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A GREAT BIG MELTING POT: EXPLORING PATTERNS OF GLASS SUPPLY, CONSUMPTION AND RECYCLING IN ROMAN COPPERGATE, YORK*

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One hundred and ninety three glass fragments from the canabae *in York were analysed (first to fourth centuries). They fall into six compositional groups: antimony colourless (Sb), high-manganese (high-Mn), low-manganese (low-Mn), mixed antimony and manganese (Sb–Mn), high iron, manganese and titanium (HIMT) and plant ash. Some groups represent production groups, some of which appear to be in limited supply in this western outpost, but are more prevalent elsewhere, and others reflect changing supply mechanisms. The majority of glasses fall into groups that demonstrate extensive recycling of glass. This has important implications for determining provenance using trace elements and isotopes.*

KEYWORDS: ROMAN GLASS, NATURALLY COLOURED, COLOURLESS, ANTIMONY, MANGANESE, PRODUCTION GROUPS, RECYCLING, BRITAIN, ICP–AES

THE ROMAN GLASS FROM COPPERGATE

Although perhaps best known for its Viking deposits (Hall 1984), the site at 16–22 Coppergate, York also produced deposits rich in Roman finds, including glass. The putative glass-making or glassworking remains have already been published (Jackson *et al.* 2003), but the site also yielded a large assemblage of glass fragments, typical of a consumption assemblage from the first to fourth centuries and which is probably unrelated to the glassworking debris found at the site (Jackson 1992). The assemblage comprises forms that can be dated from the first to fourth centuries and represents a microcosm of glass found in the western provinces at this period. The scale of the assemblage is not surprising: *Eboracum* (Roman York) was an important Roman centre in Britain, occupied from AD 71 to 410, housing a fortress and large manufacturing and civilian districts. Coppergate was outside the fortress, within the city walls, and is likely to have been a trading or manufacturing area as part of the *canabae*, although Roman remains from the site have been largely robbed (Mainman 1990).

Within scientific research into Roman glass, the composition of colourless glass has been well studied, as has later glass from the mid-third and fourth centuries onwards (e.g., Freestone *et al*. 2005; Jackson 2005; Paynter 2006; Silvestri *et al*. 2008; Foster and Jackson 2009, 2010; Gallo *et al*. 2013), but naturally coloured glass of the first to third centuries has often been neglected. 'Naturally coloured' here describes transparent glass with a range of mostly

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blue–green hues caused by small amounts of iron oxide in the glass (Price and Cottam 1998), as opposed to containing intentionally added colourants. The Coppergate assemblage is significant because it includes naturally coloured, as well as colourless, glass in many common forms from a long-lived site, including many fragments that date from the second and third centuries. This study is therefore able to analyse a large corpus of material from a single site to demonstrate the availability of different raw glass types, and the extent of recycled glass within the trading network operating throughout the Roman world. By identifying changing glass compositions through time and noting which compositional types were used to manufacture different objects, the study will begin to fill a void in our knowledge of the consumption of glasses in the far north-west provinces. Within a system where glass was centrally produced and then distributed and reworked elsewhere, glass groups found in a British context can be compared to those found elsewhere across the empire (e.g., Arletti *et al*. 2008; Schibille *et al*. 2012; Gallo *et al*. 2013) to enable a better understanding of the complex web of the movement of raw glasses, the consumption of raw and recycled glass at different glass workshops, through to the use of different glass types in finished objects at settlement sites over a period of 400 years.

The samples chosen for analysis are representative of the glass artefacts found at the site. The use of diagnostic pieces from recognizable objects of known date allows a relative chronology to be determined for the different compositional groups of glass (Price and Cottam 1998), resulting in a broad timeline for each composition and form of the glass artefacts in circulation (especially important because of the disturbance of contexts at this site). The number of diagnostic forms included was limited because the analytical technique required relatively large samples and destructive sampling; therefore the use of non-diagnostic fragments provides further evidence for different compositions at the site. A variety of forms, typical of a large consumption assemblage, are represented, including vessels, such as bottles, cups, jars and beakers, and window glass, some produced by blowing and some by casting. The range of vessels shows that occupation at the site spanned the first to fourth centuries. These include first-century forms (Isings 3, pillar moulded bowls), globular jugs (first to early second centuries, Isings 52), cylindrical cups (second to third centuries, Isings 85b), cylindrical bottles (late second to early third centuries, Isings 50/51) and fourth-century conical beakers (Isings 106). This group of glasses is one of the largest assemblages of common types and forms from the late first to fourth centuries—but most importantly from the second and third centuries—to be analysed from Britain and as such provides a valuable data set of chemical compositions for naturally coloured and colourless glass in this period.

THE PRODUCTION AND CIRCULATION OF ROMAN GLASS

Roman glass was typically made with sand and natron (or trona) as the alkali, and it is now generally believed, as postulated by Sayre (1964) and Velde (1990), that the consistent composition seen in most Roman glass is because it was manufactured in large installations and then traded as raw glass. It was subsequently shaped into utilitarian objects at the many glassworking installations throughout the provinces. This hypothesis has since been strengthened by findings of large glass blocks, which appear to be the remains of broken raw glass slabs in various locations around the Roman world (Price 2005), and by the analysis of glass to determine trace element and isotopic compositions, which has placed these installations, for late Roman and Byzantine glass in particular, in the Eastern Mediterranean, in Syro-Palestine and in Egypt (Freestone *et al*. 2002; Foy *et al*. 2003; Brems and Degryse 2014). Thus a combination of

archaeological investigation and chemical analysis has now allowed a small number of manufacturing groups with tentatively assigned provenances to be established, especially for the fourth century.

This paper uses the glass compositions from Coppergate, York, UK to establish which groups of glass were present in the north-west provinces from the first to fourth centuries and how different glass compositions were used. Only naturally coloured glass, which has a blue–green hue, and colourless glass are presented here, as these have not been modified with colourants or opacifiers and so form the best data set for examining the different manufacturing groups in circulation. The chemical groups determined in the analysis of the Coppergate glass will be discussed in the context of known glass types and also new groups or subgroups determined where the glass does not fit clearly into a defined group. The reasons for the development of new groups will be discussed in the context of our understanding of glass manufacture in the Roman period.

METHODS

The glass samples were solubilized using the method devised for silicates and analysed by ICP–AES at the Geology Department, Royal Holloway University of London. The materials, methods, instrumentation and data validation are given in Jackson *et al*. (2003). Although the sample dissolution method loses silica by volatilization, it has the advantage of providing a large, accurate data set, including elements at major, minor and trace concentrations. Eleven elements are given as oxides in wt% and 10 as ppm. Lead and antimony concentrations were calculated separately using prepared single element standards and Corning and NIST glass standards of known composition. A subsection of the data has been presented previously (Jackson 2005) in the context of colourless glass; these data are discussed here as part of the Coppergate assemblage as a whole and in the light of the production groups that have been identified more recently, or defined here.

RESULTS: IDENTIFICATION OF COMPOSITIONAL GROUPS

The results of 193 analyses of naturally coloured and colourless glass dating from the first to fourth centuries are presented in Appendix 1. The glass can be defined by six compositional groups: (1) antimony colourless (Sb); (2) low-manganese (low-Mn); (3) high-manganese (high-Mn); (4) high iron, manganese and titanium (HIMT) (including weak and strong variants); (5) plant ash; and (6) mixed antimony–manganese (Sb–Mn) (with the possible inclusion of a seventh group of 'Levantine 1'; see below). The mean compositions of the groups can be seen in Table 1. In addition, there are eight outliers that do not clearly fit into any of these groups.

Although other compositional differences relating to the primary glass-forming components used in manufacture will be discussed, the groups can broadly be described by their concentrations of antimony and manganese (Fig. 1 (a)). Comparative data from previously published analyses to support the definitions of these groups are presented in Appendix 2.

Antimony colourless (Sb)

This group of colourless glasses is well represented in assemblages from the first to third centuries. It is a very coherent group, manufactured with high-purity sands, containing low concentrations of alumina, titanium, calcium and often iron, and is also soda rich (Jackson 2005

Table 1 *Means and ranges of the compositional groups identified in the glass analysed from Coppergate, York (note that ranges are affected by sample size and relate to this data set only). Key as in Appendix 1*

No.	*Sb* 44	*Sb–Mn* 80	*High-Mn* 13	*Low-Mn* 26	*HIMT2(W)* 19	*HIMT1(S)* 1	*Plant ash* 2
Wt%							
Al_2O_3	1.97	2.40	2.92	2.67	2.38	2.62	2.28
	1.62–2.49	1.78–2.83	2.65–3.28	2.28–3.04	2.08–4.11		2.25–2.31
Fe_2O_3	0.37	0.58	0.46	0.31	0.63	1.17	0.75
	0.22–0.80	0.27–0.98	0.30–0.64	0.24–0.40	0.32–0.83		0.70–0.79
MgO	0.48	0.58	0.63	0.50	0.71	1.27	1.35
	0.3–0.87	0.39–0.86	0.51–0.88	0.43–0.65	0.42–0.88		1.29–1.41
CaO	5.82	6.59	8.48	7.66	6.19	6.48	8.07
	4.49–7.54	5.19–8.15	7.86–9.04	7.02–8.24	4.86–7.66		7.25–8.89
Na_2O	19.39	18.69	16.81	17.47	19.41	19.26	17.82
	17.99–20.62	16.20–20.42	14.76–18.39	16.03–19.87	17.20–20.46		16.92–18.71
K_2O	0.51	0.82	0.68	0.67	0.87	0.56	1.61
	0.36–0.74	0.47–1.56	0.46–0.85	0.46–1.71	0.51–1.26		1.51–1.71
TiO_2	0.07	0.09	0.08	0.07	0.11	0.23	0.14
	0.04–0.13	0.05–0.14	0.07–0.09	0.06–0.08	0.07–0.14		1.12–0.16
P_2O_5	0.04	0.11	0.11	0.13	0.09	0.06	0.40
	0.02–0.08	0.04–0.19	0.08–0.19	0.10–0.15	0.04–0.28		0.35–0.45
MnO	0.03	0.40	1.15	0.34	0.87	1.8	0.12
	0.01–0.09	0.10–1.01	0.84–1.66	0.02–0.79	0.65–1.03		~
PbO	0.04	0.06	0.01	<0.01	0.03	0.03	0.01
	b.d.–0.39	b.d.–0.45	b.d.–0.02	b.d.–0.02	b.d.–0.05		b.d.–0.01
Sb_2O_5	0.54	0.35	0.04	<0.01	0.10	0.03	0.18
	0.05–0.89	0.11–0.69	0.01–0.08	0.01–0.01	0.01–0.17		0.13–0.23
ppm							
Ba	147	229	432	243	273	342	191
	127–165	149–341	282–581	203–310	218–467		189–192
Cu	16	155	18	15	88	51	41
	5–78	14–1718	9–27	4–39	11–219		34–47
Li	10	17	10	8	18	16	9
	5–18	7–59	7–14	6–14	8–32		8–9
Ni	12	16	19	15	19	29	13
	8–19	7–24	13–24	6–49	13–22		12–14
Sr	414	415	506	430	445	588	642
	286–579	334–516	450–569	368–537	348–675		580–703
V	9	17	25	15	22	35	15
	5–16	7–29	13–62	7–27	19–28		13–16
Y	7	8	9	9	8	10	7
	60–9	6–10	8–10	8–10	9–9		~
Zn	21	36	17	17	36	31	32
	15–36	21–108	1–25	11–28	18–57		30–34
La	11	12	11	11	12	13	11
	10–12	10–14	9–13	10–12	11–13		~
Ce	18	20	20	19	21	25	20
	14–23	13–26	17–24	16–24	16–24		18–21

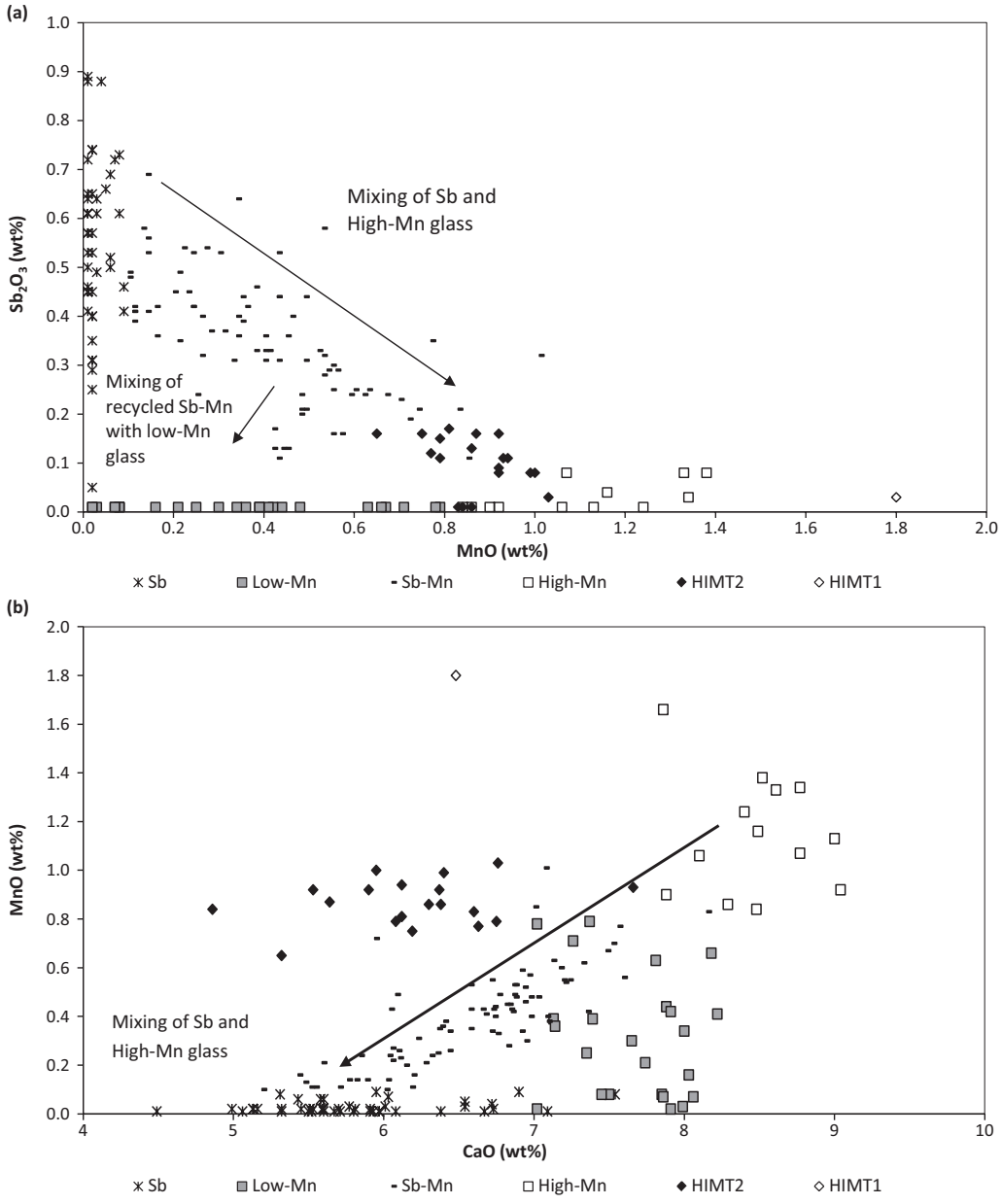

Figure 1 *(a) A plot of manganese versus antimony oxides for the Roman glass from Coppergate, York, showing the spread of manganese and antimony oxide contents for the mixed glass, between the Sb and high-Mn glass compositions. (b) A plot of calcium versus manganese oxide for the Roman glass from Coppergate, York, showing how the lime and manganese contents are correlated in the Sb–Mn glass, best fitting a mixture of high-manganese (high-Mn) glass with antimony colourless (Sb) glass.*

