Book Section:

Jackson, C. orcid.org/0000-0002-7379-7466 and Paynter, S. (2021) Friends, Romans, Puntymen, lend me your irons: The secondary glass industry in Roman Britain. In: Höpken, C., Birkenhagen, B. and Brüggler, M., (eds.) Römische Glasöfen - Befunde, Funde und Rekonstruktionen in Synthese [Roman glass furnaces contexts, finds and reconstructions in synthesis]. Denkmalpflege im Saarland, 11 . Landesdenkmalamt Saarland , Schiffweiler , pp. 253-277. ISBN 9783927856240

Denkmalpflege im Saarland 11

Constanze Höpken   Bettina Birkenhagen   Marion Brüggler

RÖMISCHE GLASÖFEN
ROMAN GLASS FURNACES

Befunde, Funde und Rekonstruktionen in Synthese

Contexts, finds and reconstructions in synthesis

Denkmalpflege im Saarland 11

Herausgeber: Landesdenkmalamt Saarland

Impressum

Herausgeber der Reihe	Landesdenkmalamt Saarland Am Bergwerk Reden 11 D-66578 Schiffweiler www.denkmal.saarland.de
Herausgeber des Bandes und Redaktion	Constanze Höpken, Bettina Birkenhagen Marion Brüggler
Layout	gabriele jakobi – design strategien
Umschlaggestaltung	gabriele jakobi – design strategien Der in der Villa Borg nach römischem Vorbild rekonstruierte Glasofen in Betrieb (Foto Inken Vogt)
Frontispiz Umschlaginnenseite	Teilnehmer der Tagung im Archäologiepark Römische Villa Borg (Foto Inken Vogt)
Bibliografische Information der Deutschen National-bibliothek	Die Deutsche Nationalbibliothek verzeichnet diese Publikation in der Deutschen Nationalbibliografie; detaillierte, bibliografische Daten sind im Internet über www.dnb.de abrufbar.

1. Auflage, 450 Stück
Gedruckt mit Mitteln der Fritz Thyssen Stiftung
Druck: repa druck GmbH, Saarbrücken

ISSN 1863-6888
ISBN 978-3-927856-24-0

Römische Glasöfen

Befunde, Funde und Rekonstruktionen in Synthese

Roman glass furnaces

contexts, finds and reconstructions in synthesis

Tagung am 11. und 12.6.2016
im Archäologiepark Römische Villa Borg

Herausgegeben von
Constanze Höpken Bettina Birkenhagen Marion Brüggler

Denkmalpflege im Saarland 11

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Friends, Romans, Puntymen, lend me your irons: The secondary glass industry in Roman Britain

Friends, Romans, Puntymen, lend me your irons: Die sekundäre Glasindustrie im römischen Britannien

Caroline M. Jackson Sarah Paynter

Abstract

Even at the edge of the Roman Empire, in Roman Britain, substantial quantities of vessel and window glass were consumed. The glass itself was not made in Britain, but imported to Britain as raw glass chunks, some as cullet, and fully formed objects. This paper will examine the nature of glass working at three workshops dating from the second to fourth century AD at Mancetter-Hartshill/Warwickshire, at Blue Boar Lane/Leicester and at St Algar's Farm/Somerset. The evidence suggests that although glassworking was relatively widespread in Britain, many sites were predominantly working blue-green glass from re-melted cullet. It appears that only in the very large commercial centres, such as London, was there easier access to imports of raw glass, and perhaps also to more specialised glassworkers.

Zusammenfassung

Obwohl am Rande des Römischen Reichs gelegen, wurden in Britannien große Mengen Gefäß- und Fensterglas konsumiert. Das Glas wurde wohl nicht in Britannien hergestellt, sondern in Form von Rohglas, Bruchglas und fertigen Objekten importiert. Dieser Beitrag beschäftigt sich mit der Glasverarbeitung in drei Werkstätten, die vom 2. bis in das 4. Jahrhundert zu datieren sind: Mancetter-Hartshill/Warwickshire, Blue Boar Lane/Leicester and St Algar's Farm/Somerset. Obwohl Glasverarbeitung in Britannien weit verbreitet war, verarbeiteten viele Werkstätten überwiegend blaugrünes Glas aus eingeschmolzenem Glasbruch. Es scheint, dass man nur in großen Wirtschaftszentren wie London leicht Zugang zu frischem Rohglas und vielleicht auch zu spezialisierteren Glasmachern hatte.

Despite being at the edge of the Roman Empire, Roman Britain consumed substantial quantities of glass. This glass was not made in Britain, but imported as raw glass chunks, cullet (recycled broken or waste glass used in glass-making which may be either remnants from local production or imported to site from elsewhere), and fully formed objects, which were then re-melted and reworked into glass products on the island by glassworkers. The artefactual evidence for this, in the form of tank and crucible-containing furnaces, glassmelting pots, melted glass waste and putative cullet, from a variety of different site types including towns, military sites and those associated with other industries, has been reviewed recently[1].

This paper will examine the nature of glassworking at three of these workshops dating from the second to fourth century AD: those of Mancetter-Hartshill/Warwickshire, Blue Boar Lane/Leicester and St Algar's Farm/Somerset (**fig. 1**). The discussion focuses on the nature of the evidence and the compositional groups found which demonstrate the changing supplies of glass to Britain and the extent to which recycled glass was used at the periphery of the empire.

Acknowledgements: Thanks to Rachel Tyson for making her report on the St Algar's Farm glass available before publication and for providing photographs of the material for the presentation and allowing sampling. Thanks also to the late Jennifer Price and to Hilary Cool of the British Academy Romano British Glass Project for access to the material from Mancetter and Leicester and for photographs of the material from Leicester (care of Leeds University); permission to sample was granted by Kay Hartley from her excavations and The Jewry Wall Museum, Leicester. The analysis was supported by Historic England (St Algar's Farm) and The Science and Engineering Research Council are thanked for financial assistance in the form of a PhD grant to CMJ (SERC 88803864) many years ago, and Drs J. N. Walsh and S. James of the then NERC ICP–AES facility at Royal Holloway, Egham, for help with chemical analysis of the samples from Mancetter and Leicester.

1 Price/Cool 1991; Price 2003; Price 2005; Shepherd/Wardle 2016, 91–97.

Roman glass making and working

In the Roman period, glass was made from raw materials on a large scale in probably only a few dedicated areas, with archaeological and documentary evidence currently pointing to Egypt and the Syria-Palestine coastal region as the primary glass producers. The furnaces were substantial tank structures producing large slabs of glass, which were then broken into chunks for transportation to workshops where the glass was shaped. These glass chunks survive in shipwrecks and workshops of the period[2]. Despite the lack of evidence for more widespread primary production, there were numerous workshops across the Roman world, including some in continental Europe and Britain, melting raw glass chunks and recycled glass cullet and turning it into vessels, windows and items of jewellery. Some of these workshops also used tank furances, e.g. Caistor/Norfolk, Basinghall Street/London, but others e.g. St Algar's Farm/Somerset (4th century), Coppergate /York (possibly 2nd/3rd century). Deansway/Worcester (2/3rd century), The Tower of London and Tower Hill (2nd century), possibly Wilderspool/Cheshire (1st/2nd century) and Verulamium (probably mid-2nd century), used pot furnaces, where the glass was melted in ceramic glass melting pots[3].

Fig. 1 Map showing the three sites with analysed glass waste.

Primary glass compositions: Roman glass was made in a wide range of colours, both transparent and opaque. The transparent glass ranges from colourless through to hues of blue and green, and these were the most common glass colours from the late first century AD onwards. These glasses are called naturally coloured as they have no colouring additives, instead their colour derives from small amounts of iron found in the raw materials. Amber coloured glasses also fall into this group. Varying amounts of manganese oxide or antimony oxide could be added to alter the glass colour or decolourise it completely. These additives, in conjunction with the base glass composition, are very important for characterising Roman glass, for defining compositional groups, and for looking at a lifespan history of these compositional groups. The type and amount of decolouriser varied depending on where and when the glass was made, but freshly made glass contains only antimony or manganese, and these are not found together in fresh glass. The colour of the glass is influenced by many factors, particularly how much decolouriser is added, together with the iron content and oxidation state of the glass.

For the first to third centuries these three elements, antimony, manganese and iron, and their relative amounts, help to define the different compositional groups produced (tab. 1). Antimony oxide was more effective at completely neutralising the glass colour even when used in quite small amounts. It tends to make the glass completely colourless and so was often used to make water-clear colourless glass (this is termed Antimony colourless glass). Fresh 'raw' glass containing manganese may be colourless (termed Manganese colourless and usually containing above 1wt% MnO) or, if less manganese is added, it may still be blue-green (termed

[2] Silvestri 2008; Foy et al. 2003; Ganio et al. 2012.

[3] May 1900; Atkinson 1929; Wardle et al. 2016; Tyson/Lambdin 2014; Price/Cool 1991; Paynter 2008; Jackson et al. 2003; Cool/Jackson 2004; Parnell 1982; Bayley 1991.

Manganese blue-green, and usually containing less than 1wt% MnO). Those which contain no discernible decolouriser are blue-green or amber[4].

In the 4th century, Antimony colourless glass becomes scarce and new glass compositions are introduced, the most prevalent of these have been termed Levantine I and HIMT. These two new glass compositional groups appear to originate from different regions in the Eastern Mediterranean and are contemporary. Antimony ceases to be used as a decolouriser although manganese is still used to produce Manganese colourless glass; the light blue Levantine I sometimes also contains low concentrations of manganese (generally below 1wt%). However, the olive-greenish HIMT glass is probably the most common compositional group in Britain for this later period[5]. It contains high concentrations of manganese, but it is also very iron-rich, and so retains a strong colour.

Recycling: A large proportion of analysed Roman glass from consumption sites contains both antimony and manganese, and this is due to glass from different production sites being mixed when objects were later recycled at workshops[6]. Compositionally this is termed 'Antimony-Manganese recycled glass'. This recycled glass has a range of hues, largely depending on the ratio of antimony to manganese: the more antimony is present, the paler the colour, but most recycled glass is blue-green. Figure 2 demonstrates compositional and colour changes through recycling. The final colour of this glass ultimately depends on the total amounts of decolouriser and iron in the glass and the furnace conditions in which it was melted. The control of these would not be easy for the glassmaker as they would not know the initial amounts of decolourisers in the cullet they were re-melting, and so sometimes the colour of the resulting glass may have been unexpected (e.g. re-melting colourless glass of one composition with colourless glass of another composition may have produced a blue-green glass).

Thus, antimony- and manganese-containing glasses make up most of the common blue-green and colourless glasses up to the late third century AD[7].

Compositional group	Antimony colourless (raw glass)	Manganese colourless (raw glass)	Manganese blue-green (raw glass)	Antimony-Manganese (recycled glass)	HIMT (raw glass)	Levantine 1 (raw glass)
Oxide Wt%						
Al_2O_3	1.97	2.92	2.67	2.40	2.62	2.93
Fe_2O_3	0.37	0.46	0.31	0.58	1.17	0.33
MgO	0.48	0.63	0.50	0.58	1.27	0.45
CaO	5.82	8.48	7.66	6.59	6.48	8.55
Na_2O	19.39	16.81	17.47	18.69	19.26	14.56
K_2O	0.51	0.68	0.67	0.82	0.56	0.72
TiO_2	0.07	0.08	0.07	0.09	0.23	0.06
P_2O_5	0.04	0.11	0.13	0.11	0.06	0.08
MnO	0.03	1.15	0.34	0.40	1.8	0.10
PbO	0.04	0.01	>0.01	0.06	0.03	0.02
Sb_2O_5	0.54	0.04	>0.01	0.35	0.03	0.05

Tab. 1 Indicative compositional groups (from Jackson and Paynter 2015, Table 1, and Foster and Jackson 2009 for Levantine 1). The table shows means from a single dataset of glass found in Britain and are presented to give an indication of compositional types discussed in the text. When 'raw glass' is stated, it is assumed the glass represents that of the original unadulterated composition (in these cases mixing 'like with like' glasses will not show evidence of recycling).

