t19	32	LS	E/M-M10	ii Levelling dump		X	LS segmented + ?silver foil			
F76 G308	BSP	t21	33	LS	L9-E10	ii Str T7		G	R square			
F74 G275	BCP	t164	36	LS	M/L9-M/L11	ii-iv Levelling dump		G	R annular			
F74 G218	E27	sp20	45	LS-SN	E/M10-M/L11	ii-vi Spit Dump	12	Y/Br	LS annular weathered surface	5.5	XRF	high-lead
F74 G113	AVI	t193	53	SN	E-M/L11	iv-v Dump assoc Str T17	9	G	LS gadrooned	5.5	XRF	high-lead
F74 G183	F31	sp67	45	LS-SN	L10-E/M11	iv-v Spit Dump & occupation		Y	LS annular	5.6	XRF	high-lead
F74 G227	F36	sp74	44	LS-SN	E-E/M11	iv-vi Spit Occupation		G	R globular			
F74 G228	F36	sp74	44	LS-SN	E-E/M11	iv-vi Spit Occupation	9	Y	LS annular weathered surface	4.9	XRF	lead-rich
F74 G66	AWR	t68	58	SN	L11-E12	vi Levelling dump		B	R cylindrical			
F74 G89	AXG	t289	36	LS	E-M/L11	vi Pit F675		'Bk'	LS annular			

Table 6: Catalogue of glass beads from Flaxengate (cont)

Finds No	Cxt	cg	LUB	Period	Date	Context description	Diam (ext)	Colour	Description	SG	Analyses	Glass type
F74 G150	E9	sp72	45	LS-SN	E-M/L11	v-vi Spit Dump	2.5	G	?R sub-conical 5mm long		XRF	high-lead
F74 G82	AZL	t69	57	SN	E/M-M/L11	vi Road surface	9	G	LS annular	4.4	XRF	lead-rich
F72 G153	AEA	999				Unphased	10	X	LS annular		XRF	alkali
F74 G1	AEE	t99	71	EM	M/L11-E/M12	viii Levelling dump	7	Y/Br	LS annular weathered	3.2	XRF	lead-rich
F74 G73	AIO	t99	71	EM	L11-E12	vii Levelling dump	2.5	G	?R conical 4mm long		XRF	high-lead
F74 G339	AOM	t81	63	SN	L11-E12	vii Levelling dump		O	LS cylindrical opaque	4.6		lead-rich
F74 G53	AQQ	t81	63	SN	L11-E12	vii Levelling dump		B	LS gadrooned			
F74 G65	ARJ	t81	63	SN	L11-E12	vii Levelling dump		B	R drawn cylindrical			
F74 G149	AVT	t81	63	SN	L11-E12	vii Levelling dump		?	LS segmented ?olive green			
F74 G5	AKP	t160	72	EM	E/M-M12	viii Dump assoc Str T27/28	6	G	LS cylindrical	4.6	XRF	lead-rich
F72 G119	ZL	t121	82	EM	M/L12-E/M13	x Levelling dump	10	Y	LS annular 2 frags	5.4	XRF	high-lead
F72 G138	ABN	t242	95	EM	E/M-M/L12	xi Pit F731			LS annular green on yellow 'eyes' on ?red			
F72 G123	ABP	t121	82	EM	M/L12-E/M13	xi Pit F734		B	LS biconical			
F72 G95	ACE	t156	85	EM	E/M-M12	x-xi Dumps assoc Str T38 & T42/43	9	Y	LS annular	5.5	XRF	high-lead
F72 G152	ACY	t156	85	EM	E/M-M12	x-xi Dumps assoc Str T38 & T42/43		B	R biconical			
F74 G60	AIT	t156	85	EM	E/M-M12	x-xi Dumps assoc Str T38 & T42/43		B	LS gadrooned			
F72 G71	YG	t143	105	EM	E/M-M/L12	xii Dump assoc Str T46 & T51		T	R segmented iridescent			
F72 G79	OW	s29	116	EM-HM	L13-M14	Garderobe Str Eii	10	Y	LS annular	5.5	XRF	high-lead
F74 G151	+					Unstratified		Bk?	LS gadrooned iridescent surface			
F76 G183	+					Unstratified			annular disintegrated			
F76 G470	+					Unstratified		T	R segmented			