(groups 1a and 1b); Paynter 2006; and reviewed in Paynter and Jackson forthcoming) (Figs 2 (a) and 2 (b)); the decolourizer is antimony. Paynter (2006) suggests there is a variant of this composition, which is low in lime, alumina and barium and often contains very high levels of antimony (Sb/low-Ca); and is found amongst very early, high-quality vessels (Appendix 2). This variant is not present in the glasses analysed here (Fig. 2 (c)). Similarly, the presence of (>300 ppm) lead in some early colourless Roman glass (Baxter *et al*. 2005), suggested by Paynter (2010) to derive from a lead-bearing antimony source, is seen in only three examples, one of which is dated to the first century (Appendix 1). Current research suggests that the antimony colourless glass may originate in the Eastern Mediterranean (Ganio *et al*. 2012), although Italy has also been postulated as a possible origin for glass with these compositional characteristics (Brems and Degryse 2014). The absence of the Sb/low-Ca glass composition and the low numbers of lead-bearing antimony examples reflect the date of the Coppergate assemblage. Since most diagnostic fragments are from the second and third centuries, they postdate these earlier compositional traits, and few high-status vessels of the type typically made from the rarer Sb/low-Ca composition are represented.

Low-manganese (low-Mn)

This group of naturally coloured glasses, predominantly blue–green or 'aqua', generally contains low concentrations of manganese of up to 0.8 wt%, but no antimony (Fig. 1). This glass tends to contain less soda, but more alumina, than the Sb colourless glass (Figs 2 (a) and 2 (b)). This naturally coloured glass is known from Roman assemblages elsewhere and is the dominant, raw, blue–green glass by the first century, and is thought to be manufactured in the Syria-Palestine region (Foy *et al*. 2000) (Appendix 2). The Coppergate samples also contain a subset of the 'light green' examples, which contain very little manganese oxide (less than 0.1 wt%), but otherwise fit the general compositional patterning for low-Mn glasses.

High-manganese (high-Mn)

This composition is characterized by high concentrations of manganese (0.8–1.5 wt%) but in other respects is similar to the low-Mn glass, but with slightly higher calcium and lower soda (Figs 1, 2 (b) and 2 (c)). The lower MnO threshold of 0.8 wt% was selected because it is the approximate minimum seen in manganese *decolourized* glass, such as the first-century colourless examples from Adria studied by Gallo *et al*. (2013) (Appendices 1 and 2). The higher MnO threshold of 1.5 wt% for this group was selected to exclude deliberately coloured purple glass. In many reported instances, the high-Mn composition produces a *colourless* glass, especially where the manganese concentrations are at the higher end of the range (see Vichy *et al*. 2003; Silvestri *et al*. 2008; Foster and Jackson 2010; Schibille *et al*. 2012; Gliozzo *et al*. 2013; Paynter and Jackson forthcoming); however, all the samples analysed here have a blue or light green hue (one nearly colourless) and cannot be distinguished visually from other blue–green or naturally coloured glasses (e.g., low-Mn).

The separation of Levantine 1, low-Mn and high-Mn is in terms of manganese content and date, since the base glass composition appears very similar otherwise (Foster and Jackson 2010); this might suggest they have a similar provenance or are a continuation of a manufacturing tradition (Appendix 2). Taking into account the similarities in composition, three late Roman samples from Coppergate (5495, 13535 and 14069), assigned here to the high-Mn group, may be the same as the Levantine 1a group of Foster and Jackson (2009).

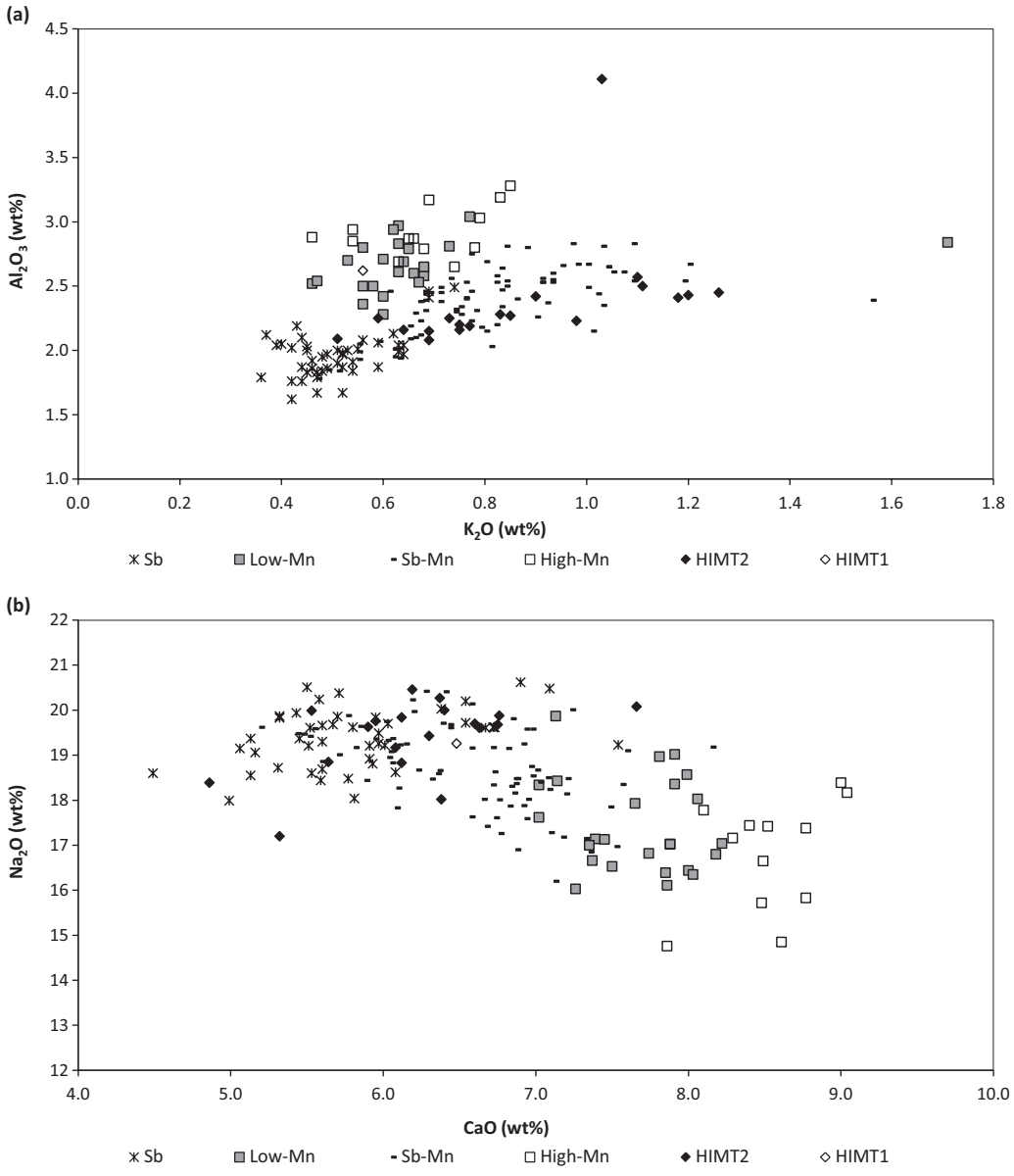

Figure 2 *A plot of oxides for the Roman glass from Coppergate, York, showing the different glass groups represented: (a) Al_2O_3 versus K_2O; (b) Na_2O versus CaO; (c) Ba versus MnO; (d) Cu versus PbO. In all charts, the Sb–Mn group shows significant mixing.*

From the fourth century onwards, the compositional range of manganese-containing glass becomes even more diverse, as illustrated by Foster and Jackson (2010) and Meek (2013), who have identified two groups of *colourless* high-manganese glasses, differing in their soda and calcium concentrations. Meek's (2013) type 2b matches the high-Mn glasses here. Meek's 2a and

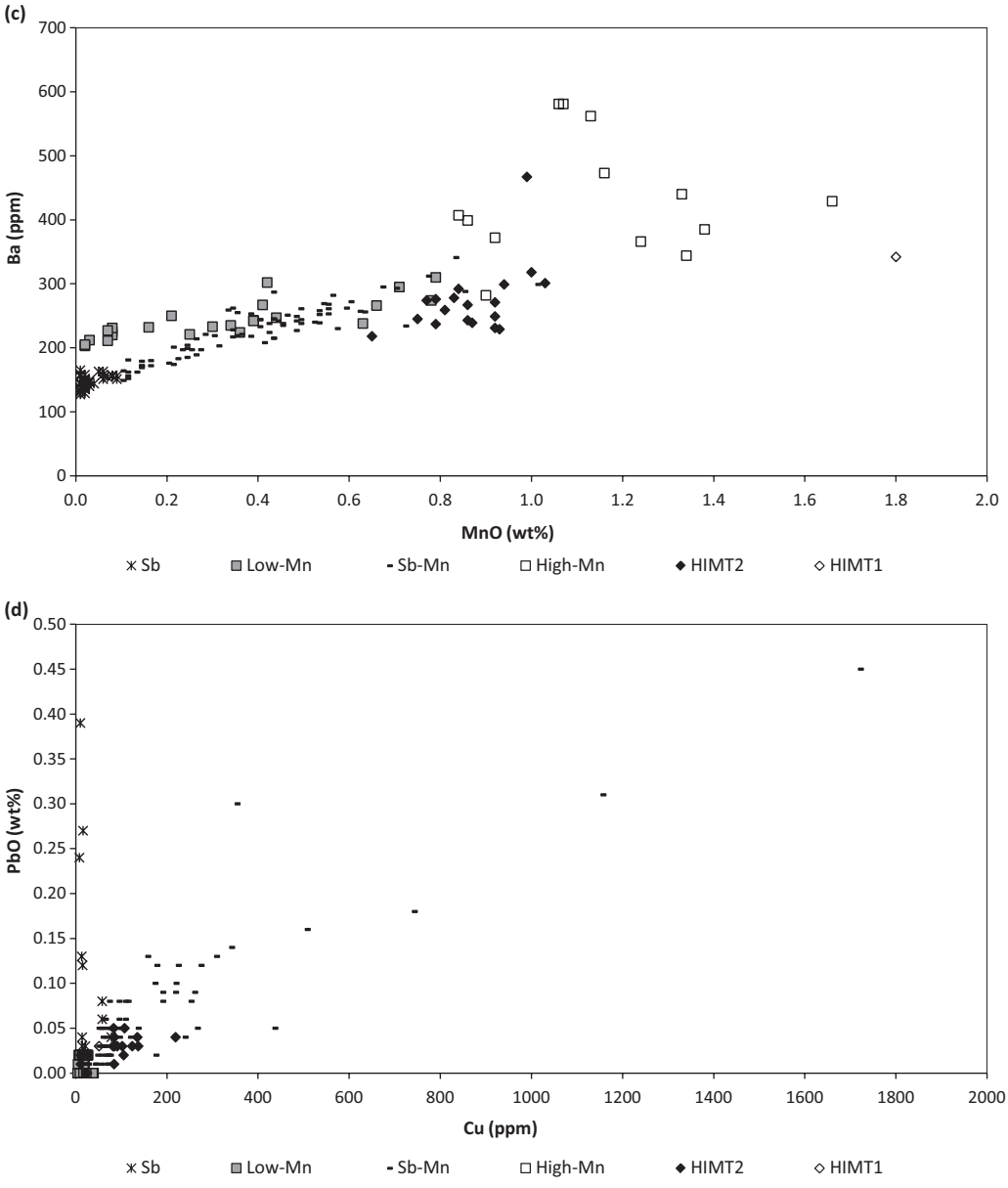

Figure 2 (*Continued*)

Foster and Jackson's (2010) 2a have higher concentrations of soda and less lime (Manganese low lime in Appendix 2); these glasses also have slightly elevated concentrations of magnesium, iron and titanium oxides and may resemble weak HIMT (below). The colourless 2b in Foster and Jackson (2010) has high lime and high soda, which indicates the presence of another group not represented here, and further illustrates the varied nature of manganese-containing glass from the fourth century.

Mixed antimony and manganese (Sb–Mn)

This is the largest compositional group amongst the analysed glass. Sb–Mn glass contains both manganese and antimony, which were probably introduced by recycling the main antimony- or manganese-containing raw glass at the time (see Discussion). Slightly raised concentrations of other elements, such as copper and occasionally lead in the Sb–Mn glass and the large range of soda, calcium and alumina concentrations, nevertheless correlated, also suggest that this is a mixed recycled group rather than a primary production group (Figs 2 (a), 2 (b) and 2 (d)). As new types of raw glass are introduced and start to be recycled, such as HIMT in the third and fourth centuries, even greater variation is seen within the Sb–Mn glass group.