4 Paynter/Jackson 2018.
5 Foster/Jackson 2009.
6 Paynter/Jackson 2016.
7 Jackson/Paynter 2015.

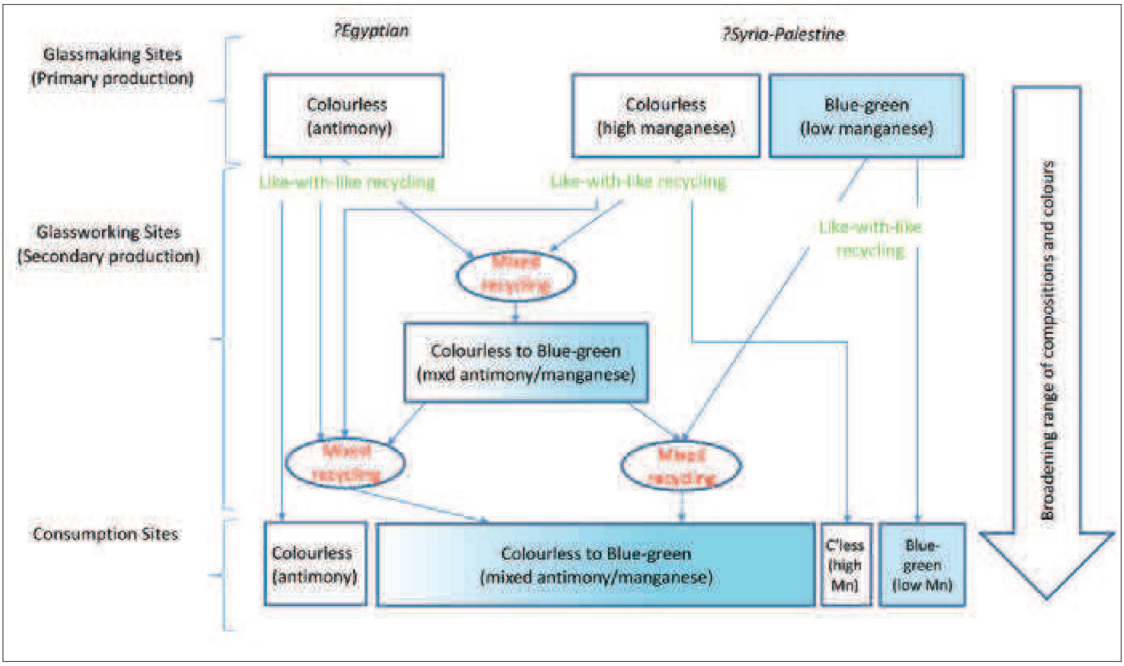

Fig. 2 Model showing glass recycling, indicating glass colours and compositions represented through different recycling campaigns from glass production through glassworking and final compositions in consumption assemblages.

The sites studied

Mancetter-Hartshill

The area around Hartshill, immediately to the south of the small settlement of Mancetter, is best known for producing vast numbers of *mortaria* from the first to fourth centuries AD[8]. The Roman-British settlement at Hartshill is probably linked to the legionary fortress to the west of Watling Street in the late first century. Thirty-five pottery kilns were found at Hartshill, producing ceramics for both local consumption and export around Britain in the second and especially the third centuries. In the 1964 excavations, a single glass furnace, dated to the second century from associated glass wasters[9], was also found associated with the pottery kilns, and a large assemblage of glassy waste. Most of the waste was found around the furnace (M24), scattered stratigraphically through the filling and stoke hole (38% of the total glass recovered and 45% of the waste) and a water channel (35% of the glass assemblage and 45% of the waste M63/64) which may suggest that there was at least one other glass furnace in the vicinity or may indicate that the material was dumped[10]. The furnace was not fully excavated in the 1964 excavations but was noted as clay-lined with dimensions of 65 x 53 x 25 cms deep with solidified glass on its side. Further excavations in 1969 suggest it had been relined four times[11].

Approximately 1350 fragments of vessel and glass waste and 25 window glass fragments were recovered (weighing less than 2 kg). Greater than 90% of the glass is blue-green, the remainder is yellow-green, yellow brown and colourless with a few fragments of polychrome. Waste material (melted fragments, blowing waste and distorted and bubbly fragments, termed wasters, as they are failed attempts to make vessels) makes up 41% of the assemblage by number of fragments. The most common vessel forms include tubular rimmed bowls (Isings

[8] Hartley 1973a.
[9] According to Price 2003.
[10] H.E.M. Cool, personal communication.
[11] Warwickshire Historic Environment Record (HER) WA6244.

44/45, mid first-late second centuries), collared jars (Isings 67b/c types, late first to early second centuries) and prismatic and cylindrical bottles (Isings 50/51 types, first-second century). The working waste consists of 'spills', trails or threads, moils, roundels and wasters. Moils were the most frequent finds. These are collars of glass formed around the end of the blowing iron during glass blowing and are 'knocked-off' when cleaning the iron, and many of those from Mancetter were streaked with iron scale. Roundels are small round/oval with a shiny convex surface on one site and a rougher concave surface on the other. It is not fully understood how these are formed, but they may also be associated with the 'knock-off' from the blowing iron and are often associated with other glassblowing waste[12]. 'Spills' are the waste glass spilled during working, and threads or trails of glass are the thin thread-like needles of glass left when the glass worker gathered glass from the crucible, applied trailed decoration or tested the viscosity of the glass. Bubbly and distorted vessel fragments were identified as wasters (failed vessels), especially when found in association with solidified molten waste. The identification of vessel wasters suggests that small utilitarian jars and collared jars were probably being produced, possibly for local consumption. The colours of the waste mimicked the assemblage as a whole.

Blue Boar Lane, Leicester

The site at Blue Boar Lane, Leicester, was excavated in 1958 but is unpublished[13]. Occupation of Roman Leicester dates from the late first century, but the remains at Blue Boar Lane consist of a second century courtyard house, which was rapidly demolished and replaced with a substantial public building, thought to be a market hall, in the third century. A furnace with glassworking debris was found in the external portico at the west end of this market hall[14]. It is thought to date to the late third century when the building was abandoned. Approximately 400 glass waste fragments (c. 400g) were found around the furnace area. These are representative of glass blowing, and consist of cylindrical moils (20% by weight), roundels (20% by weight), pinched fragments, rods, trails and lumps. They are similar in forms to the waste from Mancetter, although the Leicester waste is visually more clear and transparent and there are no obvious waster fragments. 95% of the Leicester waste is blue-green, the rest is colourless. The excavations also recovered 230 vessel and 12 window glass fragments, primarily of blue-green and colourless glass, which are typical of a domestic assemblage. Unfortunately this latter assemblage cannot conclusively be related to glassworking in the area.

St Algar's Farm, Somerset

Excavations at the rural Roman villa site at St Algar's Farm, Somerset, have taken place since 2010[15]. Excavations to 2015 had recovered over 1600 glass fragments, including 560 waste fragments from glassworking, including chunks (angular broken pieces), rounded molten lumps, moils, distorted fragments and crucible fragments. Some fragments were pre-fourth century but the majority of recognisable forms suggested that the likely date of working was late fourth to early fifth century. The majority of the vessels recovered were conical beakers, cups or bowls with cracked off rims and slightly pushed-in concave bases. Some window glass was also recovered, most of it "cast"[16]. The late date of the site is also supported by the colour

[12] Price/Cool 1991.

[13] The site is noted in the project design (Buckley) for the completion of report for Blue Boar Lane, https://archaeologydataservice.ac.uk/archiveDS/archiveDownload?t=arch-416-1/dissemination/pdf/universi1-87485_1.pdf.

[14] Wacher 1978, pl 30; Price 2003.

[15] Tyson/Lambdin 2014.

[16] Tyson 2014. The method to (re)produce this kind of window panes is actually thought to be by stretching not casting, see Mark Taylor and David Hill: http://www.theglassmakers.co.uk/archiveromanglassmakers/articles.htm#No; also Wiesenberg 2016.

of the glass, which was predominantly olive green and greenish-colourless (typical of fourth century assemblages and later). It is difficult to know whether the broken glass vessels fragments found were made on site or were cullet destined for recycling.

Furnaces

All three sites produced evidence for furnaces which were circular or oval in shape and relatively small. The Mancetter furnace is the only one where enough of the structure remains to allow measurement. At its maximum size this furnace has a diameter of only 0.8 m and had a flow of glass on one surviving wall, but there is no reason here to infer from the furnace structures that glass was melted within a built-in tank, such as those recently published from London at Basinghall Street[17]. The glass in these furnaces may have been melted in glass melting pots, perhaps similar to domestic vessels which seem to be commonly used to re-melt Roman glass[18]. There is no evidence of this from Mancetter or Leicester but at St Algar's Farm multiple fragments of glass coated ceramic melting pots were recovered.

Aims

Assessing what was being made is difficult at most glassmaking sites because, unlike pottery production centres, glass can be re-melted and recycled, so the glass found may be cullet brought to the site for recycling or waste from production at the site itself. Whilst the products may be difficult to determine, the glass compositional types and their potential origin may be more easily investigated, through compositional analysis.

Two hundred fragments of glass from the three sites were analysed to determine:

a) the compositional groups present and hence the potential origins of the glass,

b) what types of glass were reaching these sites in southern and central Britain from the second to the fourth century,

c) to what extent there was a reliance on cullet rather than fresh glass

d) whether the products being made at each site can be identified by matching the composition of wasters to the composition of the working waste and

e) the duration and scale of production at each site.

The assemblages provide an excellent window into the production of utilitarian vessels at industrial, urban and rural sites. Samples were selected to represent a cross section of the waste (and vessel glass if related to the glass waste) and included melted drips and lumps (some with pinched ends), moils, roundels and chunks of glass found in association with the waste in a range of colours.

Methods

The glass samples from Leicester and Mancetter were put into solution using the method devised for silicates, and analysed by Inductively Coupled Plasma – Atomic Emission Spectroscopy (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. This method does not measure silica which is lost through volatilisation, but does measure many elements to

[17] Wardle et al. 2016.
[18] Cool/Jackson 2004.

trace concentrations. Lead and antimony concentrations were calculated separately using prepared single element standards and Corning and NIST glass standards of known composition.

The samples from St Algar's Farm were analysed using an FEI Inspect scanning electron microscope (SEM) with an attached energy dispersive spectrometer (EDS) at Historic England Research Department, Fort Cumberland. Samples were mounted in epoxy resin and polished. The EDS data was quantified using Oxford Instruments INCA software and calculated stoichiometrically as oxides. Analytical conditions, sample preparation methods and data validation are given in Paynter et al. 2015. The suite of elements above detection by SEM-EDS is smaller than by ICP-AES. Cobalt, nickel, copper, zinc, tin, antimony and barium are below detection in most samples and are reported only when they exceed detection levels by two sigma.

The glasses from each site were selected to give a representative sample of the population excavated. The relative numbers of glasses which fall into each compositional group can be used only to provide a broad compositional ratio of different glasses at the sites (Tab. 2, Appendix 1). Only a small sample of glass from the first season of excavation (2010) was available for analysis from St Algar's Farm.

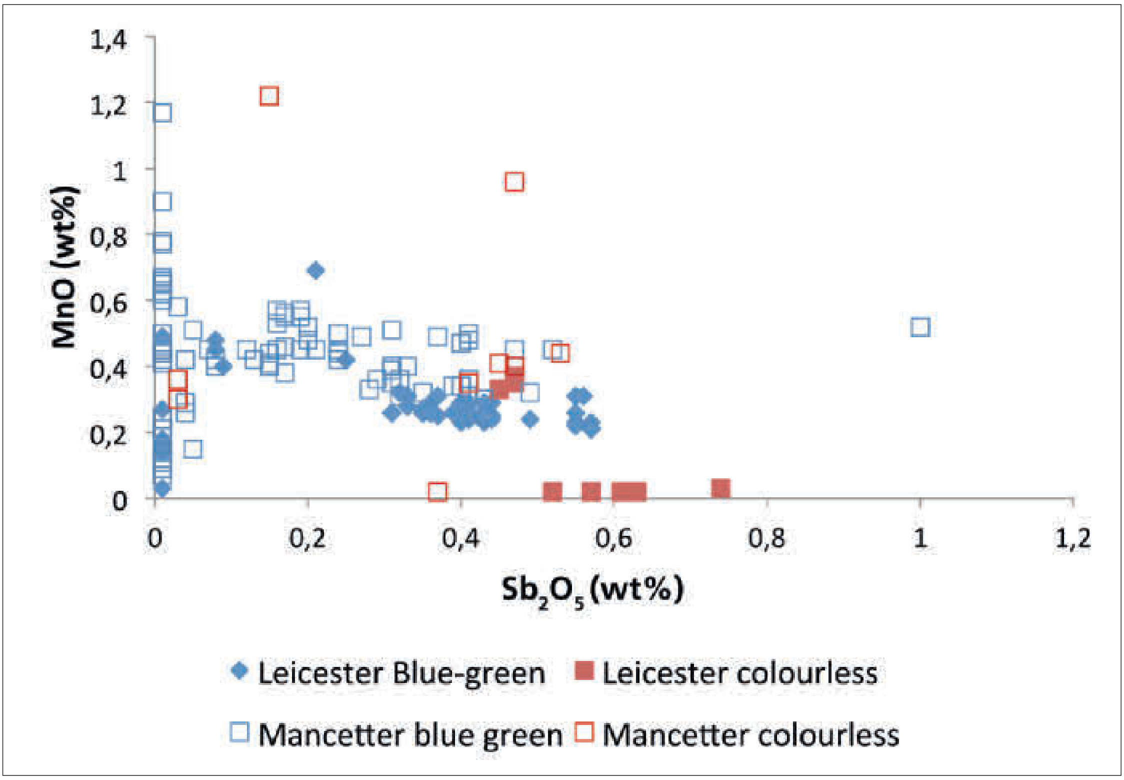

Fig. 3 Colourless and blue-green at Mancetter and Leicester.