Table 7: Catalogue of glass rings from Flaxengate

Finds No	Cxt	cg	LUB	Period	Date	Context description	Diam (int)	Description	SG	Analyses	Glass type	Comments
F74 G291	H53	sp37	38	LS	M-L10	ii-iii Spit Dump & occupation	16	yellow	5.9	XRF+SEM	high-lead	KF5
F74 G224	F70	sp61	38	LS	M-L10	iii-iv Spit Occupation/ dump/occupation		green	5.4		high-lead	
F74 G281	H12	sp88	38	LS	L10-M/L11	iii Spit Occupation	15, 22	green, 2 frags	5.7	XRF+SEM	high-lead	KF3 + TS48
F74 G192	B95	sp65	44	LS-SN	E/M11	iv-v Spit Occupation	22, 22	yellow, 2 frags	5.6	XRF+SEM	high-lead	KF2
F74 G234	F52	sp36	38	LS	ML10-E/M11	iii Spit Dump & occupation	16	green	5.3	XRF	high-lead	
F74 G244	G29	sp19	45	LS-SN	E-M/L11	iii-iv Spit Dump		yellow, whole	5.6		high-lead	
F74 G205	G31	sp58	45	LS-SN	E-E/M11	iii-iv Spit Dump & occupation		yellow, whole	5.7		high-lead	
F74 G191	H10	sp88	38	LS	L10-M/L11	iii Spit Occupation	18	yellow	6.0	XRF+SEM	high-lead	KF4
F74 G315	H10	sp88	38	LS	L10-M/L11	iii Spit Occupation	15	yellow	5.9	XRF	high-lead	
F74 G237	E13	sp113	36	LS-SN	E/M-M/L11	vi-vii Spit Pit F13	20, 22	yellow, 2 frags	5.7	XRF+SEM	high-lead	KF6 + TS47
F76 G31	BDC	t289	36	LS-SN	E-M/L11	vi Pit F675	14	yellow	5.3	XRF	high-lead	
F74 G230	F35	sp74	44	LS-SN	E-E/M11	iv-vi Spit Occupation	16	yellow	5.3	XRF	high-lead	
F72 G179	ACY	t156	85	EM	E/M-M12	x-xi Dumps assoc Str T38 & T42/3	15	pale amber	2.5	XRF	alkali	high Mn/Fe
F74 G21	APX	t235	95	EM	M12-E13	xi Pit F724	14	yellow, mismade	5.4	XRF	high-lead	Figure 3
F72 G5	AS	s1	108	EM-HM	E13-M14	Levelling dump	20	green	5.8	XRF	high-lead	
F72 G25	DN	s23	115	EM-HM	E13-M14	Pit F124 assoc Str G	15	green	5.4	XRF+SEM	high-lead	KF1