Sb–Mn glass has a range of hues depending on the relative proportions of antimony to manganese, and the concentration of iron oxide present. Published examples of Sb–Mn glasses containing a larger proportion of antimony (from antimony decolourized glass) are more likely to be colourless and so have previously been discussed in terms of *colourless* Roman glass assemblages (Mirti *et al*. 1993; Jackson 2005 (2b); Paynter 2006; Silvestri *et al*. 2008). However, those samples containing a smaller proportion of the antimony to manganese, or those that contain more iron oxide, are more likely to be naturally coloured blue, blue–green or green, and have been discussed along with naturally coloured glasses (e.g., Mirti *et al*. 1993; Jackson 1994; Silvestri 2008) (Appendix 2). Regardless of their colour, they are discussed as a single compositional group here.

High iron, manganese and titanium glass (HIMT)

As the name suggests, HIMT glass can be distinguished by elevated levels of iron, manganese and titanium relative to other glass types (Freestone 1994; Foy *et al*. 2003). These features, along with higher soda and lower lime concentrations, distinguish it from other manganese-bearing glass types such as high-Mn and low-Mn glass (Fig. 2 (b)). The glass assigned to this group displays a broad range of compositions, which Freestone (1994) ascribed to the mixing of two components during glass production (as opposed to mixing with other glass types during the recycling process). Evidence for further dilution of the HIMT composition through recycling has been identified in some examples from Western Europe, which show antimony, lead and copper contamination (Foy *et al*. 2003; Foster and Jackson 2009; Jackson and Price 2012). However, it is impossible to determine the extent of recycling in HIMT glasses, as recycling using glass of the same composition (e.g., HIMT with HIMT) would be undetectable.

HIMT, thought to originate in Egypt (Foy *et al*. 2003; Freestone *et al.* 2005), is increasingly common from about the mid-fourth century (Mirti *et al*. 1993; Freestone *et al*. 2005; Foster and Jackson 2009) (Appendix 2). Further chronological patterns have also been noted within the group: Foster and Jackson (2009) suggested that a weaker variant of HIMT (their HIMT 2) was introduced in Britain around AD 330, slightly preceding a stronger type (their HIMT 1). Foy *et al*. (2003) determined that a yet more concentrated variant (their group 1) was in use in the fifth century across a considerable area, before 'weakening' again in the sixth to eighth centuries (their group 2). The HIMT glass in the Coppergate assemblage is predominantly HIMT2, with one possible example of strong HIMT1 glass. The Coppergate weak HIMT examples also contain low levels of antimony oxide, which suggests that these may be a recycled combination of HIMT glass with an antimony-bearing glass, such as the Sb colourless or recycled Sb–Mn types. The high concentrations of potash in some of the HIMT samples from Coppergate (above 1 wt%, Fig. 2 (a)) may also suggest contamination through recycling (see Discussion).

Levantine 1 glass

This term has been used to describe glass of the fourth century and later, which is high in lime and alumina and low in soda (Appendix 2) (Brill 1988; Freestone *et al*. 2000; Foster and Jackson 2009). In terms of bulk composition, Levantine 1 glass is similar to the earlier glass groups high-Mn and, to a lesser extent, low-Mn. However, it generally does not contain any decolourizer (Freestone *et al*. 2000; but see summary in Foster and Jackson 2009) and this also differentiates it from most other first- to fourth-century types. Analysis of glass from tank furnaces at *Apollonia* has demonstrated that this glass was manufactured on the Levantine coast (Foy *et al.* 2003; Tal *et al.* 2004). Although fourth-century glass is present at Coppergate, no samples of Levantine 1 composition were identified (but see the section on high-Mn glasses). This outcome is not unexpected, as Foster and Jackson (2009) note that this glass is poorly represented in late Roman assemblages in Britain.

Plant-ash glass

Two glass samples, one from a cast window and the other from a bottle, which have mixed concentrations of antimony and manganese, also contain elevated concentrations of potash, magnesia (both around 1.5 wt%) and phosphorus (around 0.4 wt%) (Appendix 1 and Table 1). This may indicate that these glasses were made wholly or in part using soda plant ashes, or from recycled glass including some made with high-soda plant ashes or were potentially contaminated with fuel ash (Paynter 2008). Roman glasses made from plant ashes have been noted in other contexts, including strongly coloured first-century glasses (e.g., Arletti *et al*. 2008; Jackson *et al.* 2009; Gallo *et al*. 2013; Jackson and Cottam in prep.). Plant-ash compositions tend to be rare in most Roman glass assemblages and have only been noted relatively recently; their provenance has been a matter of speculation.

Outliers

Eight samples do not fall clearly into any of the groups defined above (Appendix 1 (OUT)). These outliers have characteristics that are similar to one of the defined groups but differ in particular respects (e.g., 10203 could potentially be Sb–Mn, but has exceptionally high concentrations of manganese; 14072 has low soda but higher alumina and mixed antimony–manganese). There are too few of these to speculate about whether they might indicate the existence of separate compositional groups, or are atypical examples of existing compositions (with one or two elemental anomalies), but they are included in case similar examples are found in future studies.

DISCUSSION

Recycling and contamination

By far the largest group represented is the Sb–Mn glass. The range of compositions in this group can be approximated as a mixing line between the contemporary raw glass types in circulation: the Sb colourless glass and the high-Mn glass, illustrated in Figures 1 (a) and 1 (b). This mixing of antimony and high-manganese glasses may be explained through selective recycling. Colourless glass was a valuable raw material, with the Sb colourless glass in particular reserved for finewares. It may therefore be anticipated that glassworkers would recycle colourless glass

separately wherever possible, combining Sb colourless glass and the high-Mn glass, or using high-Mn glass to extend the antimony colourless glass, even though much of the high-Mn glass often has a slight greyish or greenish tinge. This would explain the incorporation of both antimony and manganese into the glass, and the correlation between these elements. However, the levels of titanium, iron, potassium and copper oxides detected in the Sb–Mn mixed glass are higher than would be expected for a straightforward mixture of the two Sb and high-Mn raw glass types (Paynter 2006) (Table 1); other factors must be contributing to the overall composition.

Upon subsequent re-melting, all recycled glass including colourless, would gradually spoil by absorbing iron-bearing contaminants, eventually acquiring a blue–green tinge. Experimental work has shown that, during re-melting, glass absorbs aluminium, titanium, potassium and iron oxides from clay crucibles or furnace linings, as well as potassium oxide vapour generated by the furnace fuel, and lesser amounts of calcium, magnesium and phosphorus oxides from settling fuel ashes (Paynter 2008). In addition, fragments of glass-working waste are sometimes strongly coloured by iron oxide scale from the blowing iron. These extraneous materials would ultimately contaminate the glass, which would acquire a stronger blue–green hue. This may lead to the recycled 'colourless' glass becoming blue–green and eventually being used as, and recycled with, blue–green stock, as can be seen in Table 1, where the Sb–Mn glass often has higher concentrations of elements associated with recycling.

The variation in concentration is because these glasses will have different recycling histories, with recycled and raw glass combined in variable proportions an unknown number of times, and so it is not possible to quantify the extent of recycling from the compositions. The amount of crucible and vapour contamination in the glass depends upon the crucible composition, the temperature and time of melting and the number of times the glass has been re-melted (Paynter 2008, 208). Figures 1 (a) and 1 (b) do show, however, that a small number of samples are contaminated by other naturally coloured glasses in circulation at different periods—for example, low-Mn or HIMT (Foster and Jackson 2009)—indicating that some of the glass has probably been recycled at least twice: first as part of a colourless batch and subsequently, once spoiled, as part of a naturally coloured batch. Consequently, the contaminants introduced during repeated recycling, potentially with many different glass compositions, account for the discrepancies between the predicted and actual composition of the Sb–Mn mixed glass.

To demonstrate the effect of contamination during recycling, analyses of the Roman glassworking waste (partly melted material, drips and glass from inside melting pots), also from Coppergate, York (Jackson 1992; Jackson *et al*. 1998, 2003), have been plotted (Figs 3 (a) and 3 (b)), together with the typical composition of the glass-melting crucibles from Coppergate, and the average compositions of Sb colourless glass, high-Mn glass and the mixed Sb–Mn glass. In most of the waste glass and the mixed Sb–Mn glass, the concentrations of aluminium, titanium, potassium, phosphorus and iron oxides are elevated relative to the compositions of the original unaltered colourless glass types in a manner consistent with crucible and fuel vapour contamination. Some of the waste glasses have much higher concentrations of contaminants because they were in direct contact with the crucible wall.

Comparing antimony and manganese decolourized glass

At Coppergate, high-manganese (high-Mn) glass was used only rarely for high-status vessels, and predominantly during periods when the antimony decolourized glass was scarce; for example, earlier in the first century and then again in the fourth century and later. This pattern is

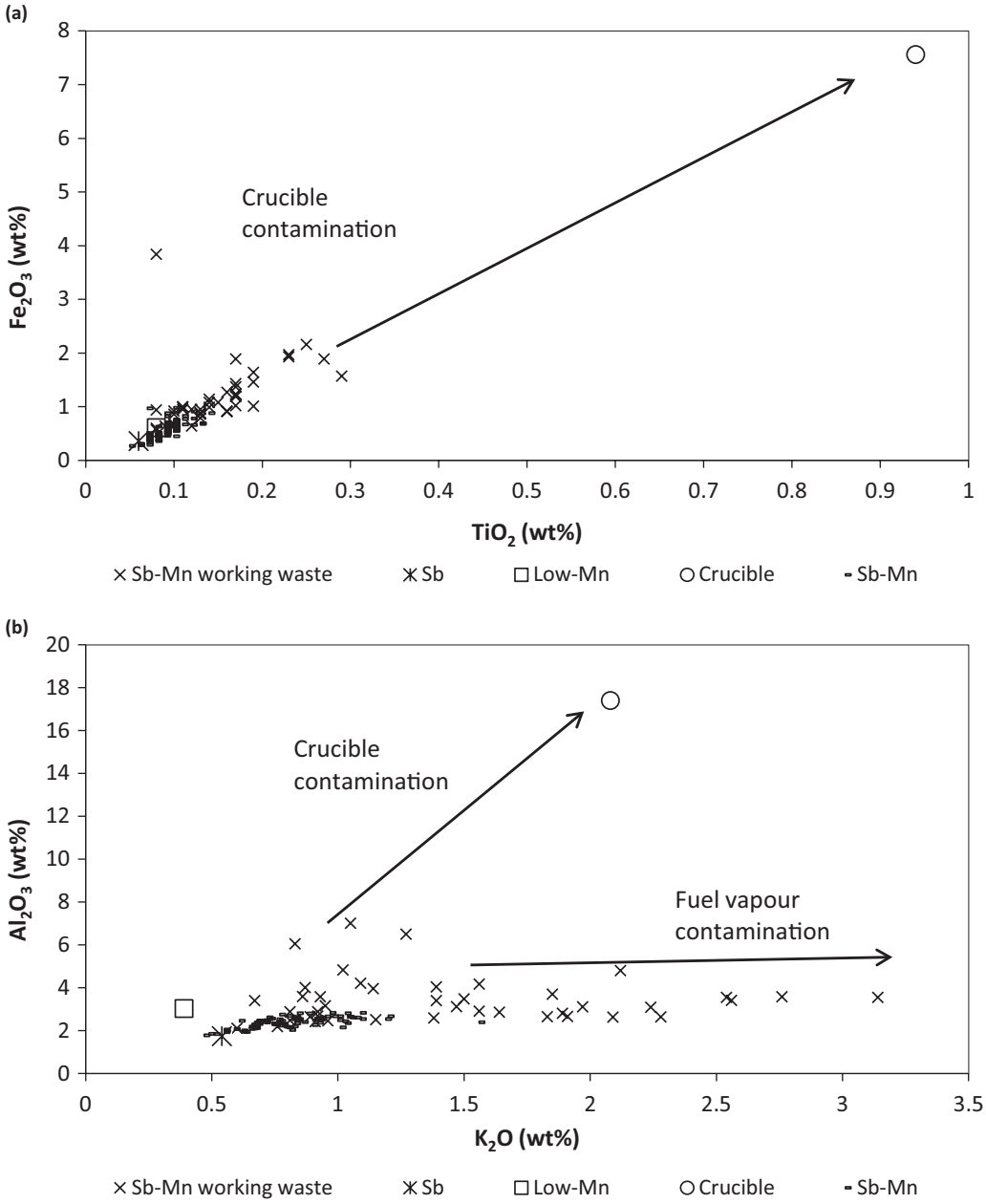

Figure 3 *(a) A plot of titanium versus iron oxide for the Roman glass-working waste (Jackson* et al. *2003) and the Sb-Mn glass from this study, showing varying levels of crucible contamination. (b) A plot of potassium versus aluminium oxide for the Roman glass waste (Jackson 1992), showing varying levels of contamination from crucibles and fuel vapour. A single data point each shows an average composition for Sb and Low-Mn glass.*

repeated elsewhere (Foy *et al*. 2003; Foster and Jackson 2009). This may be in part because the colour of high-Mn glass is more variable. While a higher concentration of manganese often produces a colourless glass (see, e.g., Foster and Jackson 2009), it sometimes has a blue–green hue, as is observed in *all* the high-Mn glasses at Coppergate. The final colour of the high-Mn glass, whether blue–green or colourless, would have been influenced by several factors including the iron oxide and manganese oxide content, and the furnace atmosphere when the glass was last melted, all playing major roles (Bingham and Jackson 2008).

Figure 4 shows the iron and manganese oxide contents of Roman high-Mn glass samples, from the literature and this study, divided according to the final colour of the glass. The colourless high-Mn samples tend to have very low levels of iron oxide (of around 0.3 wt% or less); conversely, high-Mn samples that contain slightly higher levels of iron oxide (around 0.6 wt%) are often a greenish colour, despite manganese oxide being present in excess of 1 wt%. This shows that the colour of the manganese decolourized glass is more sensitive to the iron oxide content, with slightly elevated levels resulting in a blue–green hue.