Results

Which compositional groups are present at the three glassworking sites?

The glass waste at all three sites is mainly naturally coloured, ranging from weak blue and green hues through to olive yellow. At Mancetter and Leicester, of second and third century date respectively, the glass is predominantly blue-green with some fragments of colourless glass[19]. At the later site of St Algar's Farm the glass is predominantly a stronger olive green, typical of this later period.

[19] Price/Cool 1991, 26.

Site	Date approx.	Glass colour	Antimony col'rless	Manganese blue-green	Manganese col'rless	Antimony-Manganese recycled	No decoloriser	Levantine I	HIMT
Mancetter	2nd century	Blue-green		31	1	57	5		
		Colourless	1		1	7			
Leicester	3rd century	Blue-green		8		59			
		Colourless	5			3			
St Algar's Farm	4th century	Olive-green				1		2	22
		Cobalt blue		(1)					

Tab. 2 Main compositional groups identified in the samples analysed.

The blue-green glass from Mancetter is mainly recycled Antimony-Manganese mixed glass and the rest is Manganese blue-green glass, which is relatively uncontaminated by recycling. The Manganese blue-green glass comprised moils, roundels and trails and other associated waste, along with bottles (**tab. 2,** Appendix 1). Five yellow green glasses are very similar in composition except that they do not contain any manganese decolouriser[20]. There is one chip of Antimony colourless glass which could be a fragment of vessel or waste or a raw glass chip, and two fragments of Manganese colourless glass, one of which is a piece of glass waste and the other probably a bottle fragment. In Britain, previous studies have shown that Manganese colourless glass appears to be rare in tableware after the mid-first century AD[21].

The third-century glass from Leicester, shows a similar array of glass compositional groups but in different proportions (**fig. 3**). The Manganese blue-green glass, is rare, as is Antimony colourless glass. By far the largest number of glass fragments are recycled, containing both antimony and manganese. Some of these are colourless and others are blue-green, although both contain similar proportions of antimony and manganese. As Jackson and Paynter suggest[22], successive re-melting of glasses may lead to recycled glass acquiring a blue-green colour, despite the presence of decolourisers, due to changes in the proportions of the decolourisers, the glass oxidation state, and the increased contamination from the furnace, crucibles/melting pots and fuel. The increase in potassium concentrations derived from the fuel ash in the recycled glass compositions at Mancetter can be seen in fig. 4a[23].

The St Algar's Farm fourth-century glass is predominantly a stronger olive green, and displays a different suite of compositional groups to those seen at Mancetter and Leicester. By the fourth century, new glass compositions began to dominate most assemblages. In Britain HIMT is the dominant compositional group[24] and the vessel glass and waste from St Algar's Farm reinforces this (**fig. 5**). Detectable levels of lead were present in just under half of the samples, showing that much of the glass reaching the site was probably already recycled. This pattern is seen in British glass assemblages from contemporary glass consumption sites[25]. The evidence for the use of recycled glass is supported by the presence of antimony at trace levels in most of the glasses (analysed independently by ICP-MS) perhaps from recycling with small amounts of the earlier Antimony-Manganese recycled glass. The HIMT glass composition was seen in the glass from the melting pots, conical beakers (possible products) and blowing waste (**tab. 3**). The presence of one fragment of Antimony-Manganese recycled glass suggests that some earlier glass, already part of the recycling pool, was reaching the site. Simi-

20 Foster/Jackson 2009.
21 Jackson/Paynter 2015; Foster/Jackson 2010.
22 Jackson/Paynter 2015, 11.
23 Jackson/Paynter 2015.
24 Foster/Jackson 2009.
25 Foster/Jackson 2009.

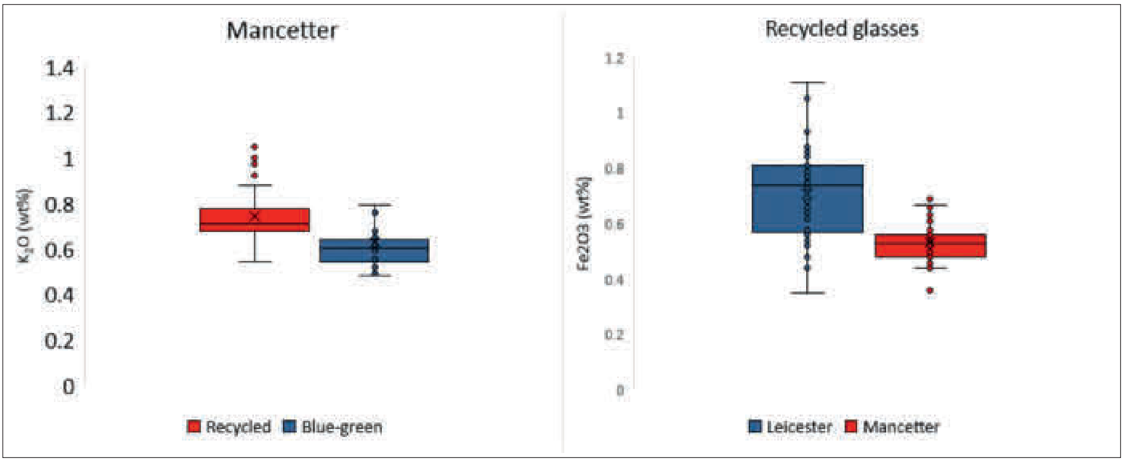

Fig. 4 Box plots: (a) Left, glass from Mancetter showing increased concentrations of potassium in recycled antimony-manganese glass compared to blue-green glasses. (b) Right, showing the range of iron concentrations in Antimony-Manganese recycled blue-green glasses at Mancetter and Leicester.

larly, one analysed sample of a dark blue cobalt-coloured vessel suggests recycling of a fragment of early Roman glass (some fragments of which were found fused together at the site) at St Algar's Farm[26]. There is also a chunk of Levantine I glass.

The compositional groups of glass from the three sites reflects the glasses in circulation at the time of operation of each glassworking facility (**tab. 2**, Appendix 1), falling into the same broad compositional groups identified and defined in Britain by Jackson and Paynter 2015. In summary the Leicester and Mancetter assemblages are dominated by blue-green recycled glass containing both antimony and manganese oxides. There are more compositional groups represented at second-century Mancetter, than at third-century Leicester (**fig. 3**) and some possible reasons for this are discussed below. HIMT glass dominates the fourth-century site at St Algars, with a small amount of Levantine I glass.

Use of raw glass and cullet

Very few chunks of potential raw glass were identified amongst the waste from Mancetter and Leicester, so much of the glass used for melting may have been from cullet. At St Algar's Farm some chips and chunks of glass were found. These may have been obtained as raw glass chunks, but could also have been glass remnants from the base of the glass melting pots because they were so small.

At the earlier site of Mancetter the supply includes a substantial amount of Manganese blue-green glass, which was either not recycled or had only been recycled with glass of the same type. This blue-green glass was in circulation by the first century or before. It would reach glassworking sites in Britain through the recycling of older vessels, or perhaps at Mancetter in the waste from earlier melting campaigns on the site, but this uncontaminated supply of blue-green glass was becoming increasingly scarce by the second century. Furthermore, there is no material evidence to suggest that the site was supplied with a large amount of raw glass chunks. The glass used a few decades later at Leicester, represented by the compositions of the moils and other waste, was predominantly mixed antimony-manganese recycled glass derived from cullet. Later still, glassworkers at St Algar's Farm used mainly HIMT glass. A significant proportion of this glass also appears to be recycled, mostly with similar HIMT glass because little else was available in this period.

[26] Tyson 2014.

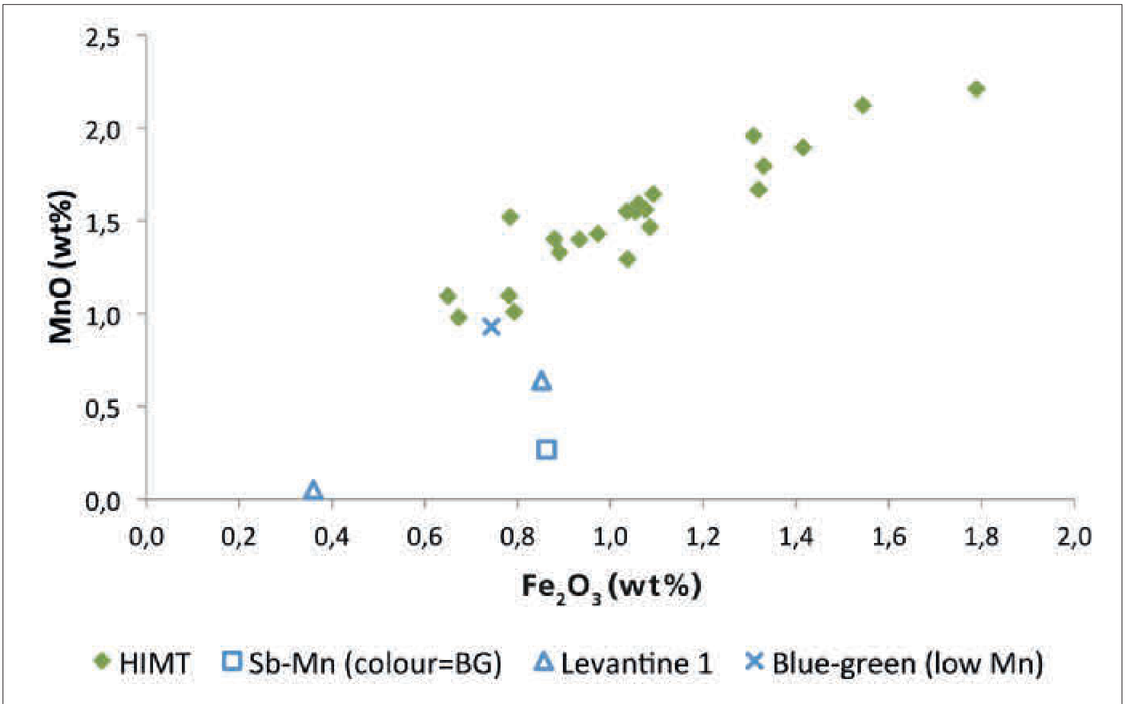

Fig. 5 St Algar's Farm, Somerset.

Site	Date approx.	Glass colour	Antimony col'rless	Manga-nese blue-green	Manga-nese col'rless	Antimony-Manganese recycled	No decol-oriser	Levantine	HIMT
Mancet-ter	2nd century	Waste	1	18		36	1		
		Vessel waster		13	2	28	4		
Leicester	3rd century	Waste	5	8		61			
		Vessel waster				1			
St Al-gar's Farm	4th century	Waste				1		1	17
		Vessel Waster		(1)				1	5

Tab. 3 Vessel (cullet or product) and waste from each of the three sites. Vessels were only counted where they could be identified, so the number may be depressed.

The recycled Antimony-Manganese blue-green glass used at both Leicester and Mancetter is broadly similar in composition but the Leicester glass tends to have a slightly higher ratio of antimony to manganese (**fig. 3**). As suggested above, we can assume that the glassworkers at both sites started with recycled mixed glass, but the composition could have been altered by the addition of different types of cullet available[27]. It might be suggested that there was more Antimony colourless glass available for melting at Leicester and more Manganese colourless glass at Mancetter, pushing the composition towards a more antimony-rich or manganese-rich glass respectively.

Although both sites have blue-green glass waste, the Leicester glass is generally more blue than the Mancetter glass (**fig. 6**). An examination of published contemporary blue-green glasses[28] shows that Manganese blue-green glass is more consistently described as blue compared to mixed recycled glass, which is often labelled greenish. On this basis, the Mancetter

[27] Paynter/Jackson 2019.
[28] Silvestri 2008; Bingham/Jackson 2008; Jackson/Paynter 2015.