Table 8: Catalogue of glass scrap and waste from Flaxengate

Finds No	Cxt	cg	LUB	Period	Date	Context description	Description	Size (mm)	Analyses	Glass type	Comments
F72 G33	+	-	-	-	-	Unstrat	?R				
F76 G210	BDQ	r90	25	LS	L9-E10	Levelling dump					
F76 G284	BNG	t259	44	LS	E/M-M10	iii Pit F670	R				
F76 G245	BNK	t261	31	LS	L9-M10	I Pit F658					
F74 G116	APN	t19	32	LS	E/M-M10	ii Levelling dump	R vessel frag				
F76 G17	BCU	t19	32	LS	E/M-M10	ii Levelling dump	R				
F76 G186	BCU	t19	32	LS	E/M-M10	ii Levelling dump	R vessel frag				
F76 G28	BCU	t19	32	LS	E/M-M10	ii Levelling dump	R				
F76 G29	BDG	t19	32	LS	E/M-M10	ii Levelling dump	R vessel handle		XRF	alkali + Sb	
F74 G290	G93	sp3	42	LS	E/M-M10	ii-iii Spit Occupation	R blob	8 x 7	XRF	alkali	
F74 G324	H89	sp7	37	LS	E/M-L10	ii-iii Spit Occupation	blob/bead, mismade	ext diam 8	XRF	alkali	
F74 G232	G29	sp19	45	LS-SN	E-M/L11	iii-iv Spit Dump	rod	9 x 3	XRF	high-lead	
F74 G188	H10	sp88	38	LS	L10-M/L11	iii Spit Occupation	R blob	9 x 8	XRF	alkali	
F74 G69	AON	t81	63	SN	L11-E12	vii Levelling dump	R				
F74 G107	ARJ	t81	63	SN	L11-E12	vii Levelling dump	R vessel handle frag	30 x 6	XRF+SEM	alkali + Sb	KF9
F74 G83	ARJ	t81	63	SN	L11-E12	vii Levelling dump	R blob	9 x 6	XRF	alkali	
F72 G149	AMG	t234	95	EM	M/L12-E13	xi Pit F723	R counter				
F74 G286	H30	sp88	38	LS	L10-M/L11	iii Spit Occupation	R blue-green vessel frag		SEM	SLS	KF10
F74 G162	G8	sp16	45	LS-SN	E/M10-M/L11	ii-iv Spit Dump	R clear vessel frag		SEM	SLS	KF11
F74 G147	AVI	t193	53	SN	E-M/L11	iv-v Dumps assoc Str T17	R green window frag		SEM	SLS	KF12
F74 G312	J11	sp37	38	LS	M-L10	ii-iii Spit Dump & Occupation	R clear vessel frag		SEM	SLS	KF13
F74 G338	F5	sp16	45	LS-SN	E/M10-M/L11	ii-iv Spit dump	R clear vessel frag		SEM	SLS	KF14
F74 G245	G32	sp58	45	LS-SN	E-E/M11	iii-iv Spit Dump & Occupation	R green window frag		SEM	SLS	KF15

Table 9: Catalogue of glass tesserae from Flaxengate

Finds No	Cxt	cg	LUB	Period	Date	Size (mm)	Colour	Elements detected by XRF	Comments
F72 G184	AKN	t306	73	EM	E/M12-E13	6 x 6	blue	Mn Fe Cu Zn Pb Sb	
F74 G49	ATS	t81	63	SN	L11-E12	6 x 10	blue	Mn Fe Cu Zn Pb Sb	
F76 G327	BNE	r91	23	LS	L9-E10	12 x 10	blue/green	Mn Fe (Ni) Cu Pb Sb	
F76 G377	CAI	r101	17	VLR-LS	VL4-L9	5 x 6	blue	Mn Fe Cu Zn Pb Sb	
F76 G484	CAS	r24	7	LR	L3	10 x 7.5	blue	Mn Fe Cu Zn Pb Sb	
F76 G454	+	-	-	-	-	10 x 6	blue	Mn Fe Cu Zn Pb Sb	
F76 G219	BEU	t19	32	LS	E/M-M10	8 x 14	blue	Mn Fe Cu Zn Pb (Sn) Sb	
F76 G442	BVN	r78	13	LR	L3-E4	10 x 7	green	Mn Fe Cu Zn Pb Sn Sb	
F76 G424	BXN	r101	17	VLR-LS	VL4-L9	5 x 7	turquoise	Mn Fe Cu Zn Pb Sb	
F76 G511	BHU	r105	17	VLR-LS	VL4-L9	4 x 6	red	Mn Fe Cu Zn Pb Sb	not a tessera
Note that cobalt, at the levels present in blue glass tesserae, was not detectable under the analytical conditions used									

Table 10: Catalogue of analysed glass linen smoothers from Flaxengate

Finds No	Cxt	cg	LUB	Period	Date	Context description	Description	Analyses	Glass type
F74 G14	ANG	t104	73	EM	E/M11-M12	viii Str T28		XRF	alkali
F74 G159	B93	sp84	44	LS-SN	L10-M/L11	iv-vi Spit Occupation		XRF	alkali
F76 G210	BDQ	r90	25	LS	L9-E10	Levelling dump		XRF	alkali
F72 G159	AHO	t120	80	EM	E/M-M12	ix Pit F712		XRF	alkali