Therefore, the wide range of blue and green hues observed in the Coppergate high-manganese glass may be because the original batch(es) inadvertently contained slightly higher levels of iron oxide, the colour being more difficult to neutralize with manganese, or because a colourless batch of high-Mn glass was subsequently contaminated during recycling. As a result, the high-Mn glass identified in Britain, which had most probably undergone successive re-melting, is often blue–green (e.g., Jackson *et al*. 1991). The same is true of any recycled Sb–Mn glass containing a high-Mn component. In contrast, the antimony decolourized glass remains colourless even with elevated levels of iron oxide; some of the colourless samples reported here (Appendix 1) contain up to 0.8 wt% iron oxide.

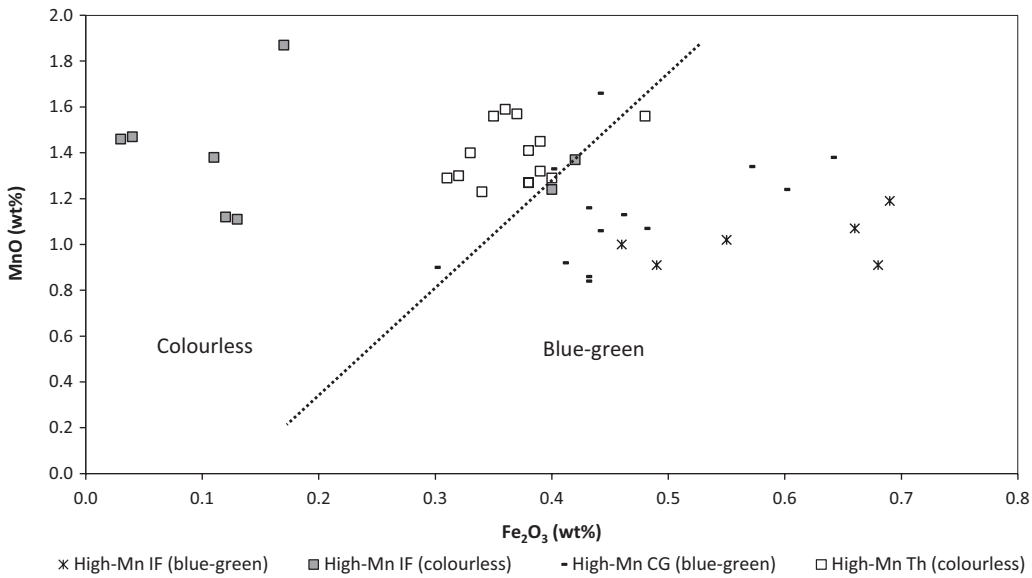

Figure 4 *High-Mn glass from* Thamusida *(Th, Gliozzo* et al. *2013), Coppergate (CG, this study) and the* Iulia Felix *(IF, Silvestri 2008; Silvestri* et al. *2008); samples to the top left are visually colourless, whereas samples towards the bottom right are blue–green.*

Glass supply and use through time

The large and varied Coppergate assemblage includes examples of multiple glass groups, some identified here and others defined previously, but all have parallels elsewhere in Europe. Therefore, the Coppergate glass fits a broader pattern of glass production, circulation and consumption, which changes over time, both in terms of the supply of raw or recycled glasses and the types of vessels used in the Roman world (Appendix 2).

The antimony colourless glass was used for fine tableware; there are no window fragments and only rarely bottles. The samples in this group, such as the faceted beaker dated to the second or third century and the Isings 21 beaker, are of high quality. The data also further illustrate how the Sb colourless glass composition changes over time, particularly with respect to the diminishing antimony oxide content (Paynter 2006; Paynter and Jackson forthcoming). Previously identified, early variants of antimony colourless glass (Sb/low-Ca or samples with >300 ppm of lead) are poorly represented in the assemblage, probably because the majority of the Coppergate antimony glasses are second/third century. There are, however, a number of the late second- and early third-century Sb samples that contain atypically high levels of lime and alumina, with low levels of antimony (Figs 1 (a) and 1 (b); Appendix 1, 'Sb/high-Ca' samples), which suggests that there may be a chronologically later subgroup as well.

The range of forms seen outside Britain in high-Mn glass—for example, the colourless examples from the *Iulia Felix* wreck (Silvestri *et al*. 2008)—suggest that this glass was predominantly used for window glass and bottles up to the third century. The Coppergate assemblage mirrors this, with windows, bottles and jugs, in an extended range of colours. However, by the late third to fourth centuries, more high-quality tablewares are also present in this glass (e.g., Isings 106), and this is also seen in other fourth-century assemblages (Foster and Jackson 2010; Schibille *et al*. 2012), illustrating a chronological change in the availability of this compositional group over time.

There may also be chronological variation in composition, since later samples in this assemblage (fourth century) contain higher levels of manganese oxide, in some cases in excess of 1 wt%, whereas earlier samples contain less. Glass with similarly high levels of manganese has been reported elsewhere from the late second or early third centuries (Ganio *et al*. 2012; Gliozzo *et al*. 2013) onwards, but it seems poorly represented in Britain until a later date, the island receiving only limited supply. The increased incidence of this glass at Coppergate in the fourth century could be related to the scarcity of the Sb colourless glass by this time; hence the need to source an alternative glass for finewares (Paynter and Jackson forthcoming).

No window glass was found in the naturally coloured, low-manganese (low-Mn) glass, but some bottles and a variety of vessels are represented, predominantly tablewares from the first century, including Isings 3 (cast pillar moulded bowls) and Isings 12 (Hofheim cups) forms. Nearly all of the diagnostic fragments are from the first or second centuries. This glass type may represent the blue–green Judean glass mentioned in the edicts of Diocletian, whereas the Sb-glass is more likely to be the glass described as Alexandrian (Barag 1987). In Britain, however, it would seem that the supply of low-Mn glass was limited, and that the recycled Sb–Mn glass largely served the same function as the low-Mn glass but was more readily available. Therefore, the mixed Sb–Mn glass becomes dominant in the second and third centuries; it is visually identical and would appear so to the glassworker.

Overall, the most common glass composition amongst the samples was recycled blue–green mixed antimony and manganese glass. Sb–Mn glass is represented in the assemblage by a variety

of different forms and dates, including cast and blown window glass fragments, a large group of bottles of different styles and a range of blown and cast vessels, including cups, beakers, bowls, jugs and flasks, as well as a hairpin shank. Many fragments in this composition are utilitarian items such as bottles or windows, with a requirement for volume rather than quality. None of the vessels that could be identified represented high-status finds. This compositional group spanned the first to fourth centuries, suggested by the date range of vessel types, including Isings 3 (first century) and Isings 85 (second to mid-third century) (Price and Cottam 1998) and a blown window fragment that may be a fourth-century example. The longevity of the group is not surprising, as it represents a mixed recycled glass that may have included many different compositional groups through time. Interestingly, the range of different types of vessel glass in this group is similar to that for low-Mn blue–green glass and so the two may not have been differentiated on reworking.

The HIMT glass has been used to make cups and beakers, jugs and bottles, and those that could be dated (e.g., Isings 96/106) put this group securely in the fourth century, as anticipated from studies of other late Roman assemblages (Freestone *et al*. 2005; Foster and Jackson 2009; Jackson and Price 2012). The proportion of each form reflects the composition of glass assemblages in general at this time, when tablewares were more common than bottles. The predominance of HIMT2, the slightly earlier, weaker variant of HIMT, which tends to show more evidence of recycling with other glass compositions, may suggest that when the supply of glass reached northern Britain it had undergone a relatively long life cycle.

Thus the compositional picture, allied to securely dated forms from the site, indicates that glassworkers in Britain had only limited access to raw glass types, whereas recycled glass was readily available. The data also demonstrate that some forms were made more readily with either raw or recycled glass (whether in Britain or elsewhere) or were manufactured in centres that had specific glass supplies.

The new definition of the three groups—namely high-Mn, low-Mn and Sb–Mn glasses—allows a more nuanced picture of glass consumption to be realized.

CONCLUSIONS

The analysis of this assemblage provides a picture of the consumption of Roman glass from the first to fourth centuries in an urban setting and gives greater detail about the different glass compositional groups that were circulating at this time throughout the Roman world, and particularly those reaching Britain. This study confirms that the dominant composition for high-quality colourless tableware was antimony colourless, but that the composition of this glass appears to change chronologically. Compositional subgroups have been identified based on calcium concentrations and the decrease in antimony over time (Paynter 2006; Paynter and Jackson forthcoming). By the late third or early fourth centuries, it appears that there were difficulties sourcing this glass in Britain and elsewhere (Sayre 1963; Foy *et al*. 2003) since alternatives, such as high-Mn glass and variants of HIMT glass, were increasingly used (Foster and Jackson 2009, 2010; Jackson and Price 2012). At the same time, tin-based opacifiers replace antimony-based ones in opaque glass (Turner and Rooksby 1959), which suggests that the increasing difficulty of obtaining the antimony decolourizer may have been a contributory factor in the rapid decline of antimony colourless glass in the fourth century.

In the first and early second centuries, unaltered raw low-manganese glass makes up a good proportion of the blue–green or greenish glass used more for common tableware and

storage vessels, but by the later second and third centuries recycled mixed Sb–Mn glass dominates.

The high-manganese glass is not well represented in the Coppergate assemblage until the later third and fourth centuries. However, it appears to be common in bottle and window assemblages from the late second and early third centuries in Continental Europe and further afield, and there are some examples from the western provinces in the first century.

A significant finding is the very high number of samples that show clear evidence of recycling. Sb–Mn glass, made from a mixture of the antimony colourless and the high-manganese glass, appears to dominate blue–green assemblages in Britain, and was used for everything except the highest-quality tablewares. The high-Mn component of this recycled glass seems relatively uncommon in Britain, so perhaps much of the mixing took place elsewhere to produce Sb–Mn recycled glass, which then reached Britain ready-made, although there is ample evidence for glassworkers re-melting and using Sb–Mn glass in Britain (Jackson *et al*. 1991).

The Coppergate assemblage illustrates how contamination of the glass during recycling by ceramic crucibles, furnace structures and other types of glass influences both the composition and colour of the glass. Some glass which was probably colourless or nearly colourless initially, eventually acquired a blue–green hue. Contaminated blue–green recycled glass was then more likely to be further mixed with other blue–green glass types, such as low-Mn or HIMT, depending on the date. This Sb–Mn recycled glass is known to have been melted and worked in Britain, as this composition is seen in the glassworking waste at the sites of Mancetter and Leicester, and it was clearly used for the manufacture of glass-hungry items such as windows and bottles and for more common vessel forms (Jackson *et al*. 1991). At the extremes of the Roman world in the second and third centuries, this recycled mixture appears to have become more readily available than the raw low-Mn blue–green glass. Since the Sb–Mn composition resulted from the dilution and recycling of antimony decolourized glass, it follows the same pattern of decline in the fourth century; HIMT glass, which is also often recycled, becomes increasingly common in its place.

The assemblage from Coppergate therefore illustrates the different compositional types reaching the western edges of the Roman world, but also how the composition and appearance of glass changes once it has been through more than one ‘great big melting pot’. The recycled antimony–manganese glass makes up more than 40% of the analysed glass. This has important implications for trace element and isotopic analysis, because if the chemical composition of the glass has been affected by glass mixing, ceramic crucibles and furnace materials, then the trace element and isotopic composition of the glass is likely to have been affected too. As one referee suggests, the ‘big melting pot’ is not entirely homogenizing all of the glass, and compositional groups can still be identified. However, these groups are the dominant primary glasses reaching their market in that particular period and as such recycling becomes almost invisible, because like is being mixed with like. It is clear from the data set that much of the glass is reused, perhaps over many years, providing a large reservoir for re-melting, against which rarer compositional groups, perhaps made on a smaller scale, traded less extensively or in decline, are more difficult to detect—for example, the products of the subordinate glass manufacturing centres referred to by Pliny the Elder (Eichholz 1962), or plant-ash glass types that may be the products of an earlier glass industry. These glasses, introduced into the recycling pool, would soon become diluted to the extent that they were difficult to recognize. Thus an appreciation of the scale and effects of recycling is key to understanding manufacturing locations and glass compositional groups.

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Appendix 1 *The composition of samples of Roman glass from Coppergate, York, analysed using inductively coupled plasma spectrometry (major and minor elements as wt% oxides, trace elements as ppm). Samples are placed into compositional groups (Sb, antimony colourless; low-Mn, low-manganese; high-Mn, high-manganese; Sb–Mn, mixed manganese and antimony; HIMT, high iron, manganese and titanium; Plant, plant ash; colour—C, colourless; BG, blue–green; LG, light green; YG, yellow green; B, light blue). Samples in italics are those that may differ slightly in some respect from the defined composition. b.d., Below detection*