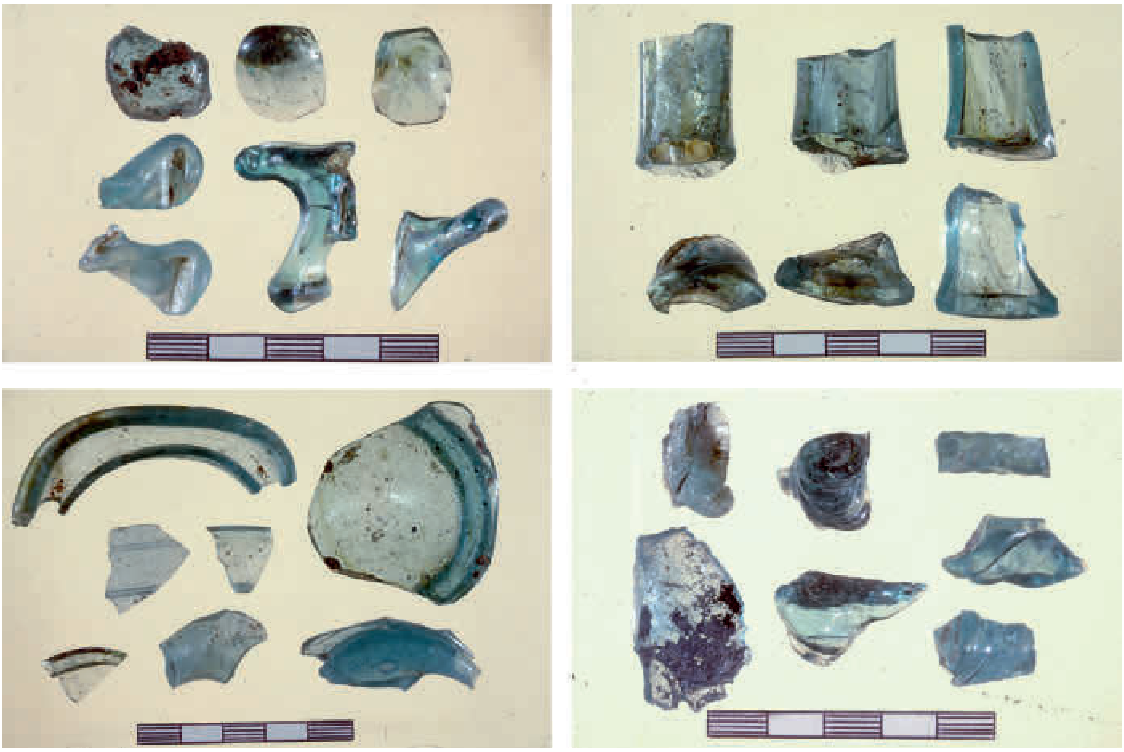

Fig. 6 Glass from Leicester and Mancetter. a. Leicester, drips and pinched fragments, roundels (top). b. Mancetter moils. c. Mancetter deformed vessel fragments (including possible cullet fragments). d. twisted and deformed working waste both sites.

assemblage should be the bluer one as it has less mixed recycled glass. However, Jackson and Paynter point out that the iron content is important in the determination of colour, and this appears to be the key factor when determining whether recycled mixed glass will be more blue or green[29]. A higher iron content will result in a bluer glass because it means there is insufficient decolouriser to oxidise all of the iron, and the remaining reduced iron has a strong blue colour. So, comparing the recycled Antimony-Manganese mixed glasses from Leicester and Mancetter showed that a third of these glasses contained in excess of 0.7wt% ferric oxide (Fe_2O_3), and they were all from Leicester (**fig. 4b**). A possible explanation for the increase in iron in the Leicester samples is through the incorporation of iron oxide scale from the blowing iron when moils were repeatedly recycled, which could have been accidental or possibly intentional since the resulting colour more closely resembles fresh Manganese blue-green glass (which may have been more desirable).

Thus, at both Mancetter and Leicester, cullet appears to be the main source of the glass used in the furnaces, and the incorporation of cullet into the melt may have been dictated by what was available, but may also have been actively managed to control colour and melting properties.

What was being made?

By comparing the composition of the vessel fragments and waste (moils, roundels, threads etc.) from each site we can attempt to identify the products being made, and differentiate these from cullet which may have been collected for re-melting and brought from elsewhere. Most of the analysed glass within each site groups fairly closely together in terms of composition. This includes production waste, such as moils and glass threads, so we can be certain that this was the composition of glass being melted at each site. The tight compositional groupings

[29] Paynter/Jackson 2016.

at these production sites contrasts strongly with the results from consumption assemblages, such as Coppergate, York, where a continuous spread of recycled compositions is seen, ranging from Antimony colourless to Manganese colourless, and everything in between (**fig. 3**)[30].

At all three sites there were moils, indicative of glassblowing, which best represent the composition of the vessels produced at the site. At Mancetter these are of the Manganese blue-green and mixed Antimony-Manganese groups, at Leicester of only mixed Antimony-Manganese glass (one colourless moil, not analysed) and at St Algar's Farm of only HIMT glass (**fig. 5**). Without analysing the whole assemblage of moils from all three sites it is impossible to categorically state that this is representative of all manufacture, but a pattern does emerge of a change in the supply of glass and increased use of recycled material for vessel production through time. This is supported by other compositions of Roman glass vessels found in Britain[31].

At Leicester, there were no recognisable wasters (failed vessels) in the glassworking waste assemblage to suggest what forms were being made. Price and Cool identified the following forms represented by wasters at Mancetter: collared jars (Isings 1957, Form 67b/c), funnel mouth jars, some jugs and bowls with base rings[32]. Some of these vessels had trailed decoration. At St Algar's Farm Tyson identified wasters which were deformed examples of conical beakers, and cups or bowls with cracked off rims and pushed-in bases[33].

At Mancetter and St Algar's Farm, there is no clear compositional distinction between the wasters and the vessel glass. It is therefore likely that many of the broken vessels found on the site represent wasters from the production process. These may be broken vessels which had been poorly annealed and so shattered upon cooling. Both sites show evidence for the production of tablewares, at Mancetter the wasters are jars, jugs, bowls and containers and, at St Algar's Farm, beakers. This reflects the change in consumption of glass where, in the fourth century, tablewares came to predominate[34].

How long were the furnaces operating?

Particular glass compositions appear to have a life-span and so the production and circulation of these, before they become heavily recycled, can help determine how long these furnaces were operating. The slightly greater spread of compositions amongst the waste from Mancetter suggests that this may have been the longest-lived industry of the three considered here, with multiple batches represented in the analysed sample. The area is already known for the vast and long-lived pottery industry in the area[35], and so the existence of a well-established glass industry would not be unexpected.

The tighter clustering of the St Algar's Farm and Leicester samples may indicate that the glassworking at these sites was of a shorter duration. At both of these sites, the glassworks have been linked with the abandonment of associated dwellings, and perhaps the reclaiming and recycling of materials, and shorter-lived glassworking activity is consistent with this interpretation, as is the smaller size of the waste assemblages.

30 Jackson/Paynter 2015.
31 Jackson/Price 2012; Jackson/Paynter 2015; Foster/Jackson 2009; Foster/Jackson 2010.
32 Price/Cool 1991, 26.
33 Tyson/Lambdin 2014, 9.
34 Price 2000, 1; Cool 2003.
35 Hartley 1973a.

Discussion

Glass available to glassworkers throughout Britain

These three sites have yielded the largest amounts of glass waste recovered from Roman glass-working sites in Britain, outside of London. All three sites show that cullet was heavily used for vessel production. This suggests that stocks of raw, uncontaminated glass were probably not readily available throughout Britain, and were certainly less abundant than in the eastern Mediterranean regions, nearer to where most Roman glass was produced. Martial and Statius[36] in the first century discuss the collection of scrap glass and it is likely this practice was far more widespread than previously appreciated, and that cullet was nearly as valuable as fresh glass. The relative scarcity of fresh glass in Britain shows that most of the glass being melted and worked had already been mixed and recycled at least once, and probably more. Some glass vessel fragments can be identified as cullet, brought to the site for re-melting, as their compositions do not match any of the waste (including wasters) from the site. Many of these cullet fragments also have a mixed Antimony-Manganese 'recycled' composition, which further indicates that each of these glass workshops, which operated at different times and in different locations, was re-melting glass that was already recycled. The same is true of the glass used at Coppergate, which is largely mixed recycled glass. These relatively small centres represent a more *typical* picture of glassworking in Britain, than the sites in London discussed below, and so help to present a fuller picture of the glass industry in Britain.

Glassworking technology and skill

From the later first century AD and for the next three centuries, high quality colourless tableware found in Britain was mainly made from Antimony colourless glass. Elaborately decorated wares, with facet-, figure- or wheel-cutting, were usually made from this glass compositional type. These products required skilled glassworkers and cutters in addition to the use of specialist glass types. The resulting products would have had a higher value than blue-green utilitarian wares, and so would have been beyond the reach of many consumers. This higher value of colourless glass is attested in the fourth-century price edict of Diocletian[37]. So, although colourless glass was particularly popular in the first and second centuries, the manufacture of these high quality colourless vessels was not necessarily widespread. It is therefore probable that only a few centres would have had the skill, and so found it profitable, to work colourless glass[38].

This is demonstrated at several British glass melting sites, where nearly all of the working waste is of blue-green glass[39] with only a few pieces of colourless or strongly coloured fragments, suggesting that colourless glass was not worked in Britain to any great extent. This also is supported by the evidence presented here, whereas London appears to be an exception. At Mancetter and Leicester only a few fragments of colourless glass, and only one colourless moil (not analysed), were identified. No colourless moils were seen at St Algar's Farm. The skills needed for the production of high quality vessels, and the lack of vessel production in colourless glass at these regional centres, suggests that such specialists worked in only a few centres (see below), which had access to the appropriate materials and markets.

Although waste assemblages represent only the material left behind, it is interesting that Antimony colourless glass is slightly more prevalent at Leicester than Mancetter, and that the recycled glass waste from Leicester also contains a higher proportion of antimony. Thus we should consider whether glassworkers may have hoarded colourless glasses (and highly

[36] Epigrams I, 1.41.3–5; Silvae 1.6.74.
[37] Whitehouse 2004, 189; Barag 2005, 184.
[38] Paynter/Jackson 2019.
[39] Price/Cool 1991; Price 2005.

coloured glass such as that from St Algar's Farm), using them sparingly and to produce specific technological or decorative effects. Peripatetic glassworkers may also have taken these glasses with them as they moved around to be used in this way[40].

Repeated recycling of glass, in (sometimes reused) domestic pots of the type seen in Britain, would have slightly increased the amount of iron in the glass by the dissolution of the pot walls and incorporation of iron scale (Turner estimated 0.5% of the walls in contact with each melt would be incorporated[41]). This increasing iron content could perhaps be counteracted by adding more Antimony colourless glass (cullet) to a batch to 'improve' the melt and the resulting colour and clarity of the glass. This is because antimony is an especially robust decoloriser and a glass refiner. Roman Antimony colourless glasses also contain more sodium than blue-green glasses, and so the increase in alkali might positively affect the working properties by lowering the melting point. In summary, antimony containing glass may have been especially useful addition to the melt to produce a paler, clearer glass, with improved melting characteristics.

Changes in supply over time

Recycled glass is seen in abundance in the waste glass at all glassworking sites in Britain. Although the glass factories in the east continued to produce fresh glass on a large scale in the second and into the third centuries, and it is found amongst the cargoes of wrecks along the coast of continental Europe[42], little of this unadulterated glass reached Britain. This can be illustrated with the three sites here. At mid-second century Mancetter, most of the glass is Manganese blue-green, with little evidence for previous recycling. Contrast this with Leicester, a little over a century later, where almost all of the blue-green glass is Antimony-Manganese recycled, and also Coppergate in York. However, the blue-green hue of most of this recycled glass meant that it could be used interchangeably in the place of fresh Manganese blue-green glass. Any fresh glass available was therefore supplemented at regional glassworking centres with cullet, some of which might have been in circulation for decades. This is tentatively demonstrated here for example at St Algar's Farm, where some pieces of dark blue glass cullet are from vessel forms likely to be at least a century older, and other fragments of Manganese blue-green glass have compositions likely to be at least decades old.

By the fourth century, a change in glass composition can be seen, presumably because of changing supply centres. By this time there must have been such an extensive network of secondary glassworking industries across the Roman world that using previously recycled material became inevitable. This would be especially true of HIMT glass which does not require careful selection in recycling; an olive green would easily be produced with many different glass mixtures because the high iron and manganese concentrations in the glass would dominate the colour. Using cullet would also have been much more cost effective and efficient for the glassworkers in Britain who may choose to recycle glass, rather than import large blocks of raw glass long distances from the eastern Mediterranean factories.

The British glass industry in context

Studies of assemblages from workshops in continental Europe, and from wrecks off the coast, have demonstrated that chunks of raw glass, containing either antimony or manganese, and supplies of coloured glass, were reaching Europe from production regions further East[43]. The cargo of the *Embiez* wreck contained Antimony colourless glass chunks and Manganese col-

[40] Paynter et al. 2015.
[41] Turner 1930.
[42] Silvestri 2008.
[43] E.g. Silvestri 2008; Foy/Nenna 2001 and http://www.sci-news.com/archaeology/roman-period-glass-factory-israel-03779.html.

ourless window glass, dated to the later second and early third centuries AD. The cargo of the *Iulia Felix* shows that cullet of all sorts was being transported by sea in the third century. Continental workshop remains provide evidence for large scale glassworking using different furnace types[44] and of specialisation in certain glass products[45]. But to date it has been far less clear how Britain compared. How much of this fresh glass was reaching glassworkers here, by what means, and to what extent did glassworkers adopt the technology or specialist skills of their European counterparts? This synthesis of the evidence from three workshops spanning the Roman period in Britain provides some insights into these questions.