Table 11: Catalogue of selected glass finds from other sites in the city

Finds No	Cxt	cg	LUB	Period	Date	Context description	Description	Analyses	Glass type	Comments
Holmes Grainwarehouse										
HG72 G57	+	-	-	-	-	Unstrat	green bead, iridescent surface		high-lead	SG=5.46
HG72 G10	AD	146	37	LS	E-M11	Dump	block of translucent yellow glass (~25x20x5mm) with included lead droplet	XRF	high-lead	
HG72 G34	BH	130	29	VLR-LS	VL4-10	Demolition Str 6	bubbly pale green glass with weathered surface	XRF	alkali	
HG72 M42	DD	165	42	HMED	14	Construction Str 9	opaque orange bead	XRF		
HG72 G92	AZ	96	25	MROM	E3	Demolition Str 5	green glass dribble similar to G34 but paler and devitrified; also second fragment	XRF	alkali	
WNW88 35	233	121	-	EM	12?	Pit	smoother fragment	XRF	alkali	

APPENDIX 4 ANALYTICAL DATA FOR GLASS FINDS

In Appendix 4 the additional columns are:
XRF peak height: The peak heights were recorded in an attempt to semi-quantify the elemental data rather than just record presence/absence. Because of the varying object shape and size, the best way to use this data is to compare element ratios as this minimises the inter-sample variability (see discussion below).

Mn	manganese
Fe	iron
Ni	nickel
Cu	copper
Zn	zinc
Pb	lead
Sn	tin
Sb	antimony

Glass type:
The green and yellow shading denotes high-lead glass of these two colours. The remainder are alkali glasses, most probably soda lime silica glass (on the basis of the lack of weathering); some have a significant antimony (Sb) content and are therefore most likely to be Roman scrap.
SEM:
Y = see Table 13 for EDX/SEM analyses of these samples.

Discussion of the analytical data

For the high-lead glass, the copper/lead peak height ratio allows us to look for deliberate additions of copper, which we would expect to find in the green glasses but not in the yellows. The average ratio for green glasses is almost twice that of the yellow glasses, which points to a deliberate addition of copper in the greens. This can be compared with the iron/lead ratio which is almost identical for both groups, suggesting that the iron is accidentally present as an impurity in all the high-lead glass.

All the alkali glass has relatively high manganese contents; it was not detectable or present at much lower levels in the high-lead glass. Most of the alkali glass is colourless or only very lightly tinted so it is likely that the manganese was deliberately added; it was a well-know decoloriser, counteracting the greenish tinge produced by traces of iron in the glass. Antimony can have a similar effect, and it is notable that two of the analyses in Table 12 have significant antimony contents.

As mentioned in Section 3, the peaks recorded as tin in Table 12 may artefacts of the analytical conditions used.

See Section 6 for discussion of the SEM/EDX data.

Table 12: XRF data for glass finds from Flaxengate

Finds No	Cxt	XRF peak height								Glass type	SEM
		Ca	Mn	Fe	Cu	Zn	Pb	Sn	Sb		
Beads											
F73 G119	ZL	1210	0	6360	1170	2093	46244	656	0		
F73 G153	AEA	424	419	705	355	626	0	0	0	alkali	
F73 G79	OW	432	0	842	865	1400	15465	135	0		
F73 G95	ACE	969	0	1255	827	1621	17815	127	0		
F74 G1	AEE	1542	722	2968	1892	2338	29482	271	0		
F74 G113	AVI	863	0	1078	1157	1425	24367	141	0		
F74 G5	AKP	780	721	1685	1497	2332	22248	182	0		
F74 G73	AIO	862	743	1612	1508	2366	12586	149	0		
F74 G150	E9	800	711	1672	1475	2334	20405	181	0		
F74 G218	E27	1900	0	1637	595	1204	25682	171	0		
F74 G228	F36	1005	0	3480	716	8640	30693	583	0		
F74 G82	AZL	921	465	1124	898	1357	24590	224	0		
Rings											
F73 G179	ACY	2461	7686	7938	1446	2494	0	0	0	alkali	
F72 G25	DN	923	0	1036	1149	1745	17529	120	0		Y
F72 G5	AS	804	0	1013	1159	1517	23046	145	0		
F74 G21	APX	691	0	1559	1239	2044	34434	481	0		
F74 G31	BDC	705	0	883	747	1382	18013	132	0		
F74 G191	H10	907	0	1577	1247	2186	45604	727	0		Y
F74 G192	B95	812	0	1233	790	1317	22098	142	0		Y
F74 G230	F35	513	0	857	761	1355	19549	156	0		
F74 G234	F52	1181	0	1866	1597	2240	40299	524	0		
F74 G237	E13	771	0	1286	731	1311	44023	977	0		Y
F74 G281	H12	418	0	1178	1495	2202	38198	397	0		
F74 G291	H53	1179	0	707	1129	1938	49924	0	0		Y
F74 G315	H10	932	0	1619	1316	2239	36183	439	0		
Scrap and waste											
F76 G29	BDG	3118	1354	4994	1554	2762	1500	0	868	alkali + Sb	
F74 G107	ARJ	2571	2996	922	1347	2306	1213	0	322	alkali + Sb	Y
F74 G83	ARJ	2160	2180	4103	1409	2278	1105	437	0	alkali	
F74 G188	H10	2782	988	4038	1536	2862	1275	383	0	alkali	
F74 G232	G29	911	0	1464	2368	2203	26355	230	0		
F74 G290	G93	2384	1603	3270	1897	2716	1150	342	0	alkali	
F74 G324	H89	1973	1238	3895	1492	2343	899	0	0	alkali	