Cat. no.	*Form*	*Estimated date (centuries AD)*	*Assigned group*	*Visual colour*	*Oxides (wt%)*											*Trace elements (ppm)*									
					Al_2O_3	*Fe_2O_3*	*MgO*	*CaO*	*Na_2O*	*K_2O*	*TiO_2*	*P_2O_5*	*MnO*	*PbO*	*Sb_2O_5*	*Ba*	*Cu*	*Li*	*Ni*	*Sr*	*V*	*Y*	*Zn*	*La*	*Ce*
13443	Undiagnostic		Sb	C	1.67	0.34	0.46	5.67	19.68	0.52	0.06	0.03	0.01	0.02	0.89	132	11	13	12	394	9	7	16	12	20
11172	Isings 21	Late 1st	Sb	C	2.04	0.25	0.30	5.60	19.66	0.63	0.04	0.02	0.01	0.39	0.88	165	10	12	15	533	7	7	16	11	21
11420	Body		Sb	C	2.08	0.49	0.50	6.72	19.62	0.56	0.08	0.04	0.04	0.13	0.88	144	13	15	15	579	11	7	19	12	23
10864	Undiagnostic		Sb	C	1.62	0.25	0.43	5.13	19.37	0.42	0.06	0.03	0.02	b.d.	0.74	129	5	8	10	358	8	6	15	10	17
12461	Body		Sb	C	2.06	0.35	0.38	5.70	19.86	0.59	0.05	0.03	0.02	0.27	0.74	158	16	12	15	416	8	7	17	11	23
14346B	Body		Sb	C	1.87	0.28	0.32	4.49	18.60	0.44	0.06	0.03	0.01	0.12	0.72	143	15	7	11	286	5	6	16	10	14
8516	Undiagnostic?		Sb	C	1.99	0.47	0.53	6.03	19.70	0.63	0.09	0.06	0.07	0.03	0.72	154	14	7	13	409	10	7	25	11	18
13493	Isings 85b	Late 2nd–early 3rd	Sb	C	2.04	0.42	0.43	5.58	20.24	0.64	0.07	0.04	0.06	0.02	0.69	163	15	14	14	358	11	7	28	11	22
13955	Isings 85b	Late 2nd–early 3rd	Sb	C	1.84	0.26	0.34	5.06	19.15	0.54	0.04	0.03	0.01	0.02	0.65	145	8	12	13	359	8	7	15	11	19
8442	Isings 85	Late 2nd–early 3rd	Sb	C	1.86	0.37	0.45	5.81	18.04	0.46	0.07	0.04	0.02	0.01	0.65	143	22	7	12	403	10	7	36	11	15
14331	Undiagnostic		Sb	C	1.97	0.28	0.37	5.52	19.61	0.64	0.05	0.03	0.01	0.02	0.64	145	13	9	12	386	7	7	19	11	17
13992	Bowl		Sb	C	1.87	0.37	0.49	5.77	18.48	0.59	0.08	0.04	0.03	0.01	0.64	149	5	8	10	400	9	6	18	10	16
12287	Body		Sb	C	1.91	0.39	0.51	6.67	19.61	0.54	0.07	0.03	0.01	0.02	0.61	131	16	14	19	486	11	8	25	12	21
12582	Undiagnostic		Sb	C	1.83	0.35	0.53	5.80	19.62	0.45	0.06	0.03	0.01	0.02	0.61	133	13	12	14	415	11	7	20	12	21
13657	Flask/jug	Late 2nd–early 3rd	Sb	C	1.95	0.34	0.41	5.50	20.51	0.48	0.07	0.03	0.01	0.01	0.61	158	10	12	13	396	9	7	15	11	17
13716	Cylindrical bottle		Sb	C	2.00	0.41	0.47	6.01	19.22	0.51	0.08	0.04	0.03	0.01	0.61	146	14	6	8	438	9	7	24	11	16
8625	Body	?4th	Sb	C	1.86	0.35	0.39	5.31	18.72	0.49	0.07	0.03	0.08	0.02	0.61	156	17	14	15	352	11	7	23	12	22
13634	Isings 85b	Late 2nd–early 3rd	Sb	C	1.79	0.33	0.39	5.32	19.87	0.47	0.05	0.03	0.01	0.02	0.57	137	12	12	12	364	9	7	22	11	20
13864	Body		Sb	C	1.92	0.27	0.32	5.59	18.44	0.46	0.05	0.03	0.02	0.24	0.57	146	8	6	10	401	6	6	16	10	15
14321A	Body		Sb	C	1.67	0.36	0.46	6.08	18.62	0.47	0.07	0.03	0.01	0.02	0.53	127	15	11	13	436	11	7	22	11	20
13778	Body		Sb	C	1.76	0.32	0.40	5.45	19.37	0.44	0.07	0.03	0.02	0.01	0.53	136	11	9	11	370	8	6	24	11	15
11894	Undiagnostic?		Sb	C	2.02	0.42	0.55	5.97	19.49	0.42	0.08	0.03	0.01	0.02	0.41	144	11	13	13	406	12	7	19	12	22
13871	Isings 85	Late 2nd–early 3rd	Sb	C	1.87	0.30	0.48	6.90	20.62	0.52	0.07	0.05	0.09	0.01	0.41	151	19	9	8	406	10	7	28	10	17
9501	Facetted beaker	2nd–3rd	Sb	C	1.83	0.31	0.37	5.51	19.21	0.47	0.06	0.04	0.02	0.01	0.40	141	14	6	10	345	7	6	19	10	15
13835	Body		Sb	C	1.84	0.22	0.33	5.13	18.55	0.48	0.05	0.03	0.02	b.d.	0.40	142	8	5	9	354	6	7	16	11	18
14264B	Body		Sb	C	2.04	0.44	0.58	5.71	20.38	0.39	0.09	0.03	0.01	0.02	0.50	158	15	11	12	419	11	8	22	11	17
12266	Body		Sb	C	2.00	0.46	0.51	5.60	19.30	0.53	0.07	0.04	0.06	0.06	0.50	151	58	14	14	382	11	7	25	11	18
12103	Cylndrical bottle	Late 2nd–early 3rd	Sb	C	2.13	0.35	0.52	6.54	19.72	0.62	0.07	0.04	0.03	b.d.	0.49	140	18	8	8	504	8	7	30	11	19
11984	Undiagnostic		Sb	C	2.03	0.41	0.55	5.97	19.26	0.45	0.08	0.03	0.01	0.02	0.46	145	11	11	15	409	12	7	18	11	20
11993	Undiagnostic		Sb	C	2.00	0.50	0.66	6.38	20.03	0.45	0.10	0.04	0.01	0.02	0.45	138	13	12	15	567	13	7	19	12	21
12201	Body		Sb	C	2.05	0.44	0.65	5.91	19.21	0.40	0.08	0.03	0.01	0.02	0.45	156	12	13	15	424	11	7	16	12	20
14130B	Body		Sb	C	2.10	0.44	0.63	5.93	18.81	0.44	0.07	0.03	0.01	0.02	0.45	157	14	13	12	429	11	7	22	12	22
12457	Body	4th	Sb	C	1.76	0.23	0.37	5.60	18.69	0.42	0.06	0.03	0.02	b.d.	0.45	137	12	6	8	384	7	7	18	10	16
14308A	Body		Sb	C	1.79	0.24	0.36	5.16	19.06	0.36	0.06	0.03	0.02	b.d.	0.35	135	8	6	8	326	6	7	18	10	15
13351	Body		Sb	C	1.90	0.26	0.41	5.32	19.83	0.51	0.05	0.03	0.02	b.d.	0.29	137	6	6	9	359	6	7	19	10	16

14320	Body	Sb	C	2.12	0.34	0.50	5.53	18.60	0.37	0.08	0.03	0.02	b.d.	0.31	146	7	7	11	358	9	7	19	11	18					
14309B	Body	Sb	LG/C	2.19	0.35	0.66	5.91	18.92	0.43	0.08	0.03	0.02	b.d.	0.31	152	11	8	10	433	9	7	16	11	16					
8674	Body	Sb	C	1.97	0.33	0.47	4.99	17.99	0.49	0.07	0.03	0.02	0.01	0.25	150	6	6	8	324	8	6	15	10	15					
14108	Body	Sb	C	1.97	0.29	0.45	6.73	19.62	0.52	0.07	0.04	0.02	b.d.	0.05	138	13	6	9	469	9	8	21	10	17					
14310A	Body	Sb	C	2.01	0.34	0.45	5.43	19.94	0.55	0.06	0.04	0.06	0.04	0.52	158	14	10	9	370	8	7	21	11	17					
14311B	Undiagnostic	Sb	C	1.98	0.44	0.55	5.95	19.84	0.52	0.08	0.05	0.09	0.08	0.46	156	58	18	11	398	10	7	26	11	15					
14321c	*Body*	*Sb/high-Ca*	*YG*	*2.49*	*0.72*	*0.77*	*6.54*	*20.20*	*0.74*	*0.12*	*0.08*	*0.05*	*0.04*	*0.66*	*163*	*78*	*11*	*13*	*509*	*12*	*7*	*31*	*12*	*17*					
10783	*Cylindrical bottle*	*Sb/high-Ca*	*LG*	*2.41*	*0.80*	*0.87*	*7.54*	*19.23*	*0.69*	*0.13*	*0.07*	*0.08*	*0.03*	*0.73*	*157*	*21*	*17*	*16*	*540*	*16*	*9*	*29*	*12*	*23*					
	3rd																											
14339c	*Body*	*Sb/high-Ca*	*LG*	*2.46*	*0.54*	*0.68*	*7.09*	*20.48*	*0.69*	*0.09*	*0.04*	*0.01*	*0.02*	*0.57*	*157*	*20*	*14*	*16*	*559*	*13*	*9*	*31*	*12*	*21*					
12369	Square bottle	?Mid-1st–end 2nd	Low-Mn	B	2.52	0.32	0.48	7.37	16.66	0.46	0.08	0.14	0.79	b.d.	0.01	310	7	7	12	417	27	8	15	11	16					
10683	Cast window		Low-Mn	BG	2.61	0.37	0.55	7.02	18.34	0.63	0.07	0.13	0.78	0.02	0.01	274	19	14	23	470	23	9	19	12	21					
12320	Body frag		Low-Mn	G	2.54	0.32	0.48	7.26	16.03	0.47	0.07	0.14	0.71	b.d.	0.01	295	8	6	49	405	26	9	18	11	19					
14321B	Body frag		Low-Mn	G	2.99	0.40	0.57	8.24	18.00	0.77	0.06	0.15	0.67	0.02	0.01	275	23	11	23	537	19	10	21	11	20					
12220	Square bottle	?Mid-1st–end 2nd	Low-Mn	B	2.42	0.30	0.54	8.18	16.80	0.60	0.07	0.13	0.66	b.d.	0.01	266	31	6	18	497	16	8	28	11	18					
14103	Ribbed body	Late 1st–early 2nd	Low-Mn	BG	2.50	0.26	0.50	7.81	18.97	0.58	0.07	0.11	0.63	b.d.	0.01	238	8	7	16	470	17	9	23	11	19					
13519	Body		Low-Mn	B	2.62	0.31	0.51	7.26	17.70	0.74	0.08	0.15	0.48	b.d.	0.01	234	24	7	16	422	16	8	27	11	16					
12601	Cylindrical bottle		Low-Mn	B	2.50	0.29	0.52	7.88	17.02	0.56	0.07	0.12	0.44	b.d.	0.01	247	39	6	14	452	17	8	16	11	18					
12537	Bottle shoulder		Low-Mn	B	2.60	0.28	0.54	7.91	19.02	0.66	0.07	0.12	0.42	b.d.	0.01	302	9	6	11	444	22	9	16	10	19					
13502	Handle		Low-Mn	B	2.71	0.27	0.51	8.22	17.04	0.60	0.06	0.13	0.41	b.d.	0.01	267	18	7	14	468	16	9	17	11	18					
12393	Body		Low-Mn	B	2.80	0.31	0.50	7.39	17.14	0.56	0.07	0.11	0.39	b.d.	0.01	243	13	6	14	438	14	9	19	11	19					
12733	Bottle		Low-Mn	BG	2.69	0.36	0.46	7.13	19.87	0.64	0.08	0.12	0.39	0.02	0.01	242	18	10	16	423	14	9	15	11	17					
12868	Isings 12 (Hoffheim cup)	1st	Low-Mn	BG	2.81	0.36	0.45	7.14	18.43	0.73	0.08	0.13	0.36	0.02	0.01	224	26	12	18	397	15	9	18	11	22					
13282	Isings 55 (jug)	Mid-1st–early 2nd	Low-Mn	B	2.36	0.28	0.52	8.00	16.44	0.56	0.07	0.12	0.34	b.d.	0.01	235	21	8	14	447	13	9	18	11	20					
14324	Body		Low-Mn	B	2.64	0.31	0.53	7.65	17.93	0.68	0.07	0.14	0.30	b.d.	0.01	233	13	6	14	452	13	9	19	11	18					
8636	Isings 3 (PMB)	1st	Low-Mn	B	3.04	0.38	0.45	7.35	17.00	0.77	0.08	0.12	0.25	0.01	0.01	221	19	6	12	384	11	9	16	11	18					
13604	Isings 3 (PMB)	1st	Low-Mn	B	2.79	0.39	0.65	7.74	16.82	0.65	0.08	0.15	0.21	b.d.	0.01	250	37	7	11	437	13	8	15	11	16					
13695	Body		Low-Mn	B	2.58	0.28	0.52	8.03	16.35	0.68	0.07	0.15	0.16	b.d.	0.01	232	15	6	12	419	12	9	15	10	19					
10148	*Body*	*1st–2nd*	*Low-Mn*	*YG*	*2.84*	*0.31*	*0.44*	*7.50*	*16.53*	*1.71*	*0.07*	*0.13*	*0.08*	*0.02*	*0.01*	*225*	*8*	*11*	*14*	*387*	*11*	*9*	*15*	*11*	*22*					
13152	*Body*		*Low-Mn*	*YG*	*2.83*	*0.30*	*0.44*	*7.45*	*17.13*	*0.63*	*0.07*	*0.13*	*0.08*	*0.02*	*0.01*	*220*	*7*	*14*	*17*	*383*	*11*	*9*	*13*	*12*	*24*					
13890	*Body*		*Low-Mn*	*YG*	*2.97*	*0.26*	*0.45*	*7.85*	*16.39*	*0.63*	*0.07*	*0.14*	*0.08*	*b.d.*	*0.01*	*231*	*5*	*6*	*10*	*401*	*9*	*8*	*13*	*11*	*19*					
13599	*Isings 44/5 (bowl)*	*Mid-1st–mid-2nd*	*Low-Mn*	*YG*	*2.94*	*0.24*	*0.45*	*7.86*	*16.11*	*0.62*	*0.07*	*0.13*	*0.07*	*b.d.*	*0.01*	*227*	*6*	*6*	*10*	*395*	*9*	*8*	*17*	*11*	*19*					
13688	*Jug and handle*		*Low-Mn*	*YG*	*2.28*	*0.31*	*0.48*	*8.06*	*18.03*	*0.60*	*0.06*	*0.13*	*0.07*	*0.02*	*0.01*	*211*	*10*	*12*	*14*	*416*	*12*	*9*	*12*	*11*	*20*					
9636	*Isings 52 (jug)*	*Late 1st–early 2nd*	*Low-Mn*	*YG*	*2.70*	*0.25*	*0.45*	*7.99*	*18.57*	*0.53*	*0.06*	*0.10*	*0.03*	*b.d.*	*0.01*	*212*	*4*	*6*	*6*	*431*	*7*	*8*	*11*	*11*	*16*					
9426	*Body*		*Low-Mn*	*G*	*2.65*	*0.32*	*0.43*	*7.02*	*17.62*	*0.68*	*0.06*	*0.11*	*0.02*	*0.01*	*0.01*	*203*	*5*	*8*	*10*	*368*	*8*	*8*	*15*	*11*	*17*					
11912	*Body*	*4th*	*Low-Mn*	*YG*	*2.53*	*0.35*	*0.48*	*7.91*	*18.36*	*0.67*	*0.07*	*0.12*	*0.02*	*0.02*	*0.01*	*205*	*7*	*14*	*14*	*409*	*11*	*9*	*17*	*11*	*22*					
11377	Cast window		High-Mn	BG	2.94	0.64	0.61	8.52	17.42	0.54	0.07	0.10	1.38	0.02	0.08	385	17	10	21	501	23	10	19	12	20					
13535	Bottle shoulder		High-Mn (Levantine 1?)	BG	2.85	0.57	0.67	8.77	15.83	0.54	0.09	0.10	1.34	0.02	0.08	344	9	12	24	541	13	10	1	9	22					
14069	*Cast window*		*High-Mn (Levantine 1?)*	*G*	*2.79*	*0.40*	*0.54*	*8.61*	*14.85*	*0.68*	*0.08*	*0.15*	*1.33*	*b.d.*	*0.03*	*440*	*23*	*7*	*19*	*488*	*38*	*9*	*18*	*10*	*20*					
11236	Cast window		High-Mn	BG	2.88	0.60	0.58	8.40	17.44	0.46	0.08	0.09	1.24	0.02	0.08	366	15	7	19	486	21	9	20	11	17					