We can place these three sites within the context of other glassworking evidence for Roman Britain. By 2003 Price listed just over 20 British sites with varying levels of evidence of glassworking, from melted glass, and fragments of crucibles/glass melting pots to furnace remains[46]. Glassworking throughout Britain often took place in towns and was associated with other industries. The furnace at Mancetter is situated in a large industrial area where *mortaria* were produced and then distributed widely. The furnace at Leicester was in the heart of the town. With the recent evidence from St Algar's Farm, on the site of a Roman villa, it can be seen that, by the fourth century at least, we have examples in Britain where glass was also being worked in rural locations[47].

The furnaces at these three sites, although small-scale, each show evidence of more than one campaign. The single furnace at Leicester seems to have produced glasses of at least four compositional types. That at Mancetter, which was rebuilt at least four times, has evidence of at least three compositional glass groups in the melted waste. There is clear evidence for the use of pots (similar to domestic vessels) or crucibles to melt the glass at St Algars. The size of the melting pots would have limited the volume of glass that could be gathered on the end of the blowing iron by the glassworker, which may have placed further restrictions on the types of products that could be made. For example, many thin, blown vessels could be made using a 'pot furnace', but windows and bottles would have required larger volumes of glass for each item, which could be met more easily by using a large capacity tank furnace[48]. Thus, the more widespread picture (outside of major cities such as London, see below) is of production of common blue-green utilitarian vessel forms using cullet in small-scale complexes for perhaps a fairly local market. The scale of these operations has prompted the suggestion that these furnaces were operated only from time to time by itinerant glassmakers when utilitarian glass was needed, and the evidence presented here might support this[49].

The sites recently discovered in London are different. The most extensive of these are the second century glassworks in the Upper Walbrook Valley, London[50] where larger scale working took place in tank furnaces that could melt large quantities of glass in one campaign (the only other putative tank furnace in the UK is at Caistor by Norwich tentatively dated to the fourth century[51]). The second century tank furnace at Basinghall Street, part of the Upper Walbrook industry, provided evidence for at least three melting campaigns. Tablewares and bottles were produced[52]. Manganese blue-green, Antimony colourless and Manganese colourless raw glasses, imported as chunks, were used in addition to mixed recycled glass. Compared to glass waste found at Mancetter, Leicester, St Algar's Farm, and also at Worcester and York, the large scale of glassworking and the range of different glass compositional groups identified at Basinghall Street is atypical for Britain.

[44] Wedepohl et al. 2003.
[45] Amrein 2001.
[46] Price 2003, Fig. 5.
[47] Tyson 2014.
[48] Wardle et al. 2016; Băeştean/Höpken 2009
[49] Price 2005, 185.
[50] Shepherd 2014.
[51] May 1900.
[52] Wardle et al. 2016, 71–73.

It is significant that the Basinghall Street furnaces, located in arguably the largest British town of its time, represent a larger industrial undertaking than the sites discussed here. London at this time was a large port and military establishment with excellent channels of communication both inland and across the sea to mainland Europe. It could therefore service a large and diverse population, and probably had more easy access to resources, such as raw glass, cullet through cullet merchants, and skilled workers from neighbouring countries. Within this vibrant industrial context the glassworking sites in the area probably welcomed craftspeople from continental Europe, and it has been suggested that the glassmakers here were not local, but travelled with the glass[53].

Hartley argues that the army were also large consumers of goods and would have had a strong influence on production and trade, and on the movement of goods[54]. For high-demand goods bought in bulk, such as pottery, it is likely the army authorities would commission and buy directly from manufacturers and play a part in the larger distribution network. The Walbrook glassworking sites are located near a fortress, and Shepherd and Wardle posit that these fortress complexes may have functioned as a provisioning hub for the province[55]. This can be illustrated by the distribution of the pottery *mortaria* produced in the Walbrook Valley, which were distributed as far as Kent. They suggest the same production/distribution patterns might be argued for glass. The link between the army, *mortaria* production and glass in the Walbrook Valley is also seen at Mancetter[56]. *Mortaria* produced in the large kiln complexes at Mancetter supplied most of central Britain by the second century. Therefore, this established trade in pottery, alongside the growing Roman road network in Britain (Leicester another garrison town was sited at an important river crossing along the Fosse Way) may have allowed a ready distribution network for the glass vessels produced at the site, although possibly on a smaller scale for Mancetter than for London. The glass from St Algar's Farm presents a different picture, although still one of small scale glassworking. By the fourth century, many sites in Britain show limited evidence of glass use, even military sites[57], and this was predominantly olive green utilitarian glass made from recycled material such as that from St Algar's Farm.

The picture presented above tentatively suggests a two-stage hierarchy in glass production throughout Britain. The same hierarchy is true of continental Europe, where there is considerable variation in the scale of glassworking, the types of glass and furnace structures used, the degree of specialisation and the products[58]. The evidence for most of the glassworking in Britain however represents a comparatively small-scale industry producing utilitarian items, in a part of Europe far away from the major glassmaking regions in the Eastern Mediterranean, apparently using more heavily recycled glass, and servicing a more marginal consumer market.

Conclusions

The evidence presented here suggests that, although glassworking was relatively widespread in Britain, many sites were predominantly working blue-green glass from re-melted cullet. Pot furnaces were used for reheating the glass and the products were blown utilitarian wares. The evidence also gives some insight into the chronological patterning of the use of glass. Recycling was widespread from the beginning of glass use in Britain, demonstrated by this glass waste and from previous vessel analyses, and by the second century a significant proportion of the blue-green glass in circulation was mixed recycled glass, apparently here increasing to almost all of the blue-green glass by the third century. Although it has been noted that the determination of recycling patterns is more difficult when glasses of the same composition

[53] Shepherd/Wardle 2016, 109; Shepherd 2014, 43.
[54] Hartley 1973b, 41–42.
[55] Shepherd/Wardle 2016, 101–102.
[56] Hartley 1973b.
[57] Jackson/Price 2012.
[58] E.g. Wedepohl et al. 2003; Cottam/Jackson 2018; Amrein 2001; Brüggler 2014.

are recycled together[59], this compositional evidence can be used to identify the predominant glass in circulation at any one time. Through the case studies presented here it can be shown that, once a particular compositional glass type becomes unavailable, it takes decades for that glass type to work through the system, becoming mixed with new compositional types through recycling, before it finally disappears. However, occasional fragments of older glass compositions are still represented amongst cullet decades or centuries after fresh glass was no longer available. In cases where the glass was particularly sought-after for its properties, it may be recycled for longer periods of time, for example, when strongly coloured Roman glass was recycled in the medieval period[60].

It appears that only in the very large commercial centres, such as London, was there relatively easy access to imported raw glass, and perhaps also to more specialist glassworkers. Here glassworking was undertaken on a larger scale, producing a more extensive range of products[61]. This large scale production is apparent in the use of tank furnaces, of raw glass and cullet (some of the latter from their own campaigns) and in the products, which included items requiring substantial quantities of glass, like bottles. In this large centre, skilled glassworkers could make full use of the market for high quality goods, and, so far, it is only here that there is clear evidence that colourless glass was worked in any substantial quantity.

So, although the evidence from London suggests that diverse materials, products, technology and markets were available there, it is clear that much of Britain was making use of heavily recycled cullet for glassmaking at local centres for local markets. Relatively little primary glass was reaching these small-scale production locations, many of which were producing common forms of thin, blown, blue-green utilitarian vessels. Britain, in virtually all respects concerning glassworking, was at the outer edge of the empire.

[59] Paynter/Jackson 2016.
[60] Paynter/Jackson 2016.
[61] Freestone et al. 2016; Shepherd/Wardle 2016, 109.

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Illustration credits

Fig. 1–6 C.M. Jackson and S. Paynter

Code	SiO_2	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	Colour	Identification	Assigned group
L19BRR	n.d.	2.32	0.84	0.55	6.19	19.78	0.70	0.10	0.11	0.24	0.09	0.49		196	195	20	15	387	15	8	33	BG	roundel	Sb-Mn recycled
L19BWAS	n.d.	2.36	0.57	0.54	6.67	19.32	0.68	0.09	0.11	0.31	0.03	0.33		214	72	21	16	409	15	8	31	BG	waste	Sb-Mn recycled
L19BRR	n.d.	2.50	0.78	0.56	6.40	18.35	0.73	0.11	0.11	0.27	0.03	0.35		207	99	24	16	395	17	9	43	BG	roundel	Sb-Mn recycled
L19BRR	n.d.	2.38	0.84	0.54	6.17	18.05	0.70	0.10	0.11	0.26	0.03	0.40		200	78	23	16	378	17	8	45	BG	roundel	Sb-Mn recycled
L19BWRL	n.d.	2.31	0.74	0.54	6.26	18.59	0.69	0.10	0.10	0.25	0.03	0.41		198	85	21	20	378	15	8	32	BG	pinched lump	Sb-Mn recycled
L19BRR	n.d.	2.34	0.54	0.54	6.76	17.62	0.68	0.09	0.13	0.42	0.04	0.25		223	119	19	18	410	17	8	30	BG	roundel	Sb-Mn recycled
L19BHAL	n.d.	2.21	0.85	0.56	6.21	19.64	0.71	0.09	0.11	0.25	0.03	0.44		196	87	21	19	392	14	8	39	BG	heat affected lump	Sb-Mn recycled
L19BWRL	n.d.	2.17	0.56	0.56	6.22	20.03	0.69	0.10	0.10	0.23	0.04	0.57		186	52	18	15	414	14	8	29	BG	pinched lump	Sb-Mn recycled
L19BTR	n.d.	2.45	0.89	0.55	6.19	18.30	0.71	0.11	0.12	0.26	0.03	0.39		206	80	24	20	378	17	8	51	BG	trail	Sb-Mn recycled
L19BRR	n.d.	2.24	0.52	0.52	6.36	18.69	0.60	0.09	0.11	0.29	0.03	0.40		196	48	20	17	391	15	8	25	BG	roundel	Sb-Mn recycled
L19BDRI	n.d.	2.27	0.75	0.55	6.24	19.53	0.67	0.09	0.11	0.25	0.02	0.41		201	72	21	16	390	15	8	33	BG	drip	Sb-Mn recycled
L8BPIN	n.d.	2.27	0.87	0.56	6.39	18.98	0.68	0.09	0.11	0.29	0.03	0.36		208	89	23	18	397	15	8	32	BG	pinched lump	Sb-Mn recycled
L19BPIN	n.d.	2.49	0.85	0.54	6.36	18.01	0.73	0.11	0.11	0.27	0.03	0.35		202	94	20	18	388	17	9	48	BG	pinched lump	Sb-Mn recycled
L19BCM	n.d.	2.43	0.44	0.50	6.77	17.70	0.74	0.08	0.15	0.48	0.02	0.08		227	111	15	14	403	15	8	24	BG	cyl moile	Sb-Mn recycled
L19BRR	n.d.	2.25	0.59	0.56	5.52	20.55	1.01	0.12	0.09	0.26	0.05	0.55		187	65	19	17	379	16	8	31	BG	roundel	Sb-Mn recycled
L19BWAS	n.d.	2.14	0.56	0.55	5.86	19.56	0.69	0.10	0.10	0.23	0.05	0.55		183	64	19	14	387	15	7	28	BG	waste	Sb-Mn recycled
L19BCM	n.d.	2.55	0.56	0.58	7.17	17.34	0.72	0.09	0.14	0.69	0.04	0.21		265	50	17	20	457	27	9	30	BG	cyl moile	Sb-Mn recycled
L19BDRI	n.d.	2.23	0.73	0.54	6.07	18.58	0.64	0.10	0.10	0.23	0.02	0.40		192	54	19	16	374	16	8	32	BG	drip	Sb-Mn recycled
L19BWAS	n.d.	2.22	0.57	0.57	6.04	20.63	0.72	0.11	0.10	0.22	0.05	0.55		189	66	16	15	405	15	8	30	BG	waste	Sb-Mn recycled
L19BLUM	n.d.	2.45	0.77	0.56	6.41	19.07	0.73	0.11	0.11	0.28	0.03	0.40		209	83	21	15	398	18	8	49	BG	lump	Sb-Mn recycled
L19BRR	n.d.	2.17	0.54	0.57	6.23	19.98	0.67	0.10	0.10	0.21	0.04	0.57		183	72	15	14	414	15	8	30	BG	roundel	Sb-Mn recycled
L19BTR	n.d.	2.22	0.48	0.52	6.44	18.66	0.62	0.09	0.11	0.31	0.03	0.37		206	46	16	16	405	15	8	24	BG	trail	Sb-Mn recycled
L19BWRL	n.d.	2.52	0.86	0.56	6.45	18.32	0.74	0.12	0.12	0.26	0.03	0.36		205	97	18	18	393	18	9	48	BG	pinched lump	Sb-Mn recycled
L19BCM	n.d.	2.34	0.78	0.58	6.37	19.34	0.73	0.10	0.11	0.26	0.03	0.41		206	76	19	15	401	16	8	34	BG	cyl moile	Sb-Mn recycled
L19BCM	n.d.	2.64	1.11	0.59	7.89	17.78	0.75	0.12	0.15	0.26	0.03	0.31		227	77	19	18	406	20	10	37	BG	cyl moile	Sb-Mn recycled
L19BWAS	n.d.	2.48	0.58	0.58	6.83	17.45	0.82	0.10	0.17	0.40	0.03	0.09		236	619	17	19	386	16	8	34	BG	waste	Sb-Mn recycled
L19BCM	n.d.	2.32	0.64	0.58	5.66	20.08	0.79	0.13	0.12	0.31	0.05	0.55		200	66	16	16	392	19	8	40	BG	cyl moile	Sb-Mn recycled
L19BWAS	n.d.	2.10	0.53	0.55	6.15	19.97	0.65	0.09	0.10	0.21	0.04	0.57		179	67	16	14	408	14	7	29	BG	waste	Sb-Mn recycled
L19WRL	n.d.	2.73	0.74	0.55	6.12	18.83	0.77	0.11	0.10	0.29	0.06	0.41		212	103	23	17	391	18	9	32	BG	pinched lump	Sb-Mn recycled
L19BCM	n.d.	2.51	0.78	0.55	6.44	18.30	0.73	0.11	0.12	0.26	0.03	0.35		208	101	22	18	396	18	9	44	BG	cyl moile	Sb-Mn recycled
L19BPIN	n.d.	2.37	0.81	0.55	6.38	19.03	0.70	0.10	0.11	0.24	0.03	0.43		202	82	18	17	391	17	8	36	BG	pinched lump	Sb-Mn recycled
L19BCM	n.d.	2.31	0.88	0.57	6.42	18.90	0.76	0.10	0.12	0.28	0.03	0.40		211	73	22	16	402	17	8	48	BG	cyl moile	Sb-Mn recycled
L19BCM	n.d.	2.50	0.78	0.56	6.46	18.57	0.73	0.11	0.12	0.26	0.03	0.36		208	106	21	15	401	17	9	47	BG	cyl moile	Sb-Mn recycled
L19BPIN	n.d.	2.57	0.80	0.56	6.43	18.41	0.75	0.12	0.12	0.26	0.03	0.35		208	100	21	17	397	18	9	45	BG	pinched lump	Sb-Mn recycled
L10BPIN	n.d.	2.24	0.84	0.56	6.26	19.49	0.73	0.09	0.12	0.23	0.03	0.43		196	85	17	14	395	15	8	41	BG	pinched lump	Sb-Mn recycled