Table 13: SEM/EDX data for glass finds from Flaxengate, wt% (analyses by R Keeley, Metropolitan Police Laboratories)

Finds No	F72 G25	F74 G192	?F74 G281	F74 G191	F74 G291	F74 G237	F74 P189	F74 P210	F74 G107	F74 G286	F74 G162	F74 G147	F74 G312	F74 G338	F74 G245
Sample No	KF1	KF2	KF3	KF4	KF5	KF6	KF7	KF8	KF9	KF10	KF11	KF12	KF13	KF14	KF15
Object	ring	ring	ring	ring	ring	ring	crucible	crucible	scrap	scrap	scrap	scrap	scrap	scrap	scrap
Na2O	1.23	1.09	1.02	1.37	1.27	1.06	0.65	1.69	14.08	16.52	9.18	16.24	8.32	14.28	16.39
MgO	nd	nd	0.19	nd	0.24	nd	nd	nd	0.63	0.47	0.37	0.59	nd	0.79	0.91
Al2O3	nd	0.13	0.18	0.20	0.37	nd	0.44	0.62	2.05	2.55	1.61	2.70	1.22	1.73	2.54
SiO2	16.84	18.54	18.48	20.99	17.13	17.64	16.45	20.56	45.93	72.67	63.08	55.01	57.34	50.59	63.55
P2O5	nd	nd	nd	nd	nd	nd	nd	nd	0.20	0.57	nd	0.19	0.31	0.35	0.59
SO2	nd	nd	nd	nd	0.74	1.05	nd	nd	nd	0.12	nd	0.15	nd	nd	nd
K2O	nd	nd	nd	nd	nd	nd	nd	nd	0.30	0.42	0.32	0.53	0.21	0.38	0.44
CaO	0.14	nd	nd	0.17	0.13	nd	0.18	0.22	3.29	6.13	3.82	4.46	2.55	2.93	5.07
MnO	nd	0.14	nd	nd	nd	nd	nd	nd	0.24	0.28	nd	0.66	nd	0.14	0.57
Fe2O3	0.17	nd	0.27	nd	nd	0.31	0.24	0.20	0.26	0.21	nd	0.11	0.19	0.22	0.21
CuO	nd	nd	nd	0.56	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.14
PbO	83.60	82.60	83.65	81.39	83.58	84.04	81.21	75.10	nd	nd	0.35	nd	nd	nd	nd
SnO2	nd	0.30	nd	nd	nd	0.11	nd	nd	nd	nd	nd	0.35	nd	nd	0.13
Cl	nd	nd	0.34	0.53	0.69	0.73	0.17	0.53	nd	0.41	0.49	nd	0.37	nd	0.36
Total	101.98	102.80	104.13	105.21	104.15	104.94	99.34	98.92	66.98	100.35	79.22	80.99	70.51	71.41	90.90

TiO2, Cr2O3, NiO and CoO were sought but not detected in any of the samples
nd = below level of detection






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