Appendix 1 (*Continued*)

Cat. no.	Form	Estimated date (centuries AD)	Assigned group	Visual colour	Oxides (wt%)											Trace elements (ppm)									
					Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	MnO	PbO	Sb_2O_5	Ba	Cu	Li	Ni	Sr	V	Y	Zn	La	Ce
12717	Flask/jug		High-Mn	LG	3.03	0.43	0.55	8.49	16.65	0.79	0.07	0.10	1.16	0.02	0.01	473	27	12	19	569	37	9	16	11	19
11316	Cup	4th	High-Mn	LG	3.28	0.46	0.68	9.00	18.39	0.85	0.08	0.09	1.13	0.02	0.04	562	18	13	18	522	20	10	20	11	23
13562	Isings106 beaker	4th	High-Mn	LG	3.17	0.48	0.70	8.77	17.38	0.69	0.08	0.09	1.07	0.02	0.01	581	22	14	18	532	20	10	17	13	23
12788	Body fragment		High-Mn	LG/C	2.65	0.44	0.59	8.10	17.78	0.74	0.07	0.08	1.06	0.02	0.08	581	25	11	16	461	21	9	18	11	21
9791	Isings 106 beaker	4th	High-Mn	G	3.19	0.41	0.59	9.04	18.17	0.83	0.08	0.10	0.92	0.02	0.01	372	14	12	17	525	18	10	17	11	19
10734	Jug	Late 1st–early 2nd	High-Mn	YG	2.80	0.30	0.51	7.88	17.03	0.78	0.07	0.19	0.90	b.d.	0.01	282	9	7	19	481	20	8	20	11	18
10179	Facetted beaker	End 3rd–early 4th	High-Mn	LG	2.87	0.43	0.62	8.29	17.16	0.65	0.08	0.10	0.86	0.02	0.01	399	18	14	19	454	19	9	16	12	24
5495	*Facetted beaker*	*End 3rd–early 4th*	*High-Mn (Levantine 1?)*	*LG*	*2.87*	*0.43*	*0.62*	*8.48*	*15.72*	*0.66*	*0.08*	*0.11*	*0.84*	*0.01*	*0.01*	*407*	*17*	*7*	*13*	*450*	*17*	*9*	*19*	*11*	*19*
13547	*Melted body fragment*		*High-Mn*	*YG*	*2.69*	*0.44*	*0.88*	*7.86*	*14.76*	*0.63*	*0.09*	*0.13*	*1.66*	*b.d.*	*0.01*	*429*	*17*	*9*	*23*	*566*	*62*	*9*	*25*	*12*	*20*
13288	Body		Sb–Mn	C	1.85	0.29	0.41	5.51	19.42	0.49	0.06	0.04	0.11	0.01	0.41	152	17	8	9	355	9	7	23	10	17
15522	Body		Sb–Mn	C	1.78	0.27	0.39	5.19	19.62	0.47	0.05	0.04	0.10	0.01	0.49	149	16	8	8	334	7	6	26	10	16
14311A	Undiagnostic		Sb–Mn	C	2.05	0.43	0.57	6.01	19.75	0.55	0.07	0.04	0.10	0.06	0.48	164	61	25	13	416	11	7	25	12	21
14346A	Body		Sb–Mn	YG	2.03	0.50	0.49	5.81	19.17	0.81	0.08	0.06	0.14	0.06	0.56	172	91	21	15	382	14	7	42	12	22
8207	Beaker flask	Late 2nd–early 3rd	Sb–Mn	C	1.84	0.37	0.43	5.47	19.47	0.51	0.07	0.04	0.13	0.02	0.58	162	19	16	16	356	12	7	25	12	23
14291A	Body		Sb–Mn	C	1.94	0.44	0.48	5.88	18.44	0.63	0.07	0.05	0.14	0.06	0.53	169	105	22	14	392	12	7	32	12	21
12037	Wheel-cut beaker	2nd	Sb–Mn	C	1.99	0.31	0.43	5.70	19.01	0.55	0.06	0.05	0.11	0.01	0.39	162	17	9	10	377	9	7	23	10	16
14308B	Body		Sb–Mn	Y	2.15	0.29	0.44	5.76	19.88	1.01	0.06	0.05	0.14	0.02	0.41	172	20	12	9	365	9	7	25	10	17
14264C	Body		Sb–Mn	LG	2.31	0.48	0.54	6.43	19.68	0.68	0.07	0.06	0.34	0.12	0.64	228	221	31	17	438	16	8	33	12	21
14306B	*Undiagnostic*		*Sb–Mn*	*G*	*2.37*	*0.68*	*0.57*	*6.02*	*19.33*	*0.92*	*0.10*	*0.10*	*0.14*	*0.05*	*0.69*	*179*	*47*	*16*	*16*	*403*	*16*	*7*	*34*	*12*	*23*
12252	Body	4th	Sb–Mn	C	2.10	0.36	0.53	6.14	19.25	0.66	0.08	0.06	0.20	0.03	0.45	176	56	13	10	403	13	7	32	11	18
9707	Vertical-ribbed jug	2nd–3rd	Sb–Mn	C	1.95	0.42	0.46	5.84	19.64	0.62	0.08	0.06	0.24	0.02	0.53	185	21	9	12	388	13	7	27	11	16
14264D	Body		Sb–Mn	LG	2.20	0.55	0.53	6.27	20.42	0.82	0.09	0.07	0.21	0.03	0.49	201	46	14	13	419	12	7	56	11	13
13952	Cup	3rd	Sb–Mn	LG	2.34	0.46	0.55	7.07	18.50	0.75	0.08	0.13	1.01	0.02	0.32	299	24	11	17	437	29	8	25	11	19
12143	Cast window		Sb–Mn	B	2.38	0.46	0.57	7.12	16.20	0.67	0.09	0.09	0.63	0.02	0.25	256	44	59	16	443	20	8	34	11	19
12657	Jar		Sb–Mn	B	2.38	0.51	0.54	6.35	18.59	0.71	0.07	0.09	0.25	0.02	0.24	197	68	11	14	388	11	8	34	11	20
14097	Jug handle		Sb–Mn	B	2.45	0.38	0.52	6.87	16.90	0.69	0.08	0.13	0.48	0.04	0.24	227	56	8	15	412	16	7	28	11	19
12212	Cast window		Sb–Mn	BG	2.46	0.73	0.60	6.91	17.88	0.77	0.10	0.13	0.59	0.08	0.24	262	111	21	21	431	22	9	35	12	22
8785	Body		Sb–Mn	BG	2.53	0.53	0.57	7.32	17.15	0.76	0.09	0.14	0.62	0.05	0.24	257	56	10	16	452	25	9	27	11	19
12253	Isings 85	Late 2nd–mid-3rd	Sb–Mn	B	2.69	0.53	0.63	7.48	17.85	0.80	0.09	0.11	0.67	0.02	0.24	295	63	14	17	466	19	9	32	11	20
13899	Cast window		Sb–Mn	G	2.75	0.59	0.63	7.52	16.97	0.77	0.10	0.12	0.70	0.08	0.23	293	187	12	17	462	22	9	36	11	19
12956	Prismatic bottle		Sb–Mn	BG	2.46	0.48	0.55	6.97	18.54	0.68	0.08	0.13	0.48	0.05	0.21	242	72	13	18	444	20	8	21	11	19
8109	Funnel-mouth jar		Sb–Mn	BG	2.61	0.83	0.68	6.76	17.26	1.05	0.11	0.13	0.49	0.16	0.21	261	504	19	18	430	20	8	72	11	19
11981	Cast window		Sb–Mn	BG	2.62	0.67	0.60	7.26	17.56	0.72	0.09	0.13	0.74	0.10	0.21	286	163	20	21	447	24	9	31	12	24

14040	Rim of bowl	2nd–3rd	Sb–Mn	BG	2.80	0.71	0.67	8.15	19.18	0.88	0.10	0.12	0.83	0.05	0.21	341	51	18	21	516	28	10	31	12	23
13857	Hairpin shank		Sb–Mn	G	2.49	0.72	0.64	7.02	18.40	1.00	0.10	0.13	0.48	0.09	0.20	249	257	20	18	436	19	8	70	12	19
10263	Blown window		Sb–Mn	BG	2.15	0.64	0.62	5.94	19.36	0.80	0.10	0.08	0.72	0.08	0.19	234	105	19	20	404	23	8	41	12	22
12998	Undiagnostic		Sb–Mn	BG	2.56	0.45	0.49	6.85	18.16	0.73	0.08	0.12	0.42	0.05	0.17	224	74	14	19	407	17	8	22	12	22
7497	Isings 44/45	Mid–1st	Sb–Mn	LG	2.53	0.49	0.58	7.19	18.14	0.93	0.09	0.16	0.55	0.04	0.16	253	116	8	17	445	17	9	26	12	18
13827	Prismatic bottle		Sb–Mn	BG	2.40	0.53	0.65	6.96	18.75	0.86	0.09	0.19	0.57	0.05	0.16	230	263	13	21	429	19	8	28	12	21
13591	Body		Sb–Mn	B	2.44	0.37	0.55	7.35	16.85	0.68	0.08	0.13	0.42	0.01	0.13	238	65	9	15	427	17	9	23	11	19
8101	Prismatic bottle		Sb–Mn	BG	2.66	0.61	0.57	6.73	17.61	0.95	0.09	0.17	0.44	0.05	0.13	242	433	7	14	386	16	8	31	11	19
8335	Isings 3 (PMB)	1st	Sb–Mn	B	2.55	0.54	0.54	6.83	18.31	0.93	0.09	0.15	0.45	0.04	0.13	238	236	11	16	403	16	9	30	12	17
11793	Prismatic bottle		Sb–Mn	BG	2.30	0.44	0.48	6.57	17.63	0.74	0.08	0.13	0.43	0.02	0.11	215	172	13	19	373	16	8	21	12	23
10674	Prismatic bottle		Sb–Mn	BG	2.32	0.75	0.54	6.10	19.23	0.74	0.10	0.09	0.23	0.05	0.45	197	96	16	17	385	16	8	36	12	21
9357	Prismatic bottle		Sb–Mn	BG	2.31	0.52	0.59	6.57	19.16	0.78	0.09	0.12	0.35	0.03	0.44	219	59	9	12	419	16	8	25	11	17
10781	Isings 85	Late 2nd–early 3rd	Sb–Mn	C	2.09	0.39	0.44	6.04	19.08	0.65	0.07	0.06	0.43	0.02	0.44	215	15	15	19	389	19	8	24	12	23
14264a	Body		Sb–Mn	YG	2.56	0.65	0.58	6.84	19.81	0.91	0.09	0.09	0.43	0.12	0.44	245	271	18	18	450	16	9	41	12	19
14291C	Body		Sb–Mn	YG	2.26	0.61	0.56	6.08	17.83	0.90	0.09	0.11	0.49	0.31	0.44	238	153	23	18	396	16	7	47	11	17
14309A	Body		Sb–Mn	C	1.93	0.29	0.42	5.54	19.59	0.55	0.07	0.05	0.11	b.d.	0.42	156	14	10	7	362	9	7	24	11	16
12392	Body		Sb–Mn	C	2.07	0.33	0.46	5.43	19.48	0.59	0.07	0.06	0.16	0.01	0.42	172	23	7	11	355	11	7	28	10	17
12620	Bottle		Sb–Mn	B	2.45	0.70	0.55	6.31	18.47	0.71	0.10	0.09	0.24	0.02	0.42	204	72	11	12	390	15	8	34	12	20
10323	Prismatic bottle		Sb–Mn	BG	2.49	0.78	0.53	6.03	18.95	0.71	0.12	0.09	0.24	0.04	0.42	199	92	19	18	385	19	9	32	13	23
13937	Prismatic bottle		Sb–Mn	G	2.54	0.45	0.56	6.38	19.71	0.84	0.10	0.10	0.36	0.03	0.42	221	63	11	15	404	16	8	28	11	18
11325	Body		Sb–Mn	C	2.18	0.55	0.64	6.43	19.61	0.79	0.09	0.07	0.26	0.03	0.40	214	62	28	13	430	15	8	40	12	18
13281	Tubular rim		Sb–Mn	GW	2.41	0.52	0.55	6.71	18.34	0.76	0.09	0.11	0.34	0.03	0.40	217	51	12	16	407	17	8	25	11	18
14339a	Body		Sb–Mn	YG	2.65	0.70	0.63	6.93	19.58	1.04	0.10	0.11	0.46	0.18	0.40	251	739	23	18	445	18	8	62	12	18
14114	Prismatic bottle		Sb–Mn	B	2.29	0.63	0.54	6.40	20.41	0.66	0.08	0.10	0.38	0.02	0.46	218	53	9	15	394	14	7	35	11	15
14291B	Body		Sb–Mn	LG	2.39	0.69	0.60	6.36	18.66	1.56	0.09	0.07	0.35	0.08	0.39	255	91	43	15	432	14	8	34	12	17
12534	Body		Sb–Mn	B	2.64	0.63	0.70	6.82	17.87	0.83	0.10	0.11	0.28	0.01	0.37	221	66	15	14	382	16	9	29	12	23
13741	Blown window	4th?	Sb–Mn	LG	2.23	0.59	0.57	6.22	18.67	0.67	0.09	0.08	0.31	0.14	0.37	203	338	19	17	408	17	7	36	12	21
14310B	Body		Sb–Mn	B	2.28	0.56	0.60	6.19	19.97	0.75	0.09	0.10	0.16	0.01	0.36	180	52	12	11	387	13	7	32	11	19
13805	Jug/flask		Sb–Mn	BG	2.83	0.88	0.62	6.91	19.25	1.09	0.14	0.14	0.34	0.05	0.36	262	94	20	18	416	20	10	35	14	23
14346D	Undiagnostic		Sb–Mn	YG	2.67	0.62	0.62	6.73	19.71	1.20	0.10	0.11	0.40	0.13	0.36	233	305	19	17	437	16	8	36	11	14
11724	Prismatic bottle		Sb–Mn	BG	2.40	0.82	0.59	6.81	19.15	0.76	0.09	0.11	0.45	0.06	0.36	235	57	17	20	421	20	9	30	12	22
13995	Isings 85	Late 2nd–mid-3rd	Sb–Mn	C	2.01	0.30	0.43	5.59	18.86	0.62	0.06	0.06	0.21	0.01	0.35	174	24	11	9	358	10	7	23	10	15
11889	Cast window		Sb–Mn	BG	2.81	0.69	0.65	7.56	18.35	0.84	0.10	0.12	0.77	0.10	0.35	312	170	18	19	486	24	9	33	12	19