Code	SiO_2	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	Colour	Identification	Assigned group
L19BCM	n.d.	2.37	0.44	0.50	6.78	17.15	0.70	0.08	0.15	0.45	0.02	0.08		219	104	14	16	391	16	8	25	BG	cyl moile	Sb-Mn recycled
L19BCM	n.d.	2.48	0.77	0.55	6.36	18.30	0.73	0.11	0.12	0.26	0.03	0.35		205	100	21	16	392	18	9	42	BG	cyl moile	Sb-Mn recycled
L19BRR	n.d.	2.26	0.58	0.61	6.16	19.47	0.74	0.10	0.11	0.21	0.03	0.57		193	73	19	15	393	15	8	31	BG	roundel	Sb-Mn recycled
LAIBTR	n.d.	2.25	0.66	0.52	6.20	18.06	0.64	0.09	0.11	0.24	0.04	0.41		190	70	16	16	382	15	8	34	BG	trail	Sb-Mn recycled
L19FUR	n.d.	2.49	0.93	0.55	6.18	16.54	1.10	0.12	0.13	0.25	0.03	0.37		209	82	1	18	371	19	9	57	BG	furnace lining	Sb-Mn recycled
L10BPIN	n.d.	2.46	0.76	0.55	6.37	17.95	0.72	0.11	0.12	0.26	0.03	0.36		205	100	21	15	393	18	9	43	BG	pinched lump	Sb-Mn recycled
L19BLUM	n.d.	2.47	1.05	0.56	7.62	17.02	0.70	0.11	0.14	0.26	0.03	0.31		218	74	19	17	393	19	9	34	BG	lump	Sb-Mn recycled
L19BCM	n.d.	2.16	0.74	0.53	6.09	17.25	0.65	0.09	0.11	0.25	0.03	0.43		189	69	17	17	366	16	8	32	BG	cyl moile	Sb-Mn recycled
LAIBTR	n.d.	2.26	0.58	0.52	6.41	17.28	0.67	0.09	0.13	0.28	0.03	0.33		203	62	21	15	385	16	8	46	BG	trail	Sb-Mn recycled
L19BDRI	n.d.	2.29	0.78	0.56	6.24	18.45	0.70	0.10	0.11	0.26	0.03	0.43		201	73	18	14	390	16	8	33	BG	drip	Sb-Mn recycled
L19BPIN	n.d.	2.30	0.78	0.53	6.28	18.20	0.65	0.10	0.11	0.25	0.03	0.41		199	76	19	15	386	17	8	43	BG	pinched lump	Sb-Mn recycled
L19BWAS	n.d.	2.30	0.57	0.58	6.55	17.60	0.68	0.09	0.12	0.32	0.02	0.32		210	52	16	16	394	17	8	28	BG	vessel waste	Sb-Mn recycled
L19BDRI	n.d.	2.52	0.65	0.55	6.16	18.69	0.74	0.11	0.10	0.29	0.06	0.44		207	79	20	16	390	18	8	30	BG	drip	Sb-Mn recycled
L19BDRI	n.d.	2.28	0.68	0.55	6.37	18.60	0.68	0.10	0.11	0.24	0.03	0.43		199	113	19	14	391	16	8	87	BG	drip	Sb-Mn recycled
L19BWAS	n.d.	2.37	0.84	0.54	6.21	17.49	0.68	0.11	0.11	0.25	0.03	0.40		197	77	20	16	374	18	8	46	BG	waste	Sb-Mn recycled
L19BCM	n.d.	2.25	0.62	0.56	5.55	19.47	0.74	0.13	0.11	0.31	0.05	0.56		194	65	15	16	386	19	8	34	BG	cyl moile	Sb-Mn recycled
L8BLUM	n.d.	2.32	0.80	0.54	6.34	18.25	0.66	0.10	0.11	0.25	0.03	0.43		200	79	19	15	387	17	8	45	BG	lump	Sb-Mn recycled
L8BRR	n.d.	2.35	0.74	0.55	6.54	18.44	0.71	0.10	0.11	0.26	0.03	0.39		204	75	22	16	401	16	8	43	BG	roundel	Sb-Mn recycled
L19BPIN	n.d.	2.19	0.84	0.54	6.13	17.99	0.69	0.10	0.11	0.24	0.04	0.44		189	108	16	15	374	15	7	40	BG	pinched lump	Sb-Mn recycled
L19BPIN	n.d.	2.62	0.82	0.54	6.25	17.79	0.73	0.11	0.09	0.29	0.04	0.43		210	68	19	15	382	17	8	31	BG	pinched lump	Sb-Mn recycled
L6BLUM	n.d.	2.35	0.65	0.54	6.73	17.91	0.72	0.10	0.12	0.28	0.06	0.33		210	48	16	15	400	15	7	37	BG	lump	Sb-Mn recycled
L19BPIN	n.d.	2.42	0.68	0.53	6.15	17.19	0.77	0.13	0.11	0.27	0.03	0.35		222	64	18	14	378	17	8	30	BG	pinched lump	Sb-Mn recycled
L19BLUM	n.d.	2.52	0.79	0.56	6.37	18.11	0.74	0.12	0.11	0.26	0.03	0.36		207	100	20	19	394	18	9	43	BG	lump	Sb-Mn recycled
L19BLUM	n.d.	2.37	0.75	0.55	6.33	18.55	0.69	0.10	0.11	0.25	0.03	0.43		205	86	18	15	394	17	8	43	BG	lump	Sb-Mn recycled
L19CCM	n.d.	2.37	0.57	0.55	6.12	19.74	0.71	0.10	0.11	0.37	0.06	0.47		214	132	18	17	409	17	8	32	LG/C	cyl moile	Sb-Mn recycled
L19CCM	n.d.	2.34	0.35	0.59	6.22	19.50	0.70	0.10	0.11	0.35	0.06	0.47		207	125	17	17	406	18	8	39	LG/C	cyl moile	Sb-Mn recycled
L8CPIN	n.d.	2.30	0.55	0.53	5.99	19.59	0.80	0.11	0.10	0.33	0.04	0.45		203	81	17	16	396	18	8	31	LG/C	pinched lump	Sb-Mn recycled
L19CWRL	n.d.	1.82	0.37	0.40	5.59	20.02	0.51	0.08	0.04	0.02	0.25	0.63		141	9	14	10	379	10	7	20	C	water rounded lump	Sb colourless
L19CPIN	n.d.	1.86	0.41	0.50	6.25	19.76	0.50	0.08	0.05	0.03	0.01	0.74		140	5	16	13	446	10	7	20	C	pinched lump	Sb colourless
L19CLUM	n.d.	1.75	0.31	0.35	5.15	18.91	0.45	0.06	0.04	0.02	0.01	0.57		140	6	14	10	360	8	6	22	C	lump	Sb colourless
L19CPIN	n.d.	1.88	0.30	0.35	4.45	18.82	0.50	0.07	0.04	0.02	0.01	0.61		155	7	13	11	286	8	6	21	C	pinched lump	Sb colourless
L19CWRL	n.d.	1.83	0.30	0.33	4.20	18.97	0.44	0.07	0.04	0.02	0.01	0.52		146	6	12	8	266	9	6	21	C	water rounded lump	Sb colourless
L19BTR	n.d.	2.34	0.43	0.58	9.42	15.72	0.59	0.08	0.13	0.14	0.01	0.01		196	5	13	13	482	11	9	17	BG	trail	Mn Blue-green
L19BRR	n.d.	2.46	0.35	0.51	7.72	16.51	0.56	0.07	0.12	0.17	0.01	0.01		220	13	12	14	407	12	9	15	BG	roundel	Mn Blue-green
L19BPIN	n.d.	2.59	0.48	0.60	8.76	14.50	0.51	0.07	0.13	0.27	0.01	0.01		240	5	12	12	519	16	9	16	BG	pinched lump	Mn Blue-green