Appendix 1 (*Continued*)

Cat. no.	Form	Estimated date (centuries AD)	Assigned group	Visual colour	Oxides (wt%)											Trace elements (ppm)									
					Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	MnO	PbO	Sb_2O_5	Ba	Cu	Li	Ni	Sr	V	Y	Zn	La	Ce
12135	Cast window		Sb–Mn	B	2.67	0.66	0.62	7.09	17.28	0.98	0.12	0.14	0.38	0.08	0.33	253	249	17	17	408	19	9	40	12	21
13341	Bottle, handle reeded		Sb–Mn	B	2.53	0.71	0.61	6.97	19.58	0.82	0.09	0.13	0.40	0.05	0.33	244	99	15	15	425	17	8	35	11	17
13984	Bottle shoulder		Sb–Mn	BG	2.34	0.50	0.60	6.67	17.42	0.83	0.08	0.16	0.41	0.05	0.33	208	60	13	19	398	17	8	24	12	23
8066	Undiagnostic		Sb–Mn	BG	2.35	0.88	0.57	6.93	17.59	1.03	0.09	0.13	0.52	0.05	0.33	240	86	36	16	415	21	8	36	12	21
12641	Prismatic bottle		Sb–Mn	B	2.19	0.97	0.49	6.09	18.27	0.65	0.07	0.08	0.26	0.01	0.32	189	40	10	14	367	12	7	32	11	19
10763	Prismatic bottle		Sb–Mn	BG	2.47	0.69	0.60	6.86	18.48	0.83	0.10	0.13	0.53	0.05	0.32	252	70	21	21	430	23	8	29	12	23
14315	Body		Sb–Mn	G	2.83	0.68	0.62	6.75	18.01	0.97	0.13	0.14	0.33	0.03	0.31	259	87	16	15	405	18	9	32	13	22
13869	Prismatic bottle		Sb–Mn	B	2.58	0.57	0.59	7.08	18.24	0.82	0.10	0.14	0.40	0.03	0.31	244	119	15	13	408	18	8	40	11	19
13907	Body		Sb–Mn	LG	2.53	0.67	0.63	6.65	18.02	0.91	0.09	0.12	0.43	0.12	0.31	287	174	20	17	423	18	8	65	12	24
8417	Body		Sb–Mn	BG	2.44	0.70	0.63	6.86	18.37	1.02	0.09	0.13	0.49	0.09	0.31	244	187	18	15	432	19	8	51	11	19
12086	Handle jug		Sb–Mn	BG	2.39	0.43	0.59	7.23	20.01	0.68	0.08	0.09	0.55	0.01	0.30	268	39	10	15	472	16	9	31	11	19
12879	Body		Sb–Mn	BG	2.50	0.70	0.62	7.20	18.48	0.84	0.10	0.13	0.54	0.08	0.29	269	70	12	15	440	21	9	33	11	18
9866	Bottle, reeded handle		Sb–Mn	BG	2.81	0.67	0.63	7.59	19.10	1.03	0.11	0.14	0.56	0.05	0.29	282	133	29	19	452	23	9	35	13	24
8391	Prismatic bottle		Sb–Mn	G	2.54	0.77	0.67	6.87	18.48	1.19	0.11	0.13	0.53	0.09	0.28	258	215	28	16	441	20	9	108	12	18
10249	Prismatic bottle		Sb–Mn	LG/BG	2.65	0.60	0.70	7.00	18.67	1.04	0.10	0.11	0.85	0.03	0.11	288	91	19	20	430	20	9	38	12	21
10219	Cast window		Sb–Mn	BG	2.54	0.76	0.66	6.71	19.17	1.09	0.10	0.13	0.55	0.10	0.25	261	216	39	20	443	21	8	86	13	23
14041	Prismatic bottle		Sb–Mn	G	2.60	0.55	0.75	7.17	17.18	0.93	0.10	0.17	0.60	0.02	0.25	272	67	12	15	464	23	8	29	11	20
13259	Melted bottle		Sb–Mn	BG	2.67	0.91	0.86	6.94	18.02	1.00	0.12	0.10	0.30	0.04	0.53	219	75	26	20	362	21	10	34	13	26
14130A	Body		Sb–Mn	YG	2.53	0.98	0.62	6.72	18.63	0.91	0.10	0.13	0.43	0.45	0.53	245	1718	19	19	400	18	8	70	11	18
9718	Body		Sb–Mn	LG/C	2.12	0.51	0.52	6.05	19.37	0.67	0.08	0.07	0.22	0.30	0.54	183	350	27	16	401	15	7	60	11	21
13755	Bottle		Sb–Mn	BG	2.23	0.55	0.59	6.05	18.83	0.77	0.10	0.11	0.27	0.05	0.54	197	69	9	14	382	16	7	31	12	19
12092	Bottle/jug		Sb–Mn	LG/BG	2.61	0.69	0.67	6.57	20.14	1.07	0.13	0.15	0.53	0.13	0.58	239	154	14	24	460	22	9	36	13	23
14130C	Body		Sb–Mn	LG	2.46	0.51	0.61	6.18	20.23	0.61	0.09	0.06	0.11	0.04	0.41	181	63	22	14	471	12	7	37	12	15
9904	Jug, tubular, pushed in base ring		HIMT2(W)	LG	2.41	0.66	0.70	6.60	19.70	1.18	0.11	0.08	0.83	0.03	0.01	278	83	20	20	456	21	8	35	12	21
13925	Body		HIMT2(W)	B	4.11	0.32	0.42	4.86	18.39	1.03	0.08	0.15	0.84	b.d.	0.01	292	25	8	21	348	19	9	23	11	18
9573	Body	4th	HIMT2(W)	LG	2.43	0.83	0.79	6.40	20.00	1.20	0.14	0.10	0.99	0.03	0.08	467	137	25	20	462	25	8	53	13	23
13564	Body	4th	HIMT2(W)	LG	2.09	0.67	0.86	6.76	19.88	0.51	0.13	0.04	1.03	0.02	0.03	301	16	14	19	562	22	8	18	12	23
10315	Body		HIMT2(W)	LG/C	2.23	0.71	0.74	5.95	19.76	0.98	0.12	0.07	1.00	0.03	0.08	318	85	24	21	430	22	8	44	12	22
12628	Isings 96/106 (cup/beaker)	4th	HIMT2(W)	LG/C	2.27	0.73	0.77	5.53	19.99	0.85	0.13	0.07	0.92	0.04	0.16	231	84	22	18	394	24	8	38	12	22

11972	Isings 96/106 (cup/beaker)	4th	HIMT2(W)	LG	2.15	0.67	0.72	5.90	19.63	0.69	0.11	0.07	0.92	0.03	0.08	249	91	18	20	418	22	8	30	12	24			
8188	Body		HIMT2(W)	LG	2.42	0.71	0.78	6.30	19.43	0.90	0.12	0.09	0.86	0.04	0.13	267	135	32	20	434	25	8	57	13	23			
9466	Jug		HIMT2(W)	G	2.45	0.64	0.71	6.63	19.61	1.26	0.11	0.09	0.77	0.03	0.12	274	82	13	16	450	20	8	37	12	17			
9533	Body	4th	HIMT2(W)	G	2.20	0.65	0.73	6.12	19.84	0.75	0.11	0.07	0.94	0.04	0.11	299	84	21	18	449	22	8	32	12	22			
12872	Bottle handle, ribbed		HIMT2(W)	LG	2.50	0.55	0.71	6.75	19.68	1.11	0.11	0.09	0.79	0.01	0.11	276	84	16	15	449	20	8	41	11	20			
10506	Prismatic bottle		HIMT2(W)	BG	2.25	0.68	0.73	6.37	20.27	0.73	0.11	0.08	0.92	0.03	0.09	271	102	13	16	443	20	7	30	12	16			
12866	Prismatic bottle		HIMT2(W)	G	2.08	0.52	0.64	5.32	17.20	0.69	0.10	0.08	0.65	0.02	0.16	218	105	22	13	376	20	7	45	11	18			
14338	Undiagnostic		HIMT2(W)	G	2.28	0.65	0.68	6.19	20.46	0.83	0.11	0.09	0.75	0.05	0.16	245	83	13	16	431	22	8	43	12	18			
13770	Body	4th	HIMT2(W)	LG/C	2.16	0.69	0.77	5.64	18.85	0.75	0.12	0.07	0.87	0.03	0.16	239	124	18	20	418	24	7	35	12	23			
8526	Body		HIMT2(W)	LG	2.19	0.66	0.70	6.08	19.17	0.77	0.10	0.08	0.79	0.05	0.15	237	107	21	20	405	23	8	38	12	24			
13025	Bottle body		HIMT2(W)	BG	2.16	0.33	0.42	6.38	18.02	0.64	0.07	0.13	0.86	0.02	0.01	243	11	14	22	424	20	8	20	12	22			
12096	Body		HIMT2(W)	C	2.25	0.75	0.81	7.66	20.08	0.59	0.13	0.05	0.93	0.01	0.11	229	11	13	19	675	28	8	19	12	22			
14144	Body		HIMT2(W)	B	2.57	0.62	0.88	6.12	18.83	1.10	0.13	0.28	0.81	0.04	0.17	259	219	9	22	436	24	9	39	12	19			
13761	Body		HIMT1(S)	YG	2.62	1.17	1.27	6.48	19.26	0.56	0.23	0.06	1.80	0.03	0.03	342	51	16	29	588	35	10	31	13	25			
13287	Prismatic bottle		PLANT	B	2.31	0.70	1.29	8.89	18.71	1.51	0.12	0.35	0.12	b.d.	0.23	192	47	8	12	703	13	7	30	11	18			
12021	Cast window		PLANT	B	2.25	0.79	1.41	7.25	16.92	1.71	0.16	0.45	0.12	0.01	0.13	189	34	9	14	580	16	7	34	11	21			
14306a	*Body*		*OUT*	*G*	*3.01*	*0.80*	*0.85*	*8.65*	*18.79*	*1.20*	*0.16*	*0.10*	*0.69*	*0.02*	*0.01*	*275*	*50*	*18*	*23*	*532*	*23*	*11*	*30*	*12*	*23*			
10203	*Cast window*		*OUT*	*LG*	*2.46*	*0.61*	*0.77*	*7.52*	*18.30*	*0.74*	*0.09*	*0.21*	*1.71*	*0.02*	*0.12*	*404*	*34*	*14*	*24*	*509*	*50*	*8*	*20*	*13*	*22*			
9381	*Isings 67*	*Late 1st–early 2nd*	*OUT*	*LG*	*1.86*	*0.27*	*0.33*	*5.61*	*18.32*	*0.51*	*0.06*	*0.08*	*0.13*	*0.01*	*0.01*	*174*	*12*	*6*	*8*	*303*	*8*	*6*	*15*	*10*	*15*			
13153	*Cylindrical bottle*		*OUT*	*B*	*2.11*	*0.30*	*0.42*	*5.46*	*17.71*	*0.57*	*0.07*	*0.12*	*0.47*	*b.d.*	*0.01*	*202*	*12*	*8*	*16*	*337*	*15*	*7*	*25*	*11*	*17*			
12302	*Cylindrical bottle*	*Mid-1st–end 2nd*	*OUT*	*B*	*2.62*	*0.41*	*0.52*	*7.21*	*18.37*	*0.82*	*0.08*	*0.16*	*0.44*	*0.02*	*0.09*	*239*	*167*	*7*	*15*	*411*	*14*	*8*	*25*	*11*	*16*			
14339B	*Body*		*OUT*	*LG*	*2.50*	*0.37*	*0.48*	*7.23*	*19.64*	*0.98*	*0.06*	*0.19*	*0.46*	*0.02*	*0.08*	*238*	*23*	*10*	*18*	*397*	*14*	*8*	*25*	*11*	*17*			
13872	*Isings 3 (PMB)*	*1st*	*OUT*	*B*	*2.58*	*0.39*	*0.52*	*7.15*	*18.37*	*0.78*	*0.09*	*0.15*	*0.40*	*0.01*	*0.08*	*237*	*177*	*8*	*14*	*407*	*13*	*8*	*24*	*11*	*17*			
14072	*Prismatic bottle*		*OUT*	*B*	*2.36*	*0.35*	*0.50*	*7.30*	*15.24*	*0.68*	*0.08*	*0.13*	*0.32*	*0.01*	*0.07*	*213*	*142*	*7*	*12*	*383*	*13*	*7*	*21*	*11*	*21*			

*Appendix 2 Correspondence between compositional groups for first- to fourth-century glass from selected studies, and representative compositions as wt% oxides unless stated otherwise (Ba and Cu as ppm). (nm, not measured, below detection or not quoted): *indicates mean affected by one or two very high or low values*

Decolourizer	*Major elements*	*Known as*	*References*	*Site/region*	*Approx. date (mostly centuries AD)*
Antimony (Sb) (colourless)					
Antimony	High soda, low lime, low alumina	Group 4	Foy *et al*. (2004)	Egypt, France, Tunisia	1st to mid-3rd
		Antimony only	Paynter (2006)	Binchester, Colchester, Lincoln	1st to 3rd
		CL1	Silvestri *et al*. (2008)	*Iulia Felix*	3rd
		Group 1a	Jackson (2005)	York, Mancetter, Leicester	1st–4th (mostly 2nd–3rd)
		N2 (selection)	Gallo *et al*. (2013)	Adria, Italy	2nd
		Colourless	Jackson and Price (2012)	South Shields	3rd–4th
		Colourless 1	Foster and Jackson (2010)	UK various	3rd–4th
			Paynter and Jackson (in prep.)	British sites	1st–3rd
Antimony low lime (Sb/low-Ca) (colourless)					
Antimony (high)	High soda, very low lime, alumina and barium	Lot A	Foy *et al*. (2004)	Carthage and France	Hellenistic
		Low-barium	Paynter (2006)	Binchester, Colchester, Lincoln	Mid-1st–mid-2nd
		Included in N2	Gallo *et al*. (2013)	Adria, Italy	2nd
		Facet-cut (some)	Baxter *et al*. (2005)	Across UK	1st–2nd
		LLAC	Paynter and Jackson (in prep.)	British sites	1st–3rd
Low-manganese (low-Mn) (blue–green)					
Manganese (low)	Low soda, high lime, high alumina	Group 3	Foy *et al*. (2000)		
			Gliozzo *et al*. (2013)	*Thamusida*, Morocco	2nd–3rd
		ADN1	Gallo *et al*. (2013)	Adria, Italy	1st
			Jackson (1994)	Mancetter	2nd–3rd
			Jackson (1992)	Coppergate	1st–3rd
			Jackson (1994)	Leicester	2nd–3rd
High-manganese (high-Mn) (varying from colourless to blue–green)					
Manganese (high)	Low soda, high lime, high alumina	Group 2b	Jackson (1992)	Coppergate	1st–4th, mainly 2nd–3rd
		CL2	Silvestri *et al*. (2008)	*Iulia Felix*	3rd
		CL2	Ganio *et al*. (2012)	Embiez	Late 2nd–early 3rd
			Jackson (1994)	Mancetter	2nd–3rd
		Levantine 1a	Foster and Jackson (2009)	UK various	4th
		2b	Meek (2013)	UK	4th–7th
		Petra 2	Schibille *et al*. (2012)	Petra	Mainly 4th
			Gliozzo *et al*. (2013)	*Thamusida*, Morocco	2nd–3rd
		ADN1	Gallo *et al*. (2013)	Adria, Italy	1st
Manganese low lime (Mn/low-Ca) (colourless)					
Manganese	High soda, lower alumina, lime and barium	2a	Meek (2013)	Unprovenanced	3rd–7th
		2a	Foster and Jackson (2010)	UK	4th
		Group 3.2	Foy *et al*. (2003)	France	4th–5th
Mixed antimony and manganese (Sb–Mn) (varying from blue–green to colourless)					
Manganese and antimony	Intermediate soda and lime, sometimes elevated iron, alumina, potassium and copper	Group 2a	Jackson (2005)	Leicester	3rd
		Cu blue–green	Paynter (2006)	Binchester, Lincoln, Colchester	Mid-1st–3rd
		Group 2a	Jackson (2005)	York	2nd–3rd
		CL1/2	Silvestri *et al*. (2008)	*Iulia Felix*	3rd
		Colourless 3	Foster and Jackson (2010)	UK various	4th
			Jackson (1994)	Mancetter	2nd–3rd
		N2 (part of)	Gallo *et al*. (2013)	Adria, Italy	3rd
		Group 2a	Jackson (2005)	Coppergate	2nd–4th
			Paynter and Jackson (in prep.)	British sites	1st–3rd

n	SiO_2	Na_2O	*CaO*	Al_2O_3	K_2O	*MgO*	Fe_2O_3	TiO_2	*MnO*	Sb_2O_3	P_2O_5	*PbO*	*Ba (ppm)*	*Cu (ppm)*	SO^3	*Cl*
94	71	19.05	5.56	1.94	0.42	0.43	0.34	0.06	0.02	0.63	0.02	nm	nm	nm	nm	nm
167	nm	18.90	5.67	2.01	0.43	0.41	0.37	0.06	0.02	0.43	0.05	0.04	148	12	nm	nm
60	70.15	19.80	4.80	2.00	0.4	0.4	0.40	0.07	bd	0.8	0.03	<0.01	118	18	0.3	1.4
53	nm	19.34	5.63	1.91	0.5	0.45	0.35	0.07	0.04	0.5	0.04	0.04	148	17	nm	nm
3	69.2	18.84	5.44	1.87	0.46	0.51	0.40	0.08	0.09	0.53	0.04	<0.01	134	9	0.31	1.6
23	nm	18.93	5.62	1.79	0.42	0.51	0.39	0.07	0.03	0.46	0.02	bd	138	23	nm	nm
46	nm	18.99	5.74	1.90	0.39	0.49	0.40	0.06	0.04	0.35	0.02	0.01	148	23	nm	nm
70	nm	18.70	5.70	1.90	0.5	0.4	0.40	0.06	bd	0.9	0.04	0.06	131	13	nm	nm
2	74.7	18.00	4.09	1.12	0.56	0.55	0.40	0.075	bd	2.97	bd	1.30	nm	nm	nm	nm
9	nm	18.52	4.51	1.53	0.61	0.40	0.43	0.06	0.06	0.96	0.05	0.26	85	16	nm	nm
1	70.25	17.13	4.22	1.48	0.75	0.44	0.51	0.10	0.16	1.14	0.04	0.11	<10	151	nm	nm
10	nm	17.77	3.96	1.30	0.58	0.43	0.51	0.09	0.05	2.20	0.06	0.44	87	33*	nm	nm
3	nm	18.36	4.09	1.39	0.55	0.34	0.37	0.04	0.02	2.51	0.04	0.35	74	18	nm	nm
22	69.80	17.00	8.01	2.54	0.61	0.61	0.54	0.06	0.63	nm	0.23	nm	nm	nm	nm	nm
9	70.52	14.92	8.18	2.57	0.53	0.49	0.60	0.06	0.29	11 ppm	0.12	12 ppm	nm	10	0.09	nm
13	69.02	17.55	7.71	2.51	0.64	0.51	0.40	0.06	0.50	0.06	0.13	61 ppm	nm	98	0.20	1.4
32	nm	16.70	7.70	2.48	0.64	0.52	0.40	0.07	0.39	0.02	0.14	0.01	236	28	nm	nm
27	nm	17.59	7.65	2.66	0.71	0.50	0.32	0.07	0.30	0.02	0.13	0.01	236	32	nm	nm
5	nm	17.54	7.44	2.40	0.60	0.61	0.47	0.09	0.20	0.01	0.12	0.01	210	10	nm	nm
16	nm	16.85	8.24	2.86	0.65	0.60	0.44	0.08	1.07	0.03	0.12	0.01	406	17	nm	nm
12	70.29	15.20	7.80	2.60	0.5	0.6	0.20	0.07	1.40	bd	0.14	21 ppm	369	17	0.10	1.2
5	65.27	15.55	8.44	2.26	0.54	0.45	0.28	0.05	1.35	0.16	0.16	nm	433	nm	nm	nm
2	nm	14.93	7.86	2.51	0.71	0.63	0.49	0.08	1.20	0.03	0.18	0.01	286	25	nm	nm
16	nm	15.55	8.45	2.81	0.6	0.59	0.42	0.07	1.23	0.06	0.09	<0.01	383	20	nm	nm
3	70.1	15.67	8.70	3.02	0.67	0.65	0.44	0.06	1.17	nm	nm	nm	bm	nm	nm	nm
18	68.45	16.13	8.16	2.73	1.04	0.46	0.36	0.07	1.08	0.02	0.15	<0.01	308	59	0.17	0.9
14	71.94	14.16	7.60	2.31	0.45	0.51	0.37	0.06	1.39	110	0.14	12 ppm	nm	8	0.05	nm
2	68.54	18.04	7.63	2.50	0.77	0.64	0.38	0.05	1.05	nm	0.10	10 ppm	283	23	0.31	1.2
3	67.42	18.81	6.41	2.36	0.53	0.73	0.63	0.09	0.97	nm	nm	nm	nm	nm	nm	1.3
5	nm	18.46	5.77	1.81	0.29	0.67	0.48	0.09	1.14	0.06	0.03	bd	199	14	nm	nm
17	68.07	18.79	7.05	1.92	0.44	0.65	0.70	0.09	0.89	18	0.08	179 ppm	243	25	nm	nm
70	nm	18.50	6.36	2.33	0.70	0.54	0.67	0.10	0.26	0.40	0.11	0.04	201	82	nm	nm
18	nm	19.44	5.68	2.21	0.54	0.48	0.49	0.09	0.26	0.51	0.08	0.04	179	22	nm	nm
11	nm	19.25	6.10	2.28	0.71	0.56	0.54	0.10	0.34	0.46	0.10	0.07	207	116	nm	nm
13	69.13	19.02	5.64	2.14	0.54	0.66	0.64	0.12	0.19	0.79	0.07	83 ppm	144	24	0.28	1.3
69	nm	19.48	6.12	2.08	0.53	0.59	0.55	0.09	0.35	0.04	0.05	0.07	219	121	nm	nm
64	nm	18.08	6.63	2.41	0.73	0.54	0.52	0.09	0.43	0.28	0.13	0.04	223	76	nm	nm
1	68.28	18.49	6.38	2.16	0.55	0.53	0.46	0.08	0.54	0.41	0.09	0.01	195	155	nm	nm
87	nm	18.70	6.57	2.39	0.81	0.57	0.58	0.09	0.40	0.35	0.10	0.06	228	151	nm	nm
6	nm	19.21	5.51	2.14	0.60	0.46	0.51	0.10	0.27	0.90	0.08	0.05	171	60	nm	nm

Appendix 2 *(Continued)*

Decolourizer	*Major elements*	*Known as*	*References*	*Site/region*	*Approx. date (mostly centuries AD)*
Levantine 1 (blue–green)					
None	Low soda, high alumina and lime		Jackson (1994)	Mancetter	3rd–4th
		Levantine 1b	Foster and Jackson (2009)	Various UK	4th
		Levantine	Freestone *et al*. (2000)	Dor, *Appollonia*	6th–7th
HIMT (olive green)					
Manganese	High soda, low lime, high titanium and iron	HIMT2	Foster and Jackson (2009)	UK	4th
		HIMT1	Foster and Jackson (2009)	UK	4th
		Group 1	Foy *et al*. (2003)	France, Tunisia and Egypt	5th
		HIMT London	Freestone *et al*. (2005)	London	4th
		HIMT Carthage	Freestone *et al*. (2005)	Carthage	4th
		HIMT1	Jackson and Price (2012)	South Shields	4th
		HIMT2	Jackson and Price (2012)	South Shields	4th
Plant ash (blue–green)					
Manganese	High potassium, high magnesium	Plant ash glass	Jackson *et al*. (2009)	Colchester	1st
			Gallo *et al*. (2013)	Adria, Italy	1st
			Henderson (1996)	Fishbourne	1st
			Thirion-Merle (2005)	GdeFoss/Ruscino	1st
			Jackson and Cottam (forthcoming)	Barzan, France	1st
			Jackson and Cottam (forthcoming)	Ribnica, Slovenia	1st

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n	SiO_2	Na_2O	*CaO*	Al_2O_3	K_2O	*MgO*	Fe_2O_3	TiO_2	*MnO*	Sb_2O_3	P_2O_5	*PbO*	*Ba (ppm)*	*Cu (ppm)*	SO^3	*Cl*
5	nm	16.74	8.72	2.46	0.67	0.56	0.39	0.07	0.04	0.01	0.14	0.01	206	5	nm	nm
8	nm	14.56	8.55	2.93	0.72	0.45	0.33	0.06	0.10	0.06	0.08	0.02	254	15	nm	nm
23	69.01	15.98	9.06	2.99	0.83	0.63	0.42	0.12	nm	nm	0.14	nm	223	nm	0.3	0.9
221	nm	19.65	6.00	2.25	0.58	0.76	0.72	0.12	0.98	0.11	0.05	0.02	290	105	nm	nm
123	nm	19.11	6.08	2.49	0.5	0.98	1.36	0.33	1.71	0.05	0.05	0.01	600	91	nm	nm
43	64.5	19.1	6.22	2.88	0.41	1.23	2.28	0.49	2.02	7 ppm	0.11	63 ppm	654	79	nm	nm
14	66.38	18.54	5.99	2.47	0.57	0.92	1.28	0.33	1.9	nm	nm	nm	nm	nm	nm	nm
1	64.77	18.74	5.24	3.18	0.44	1.29	2.30	0.68	2.66	nm	nm	nm	nm	nm	nm	nm
9	nm	18.79	5.74	2.26	0.49	0.93	1.14	0.23	1.39	0.01	0.05	0.01	249	71	nm	nm
8	nm	18.1	5.78	2.05	0.64	0.74	0.70	0.12	0.83	0.08	0.06	0.02	263	99	nm	nm
16	63.06	16.54	6.96	2.14	1.73	1.84	1.44	0.19	0.79	0.34	0.77	0.49	600	16 720	0.24	0.9
6	63.44	17.94	6.73	2.26	1.46	1.96	1.26	0.18	0.73	0.05	0.83	0.04	312	13 084	0.27	1.3
5	64.04	15.54	6.88	2.04	1.88	2.24	1.09	0.10	0.88	nm	1.00	0.10	nm	18 000	0.34	1.0
5	64.66	17.26	6.75	2.32	1.64	1.76	1.55	0.20	1.07	518 ppm	1.06	0.13	420	15 091	nm	nm
12	62.12	17.10	6.63	2.62	1.50	1.85	1.27	0.18	0.80	0.29	0.65	0.29	100	16 400	0.28	1.0
19	62.69	16.64	6.47	2.42	1.70	2.20	1.34	0.18	0.86	0.14	0.73	0.06	200	18 080	0.27	0.9

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