Code	SiO_2	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	Colour	Identification	Assigned group
L19BRR	n.d.	2.43	0.48	0.56	7.60	15.57	0.62	0.08	0.16	0.49	0.01	0.01	251	15	13	13	408	21	8	21	BG	roundel	Mn Blue-green
L19BLUM	n.d.	2.45	0.42	0.61	9.79	16.22	0.62	0.08	0.13	0.14	0.01	0.01	209	6	11	12	518	12	10	19	BG	lump	Mn Blue-green
L19BR	n.d.	2.40	0.80	0.99	5.37	21.68	0.37	0.14	0.07	0.03	0.01	0.01	154	9	21	14	392	15	8	19	YBR	lump	Mn Blue-green
L19BDRI	n.d.	2.44	0.35	0.51	7.70	16.27	0.62	0.07	0.13	0.16	0.01	0.01	223	12	11	13	410	12	8	17	BG	drip	Mn Blue-green
L8BPIT	n.d.	2.27	0.32	0.39	6.75	17.95	0.75	0.07	0.12	0.18	0.01	0.01	212	7	16	12	356	10	8	15	BG	pitted frag	Mn Blue-green
M63YGHA	n.d.	2.55	0.41	0.54	8.24	17.58	0.63	0.07	0.14	0.03	0.01	0.01	216	5	17	11	426	9	9	18	Y	heat affected lump	No decol
M63YBR	n.d.	2.42	0.35	0.53	7.87	16.67	0.74	0.07	0.18	0.03	0.01	0.01	211	4	14	13	402	8	9	15	Y	vessel	No decol
M24YG	n.d.	2.43	0.37	0.52	8.06	17.15	0.61	0.07	0.14	0.04	0.01	0.00	208	6	17	11	419	8	9	26	YG	vessel	No decol
M24YG	n.d.	2.44	0.40	0.60	9.71	15.86	0.68	0.08	0.13	0.05	0.01	0.01	195	4	15	13	497	10	9	17	YG	vessel	No decol
M24YG	n.d.	2.48	0.41	0.61	9.74	16.42	0.67	0.08	0.13	0.05	0.01	0.01	200	4	14	12	507	10	10	18	YG	vessel	No decol
M65BOBU	n.d.	2.49	0.47	0.55	7.16	18.08	0.68	0.09	0.13	0.38	0.02	0.17	234	51	13	18	433	18	9	24	BG	bubbly frag	Sb-Mn recycled
M24BHAL	n.d.	2.40	0.45	0.54	7.62	17.76	0.64	0.08	0.13	0.40	0.02	0.15	233	43	17	20	440	17	9	29	BG	heat affected lump	Sb-Mn recycled
M24BHAL	n.d.	2.49	0.48	0.55	7.32	18.14	1.00	0.08	0.14	0.40	0.02	0.15	115	43	20	18	432	16	8	25	BG	heat affected lump	Sb-Mn recycled
M24CTR	n.d.	2.31	0.57	0.52	6.01	17.76	0.65	0.10	0.11	0.30	0.03	0.41	202	54	18	15	384	15	8	29	C	trail	Sb-Mn recycled
M63BVBU	n.d.	2.40	0.51	0.54	6.68	18.38	0.72	0.09	0.11	0.31	0.03	0.32	218	46	19	16	407	16	7	27	BG	bubbly frag	Sb-Mn recycled
M65BTR	n.d.	2.34	0.56	0.52	6.10	18.61	0.69	0.10	0.11	0.30	0.03	0.43	205	62	21	21	390	16	8	29	BG	trail	Sb-Mn recycled
M24BBOT	n.d.	2.34	0.54	0.52	6.11	18.78	0.69	0.10	0.11	0.31	0.03	0.41	209	45	16	15	387	17	8	25	BG	bottle	Sb-Mn recycled
M63BVBU	n.d.	2.37	0.54	0.54	6.60	18.15	0.70	0.10	0.11	0.32	0.03	0.35	215	52	18	16	408	16	8	30	BG	bubbly vess frag	Sb-Mn recycled
M64BBOT	n.d.	2.25	0.54	0.53	5.82	19.93	0.76	0.10	0.10	0.32	0.04	0.49	201	59	17	17	388	16	8	30	BG	bottle	Sb-Mn recycled
M63BBOT	n.d.	2.36	0.48	0.51	6.55	18.16	0.65	0.08	0.11	0.33	0.02	0.28	217	43	16	15	394	16	8	25	BG	bottle	Sb-Mn recycled
M63BBOT	n.d.	2.32	0.51	0.51	6.30	18.42	0.68	0.09	0.10	0.34	0.03	0.39	211	48	19	15	390	16	8	28	BG	bottle	Sb-Mn recycled
M63BBOT	n.d.	2.34	0.54	0.53	6.12	19.19	0.65	0.09	0.11	0.34	0.03	0.40	210	57	19	17	392	16	8	25	BG	bottle	Sb-Mn recycled
M63BSTA	n.d.	2.37	0.55	0.54	6.19	19.03	0.67	0.10	0.11	0.34	0.03	0.40	213	56	17	15	395	17	8	27	BG	worn frag	Sb-Mn recycled
M63BHAL	n.d.	2.47	0.53	0.55	6.55	18.55	0.75	0.09	0.12	0.35	0.04	0.31	225	61	20	15	411	17	8	28	BG	heat affected lump	Sb-Mn recycled
M63C	n.d.	2.30	0.56	0.55	6.09	18.70	0.71	0.11	0.12	0.35	0.04	0.47	207	142	17	19	400	18	8	52	C	vessel	Sb-Mn recycled
M63BBR	n.d.	2.48	0.52	0.55	6.78	19.01	0.71	0.09	0.12	0.36	0.03	0.29	229	54	17	19	420	17	9	35	BG	roundel	Sb-Mn recycled
M63BHAL	n.d.	2.48	0.55	0.55	6.64	18.76	0.75	0.09	0.12	0.36	0.04	0.32	225	64	19	18	411	17	8	30	BG	heat affected lump	Sb-Mn recycled
M63BBOT	n.d.	2.36	0.55	0.54	6.23	19.28	0.71	0.10	0.11	0.36	0.05	0.41	215	128	21	17	406	17	8	33	BG	bottle	Sb-Mn recycled
M24CCH	n.d.	2.32	0.55	0.55	6.10	19.19	0.74	0.11	0.11	0.36	0.04	0.45	209	63	17	16	410	19	8	29	C	chip	Sb-Mn recycled
M24BTR	n.d.	2.40	0.50	0.54	6.70	18.85	0.70	0.09	0.12	0.39	0.04	0.31	225	62	20	18	419	16	8	27	BG	trail	Sb-Mn recycled
M24BHAL	n.d.	2.36	0.49	0.53	6.71	17.69	0.68	0.09	0.13	0.40	0.04	0.31	217	78	18	14	409	17	8	26	BG	heat affected lump	Sb-Mn recycled
M63BCH	n.d.	2.50	0.46	0.50	6.83	17.46	0.79	0.08	0.15	0.40	0.02	0.08	229	232	17	16	388	15	8	26	BG	chip	Sb-Mn recycled
M63BHAL	n.d.	2.44	0.54	0.56	6.65	17.68	0.97	0.10	0.12	0.40	0.03	0.33	235	54	18	17	418	18	7	31	BG	heat affected lump	Sb-Mn recycled
M24CCH	n.d.	2.24	0.63	0.57	5.47	19.86	0.68	0.12	0.11	0.40	0.05	0.53	202	73	19	19	392	19	8	33	C	chip	Sb-Mn recycled
M64CTR	n.d.	2.31	0.56	0.56	6.17	19.49	0.70	0.11	0.12	0.41	0.05	0.47	214	124	20	16	412	18	8	32	C	trail	Sb-Mn recycled

Code	SiO_2	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	Colour	Identification	Assigned group
M63BOBU	n.d.	2.54	0.49	0.55	7.31	17.73	0.67	0.09	0.13	0.41	0.02	0.15		242	47	18	15	441	17	9	26	BG	bubbly frag	Sb-Mn recycled
M63BHAL	n.d.	2.42	0.49	0.51	7.00	16.32	0.93	0.08	0.14	0.42	0.03	0.13		230	37	15	17	414	17	8	23	BG	heat affected lump	Sb-Mn recycled
M24BSTA	n.d.	2.43	0.51	0.54	6.85	17.24	0.67	0.08	0.12	0.42	0.04	0.24		226	67	17	15	414	19	8	25	BG	worn frag	Sb-Mn recycled
M24BSTA	n.d.	2.43	0.48	0.50	7.03	17.65	0.72	0.08	0.14	0.42	0.06	0.08		226	130	13	16	397	15	8	24	BG	worn frag	Sb-Mn recycled
M63BT	n.d.	2.43	0.62	0.52	6.89	17.17	0.69	0.08	0.13	0.44	0.05	0.24		232	99	16	15	417	16	7	29	BG	pinched lump	Sb-Mn recycled
M63BTR	n.d.	2.38	0.55	0.55	6.73	17.37	0.76	0.08	0.16	0.44	0.04	0.15		227	142	16	18	398	15	8	28	BG	trail	Sb-Mn recycled
M63C	n.d.	2.33	0.51	0.56	6.49	18.92	0.69	0.10	0.12	0.44	0.04	0.37		224	68	16	17	427	20	8	27	C	chip	Sb-Mn recycled
M64BVBU	n.d.	2.45	0.51	0.53	6.96	17.43	0.69	0.09	0.14	0.45	0.03	0.16		234	80	16	17	420	17	7	28	BG	bubbly frag	Sb-Mn recycled
M24BRR	n.d.	2.41	0.63	0.53	6.84	17.77	0.76	0.08	0.16	0.45	0.03	0.12		229	165	18	19	405	15	8	29	BG	roundel	Sb-Mn recycled
M24BCH	n.d.	2.38	0.47	0.52	6.79	17.36	0.67	0.08	0.13	0.45	0.05	0.19		226	82	16	16	412	17	8	29	BG	chip	Sb-Mn recycled
M64BSTA	n.d.	2.31	0.61	0.59	5.83	19.82	0.74	0.12	0.12	0.46	0.05	0.47		216	81	19	17	415	20	8	34	BG	bubbly frag	Sb-Mn recycled
M64BCM	n.d.	2.42	0.52	0.56	6.93	17.59	0.72	0.09	0.14	0.47	0.02	0.24		232	70	17	18	425	19	8	31	BG	cyl moile	Sb-Mn recycled
M24BBOT	n.d.	2.38	0.66	0.62	5.95	19.56	0.85	0.12	0.16	0.48	0.11	0.52		220	143	21	21	416	19	8	34	BG	bottle	Sb-Mn recycled
M24BSTW	n.d.	2.41	0.49	0.57	6.79	17.75	0.70	0.09	0.15	0.48	0.05	0.21		226	100	15	16	419	18	8	28	BG	worn vess frag	Sb-Mn recycled
M24BFBU	n.d.	2.43	0.49	0.51	6.76	17.27	0.71	0.09	0.13	0.49	0.04	0.16		230	58	17	20	411	16	8	28	BG	bubbly vess frag	Sb-Mn recycled
M24BHAL	n.d.	2.46	0.47	0.52	7.03	17.48	0.67	0.08	0.14	0.49	0.04	0.17		235	70	17	18	423	16	8	30	BG	heat affected lump	Sb-Mn recycled
M63BLUM	n.d.	2.38	0.64	0.61	5.99	19.63	0.79	0.12	0.14	0.50	0.08	0.40		227	112	16	18	424	23	8	32	BG	rounded lump	Sb-Mn recycled
M63BBOT	n.d.	2.35	0.62	0.60	6.06	18.98	0.79	0.12	0.14	0.50	0.08	0.40		225	103	14	19	422	23	8	31	BG	bottle	Sb-Mn recycled
M63BBOT	n.d.	2.45	0.48	0.56	7.09	17.99	0.70	0.08	0.14	0.51	0.04	0.20		243	77	18	21	441	19	8	22	BG	bottle	Sb-Mn recycled
M64BCM	n.d.	2.41	0.67	0.62	6.18	18.33	0.81	0.12	0.14	0.52	0.08	0.41		230	111	19	18	426	22	8	35	BG	cyl moile	Sb-Mn recycled
M63BBOT	n.d.	2.44	0.54	0.57	6.53	18.58	0.68	0.10	0.12	0.52	0.05	0.27		232	78	17	18	429	19	8	25	BG	bottle	Sb-Mn recycled
M63BBOT	n.d.	2.34	0.66	0.60	6.02	17.88	0.78	0.12	0.15	0.53	0.09	0.37		224	133	17	19	416	22	8	35	BG	bottle	Sb-Mn recycled
M24BFBU	n.d.	2.62	0.62	0.61	7.01	17.30	0.88	0.10	0.16	0.55	0.03	0.24		248	59	20	18	428	24	9	29	BG	bubbly vess frag	Sb-Mn recycled
M24BVBU	n.d.	2.35	0.64	0.60	6.07	18.86	0.92	0.12	0.13	0.55	0.08	0.41		231	104	21	20	431	22	8	37	BG	bubbly vess frag	Sb-Mn recycled
M24BHAL	n.d.	2.40	0.54	0.54	7.14	16.87	0.79	0.08	0.13	0.56	0.05	0.31		242	72	24	20	438	19	8	25	BG	heat affected lump	Sb-Mn recycled
M63BTR	n.d.	2.77	0.58	0.50	7.33	16.10	0.68	0.08	0.14	0.57	0.01	1.00		248	31	16	19	440	16	8	27	BG	trail	Sb-Mn recycled
M63BHAL	n.d.	2.50	0.54	0.58	7.21	16.86	1.05	0.09	0.14	0.57	0.04	0.20		255	82	21	21	442	20	9	32	BG	heat affected lump	Sb-Mn recycled
M63BCH	n.d.	2.51	0.53	0.56	6.98	17.44	0.73	0.09	0.15	0.58	0.03	0.16		246	60	20	21	432	19	9	26	BG	chip	Sb-Mn recycled
M24BHAL	n.d.	2.46	0.49	0.54	6.82	18.07	0.75	0.08	0.13	0.60	0.04	0.17		240	68	18	20	430	18	8	27	BG	heat affected lump	Sb-Mn recycled
M24BRR	n.d.	2.45	0.48	0.55	6.84	17.73	0.76	0.09	0.14	0.62	0.05	0.19		243	81	15	20	432	18	9	29	BG	roundel	Sb-Mn recycled
M63BCM	n.d.	2.43	0.69	0.72	6.27	17.84	0.98	0.12	0.22	0.63	0.04	0.17		237	264	18	19	398	21	7	41	BG	cyl moile	Sb-Mn recycled
M63BFBU	n.d.	2.45	0.48	0.55	6.87	17.54	0.75	0.09	0.15	0.65	0.04	0.19		240	75	17	21	431	19	8	29	BG	bubbly frag	Sb-Mn recycled
M63BBOT	n.d.	2.49	0.48	0.55	7.08	17.99	0.76	0.09	0.15	0.65	0.04	0.16		247	66	18	22	444	19	8	28	BG	bottle	Sb-Mn recycled
M63CCM	n.d.	2.22	0.36	0.44	6.30	17.53	0.63	0.06	0.15	0.96	0.01	0.15		244	14	19	26	426	20	8	31	C	cyl moile	Sb-Mn recycled
M24BCM	n.d.	2.41	0.36	0.54	8.15	16.65	0.54	0.07	0.13	0.44	0.01	0.05		236	13	14	19	462	16	9	22	BG	cyl moile	Sb-Mn recycled

Code	SiO_2	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	Colour	Identification	Assigned group
M24BVBU	n.d.	2.40	0.44	0.55	7.74	17.60	0.67	0.07	0.15	0.66	0.01	0.07		242	30	16	22	472	18	9	30	BG	bubbly frag	Sb-Mn recycled
M63BRR	n.d.	2.42	0.36	0.47	7.31	17.76	0.62	0.07	0.13	0.24	0.01	0.05		234	22	16	12	413	13	8	19	BG	roundel	Sb-Mn recycled
M63BBOT	n.d.	2.49	0.44	0.60	7.66	16.60	0.87	0.08	0.17	0.34	0.02	0.04		227	57	17	19	422	15	9	26	BG	rounded lump	Sb-Mn recycled
M64BBOT	n.d.	2.47	0.49	0.54	7.77	17.27	0.81	0.08	0.16	0.34	0.03	0.04		238	251	18	16	413	13	9	26	BG	bottle	Sb-Mn recycled
M24CCH	n.d.	1.78	0.34	0.38	5.78	19.44	0.53	0.07	0.05	0.02	0.01	0.49		138	7	15	11	454	8	6	17	C	chip	Sb colourless
M24BBOT	n.d.	2.59	0.53	0.70	8.24	15.65	0.79	0.09	0.20	1.17	0.01	0.03		292	32	15	24	528	37	8	27	BG	bottle	High Mn
M64CBUB	n.d.	2.43	0.44	0.56	7.47	14.20	0.63	0.07	0.15	1.22	0.01	0.03		280	17	14	28	497	28	9	35	C	bubbly vess frag	High Mn
M24BCH	n.d.	2.59	0.37	0.46	7.57	15.71	0.56	0.07	0.16	0.07	0.01	0.01		212	5	13	12	397	9	8	18	BG	chip	Mn Blue-green
M63YG	n.d.	2.64	0.35	0.48	7.10	17.30	0.57	0.07	0.14	0.09	0.01	0.01		218	7	16	12	381	10	8	16	YG	vessel	Mn Blue-green
M63BHAL	n.d.	2.66	0.41	0.50	7.35	17.12	0.63	0.07	0.15	0.11	0.01	0.01		221	6	15	10	389	11	8	18	BG	heat affected lump	Mn Blue-green
M63BCM	n.d.	2.58	0.37	0.49	7.36	16.58	0.65	0.07	0.13	0.47	0.01	0.01		234	8	15	19	450	14	8	24	BG	cyl moile	Mn Blue-green
M63BFBU	n.d.	2.39	0.37	0.49	7.40	15.86	0.54	0.07	0.14	0.51	0.01	0.01		251	34	15	17	418	21	8	21	BG	bubbly frag	Mn Blue-green
M64BCM	n.d.	2.47	0.42	0.51	7.57	17.94	0.76	0.07	0.14	0.41	0.01	0.01		224	38	15	18	431	13	8	27	BG	cyl moile	Mn Blue-green
M63BVBU	n.d.	2.50	0.43	0.53	7.84	16.76	0.64	0.07	0.15	0.42	0.01	0.01		240	20	16	16	450	16	9	21	BG	bubbly frag	Mn Blue-green
M24BHAL	n.d.	2.68	0.38	0.59	8.47	16.14	1.54	0.07	0.14	0.42	0.01	0.01		274	17	16	20	495	16	9	17	BG	heat affected lump	Mn Blue-green
M24BHAL	n.d.	2.50	0.36	0.53	8.51	15.46	0.60	0.07	0.16	0.45	0.01	0.01		238	9	15	17	482	15	8	22	BG	pinched lump	Mn Blue-green
M63BCM	n.d.	2.67	0.34	0.49	6.94	18.04	0.54	0.06	0.11	0.44	0.01	0.01		258	17	14	13	414	14	8	18	BG	cyl moile	Mn Blue-green
M63BSTW	n.d.	2.43	0.37	0.50	7.51	17.24	0.66	0.07	0.14	0.44	0.01	0.01		221	34	14	18	431	13	8	21	BG	bubbly frag	Mn Blue-green
M63BSTA	n.d.	2.58	0.36	0.54	8.53	16.97	0.55	0.07	0.13	0.45	0.01	0.01		237	10	15	14	443	14	8	17	BG	bubbly frag	Mn Blue-green
M63BTR	n.d.	2.59	0.58	0.56	7.61	16.74	0.68	0.08	0.17	0.50	0.01	0.04		271	31	13	19	438	24	9	22	BG	trail	Mn Blue-green
M24BBOT	n.d.	2.53	0.45	0.61	8.44	17.75	0.79	0.08	0.17	0.67	0.01	0.01		253	10	15	19	488	19	9	24	BG	bottle	Mn Blue-green
M24BCH	n.d.	2.30	0.36	0.49	8.10	15.94	0.68	0.07	0.13	0.77	0.01	0.01		242	13	17	20	487	22	9	25	BG	chip	Mn Blue-green
M24BBOT	n.d.	2.38	0.34	0.47	7.35	17.22	0.56	0.06	0.11	0.78	0.01	0.01		254	14	14	22	487	19	9	26	BG	bottle	Mn Blue-green
M63BCH	n.d.	2.33	0.37	0.52	7.31	16.75	0.49	0.06	0.11	0.90	0.01	0.01		271	15	15	21	460	22	8	22	BG	chip	Mn Blue-green
M64GOP	n.d.	2.22	0.34	0.46	7.08	16.14	0.63	0.06	0.15	0.12	0.01	0.01		197	16	29	16	369	11	7	33	GOP	glass w/ pot	Mn Blue-green
M24BPIN	n.d.	2.58	0.37	0.54	7.57	16.11	0.61	0.07	0.14	0.14	0.01	0.01		218	11	13	14	409	12	8	18	BG	pinched lump	Mn Blue-green
M24BBOT	n.d.	2.58	0.37	0.48	7.45	17.03	0.60	0.07	0.14	0.15	0.01	0.01		210	12	14	12	402	10	8	18	BG	bottle	Mn Blue-green
M64BFBU	n.d.	2.63	0.36	0.48	7.26	16.35	0.50	0.06	0.11	0.15	0.01	0.01		227	19	13	13	402	11	8	20	BG	bubbly frag	Mn Blue-green
M63BCM	n.d.	2.32	0.37	0.51	7.51	16.27	0.69	0.07	0.13	0.21	0.02	0.01		208	18	15	17	413	12	9	28	BG	cyl moile	Mn Blue-green
M63BRR	n.d.	2.64	0.50	0.63	7.76	15.66	0.63	0.08	0.16	0.21	0.01	0.01		239	33	15	15	418	14	8	19	BG	roundel	Mn Blue-green
M63BHAL	n.d.	2.71	0.37	0.47	7.50	16.57	0.48	0.07	0.13	0.21	0.01	0.01		219	18	12	13	398	12	8	18	BG	heat affected lump	Mn Blue-green
M63BFBU	n.d.	2.59	0.35	0.49	7.40	16.00	0.57	0.07	0.13	0.24	0.01	0.01		222	16	15	15	407	13	7	31	BG	bubbly frag	Mn Blue-green
M63BCM	n.d.	2.27	0.38	0.48	7.88	16.28	0.52	0.07	0.14	0.26	0.01	0.01		230	31	15	15	421	16	9	19	BG	cyl moile	Mn Blue-green
M24BCM	n.d.	2.35	0.43	0.51	8.02	17.52	0.56	0.07	0.14	0.29	0.01	0.01		242	33	13	14	442	17	9	19	BG	cyl moile	Mn Blue-green
M24BRR	n.d.	2.63	0.46	0.47	7.25	16.26	0.59	0.07	0.12	0.30	0.01	0.01		222	6	15	17	426	11	8	23	BG	roundel	Mn Blue-green

Code	SiO_2	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	Colour	Identification	Assigned group
M63BBOT	n.d.	2.30	0.32	0.49	8.14	16.05	0.52	0.07	0.13	0.31	0.01	0.01	223	19	15	13	457	13	8	19	BG	bottle	Mn Blue-green
M63BBOT	n.d.	2.52	0.33	0.50	7.52	17.19	0.53	0.07	0.11	0.37	0.01	0.01	260	6	12	13	434	19	9	16	BG	bottle	Mn Blue-green
M63BHAL	n.d.	2.55	0.53	0.52	7.91	16.20	0.62	0.07	0.15	0.38	0.01	0.01	232	11	15	17	430	15	8	24	BG	heat affected lump	Mn Blue-green
GL 75	67.30	2.19	0.78	1.06	6.28	18.54	0.45	0.16	b.d.	1.52	0.08	<10	b.d	b.d	b.d	b.d	b.d	b.d	b.d	b.d	LG	Waste/cullet?	HIMT
GL 97	66.43	2.45	1.09	0.98	6.36	17.38	1.32	0.35	b.d.	1.64	0.09	60	b.d	b.d	b.d	b.d	b.d	b.d	b.d	b.d	LG	Vessel	HIMT
GL 98	67.46	2.13	0.67	0.77	6.32	18.58	0.63	0.10	b.d.	0.98	0.10	740	b.d	b.d	b.d	b.d	b.d	b.d	b.d	b.d	LG	Vessel	HIMT
GL 152	66.56	2.20	0.78	0.80	6.44	18.90	0.71	0.13	b.d.	1.10	0.08	290	b.d	b.d	b.d	b.d	b.d	b.d	b.d	b.d	YG	Vessel	HIMT
GL 199	66.67	2.30	1.02	0.92	6.40	18.34	0.57	0.23	b.d.	1.53	0.12	230	b.d	b.d	b.d	b.d	b.d	b.d	b.d	b.d	YG	Vessel	HIMT
GL 254	67.70	2.28	0.74	0.73	6.65	17.96	0.67	0.13	b.d.	0.93	0.10	240	b.d	b.d	b.d	b.d	b.d	b.d	b.d	b.d	LB	Vessel	Mn Blue-green
GL 364	66.54	2.36	0.65	0.88	7.15	18.38	0.43	0.11	b.d.	1.09	0.10	<10	b.d	b.d	b.d	b.d	b.d	b.d	b.d	b.d	YG	Vessel	HIMT
2011 401*	67.84	2.41	0.85	0.53	8.73	15.77	0.72	0.08	b.d.	0.64	0.06	110	b.d	b.d	b.d	b.d	b.d	b.d	b.d	b.d	DB	Vessel	Levantine
2011 106	66.22	2.39	1.32	0.98	6.16	18.16	0.70	0.33	b.d.	1.67	0.06	20	b.d	b.d	b.d	b.d	b.d	b.d	b.d	b.d	LG	Thread	HIMT
GL 6	65.03	2.56	1.04	0.90	6.72	15.48	4.90	0.27	b.d.	1.29	0.06	140	b.d	b.d	b.d	b.d	b.d	b.d	b.d	b.d	YG	Thread	HIMT
GL 126	66.50	2.22	0.97	0.88	6.67	18.32	0.59	0.23	b.d.	1.43	0.10	140	b.d	b.d	b.d	b.d	b.d	b.d	b.d	b.d	LG	Chunk	HIMT
GL 121	66.96	2.70	1.54	1.05	4.59	18.03	0.51	0.40	b.d.	2.12	0.08	<10	b.d	b.d	b.d	b.d	b.d	b.d	b.d	b.d	YG	Chunk	HIMT
GL 120	72.14	2.47	0.36	0.40	7.90	13.94	0.82	0.08	b.d.	0.05	0.12	<10	b.d	b.d	b.d	b.d	b.d	b.d	b.d	b.d	YG	Chunk	Levantine
GL 83	66.34	2.41	1.33	1.14	5.98	18.21	0.39	0.23	b.d.	1.79	0.08	<10	b.d	b.d	b.d	b.d	b.d	b.d	b.d	b.d	YG	Chunk	HIMT
GL 79	65.98	2.52	1.42	0.95	5.95	18.29	0.51	0.42	b.d.	1.89	0.09	<10	b.d	b.d	b.d	b.d	b.d	b.d	b.d	b.d	YG	Lump	HIMT
GL 115	65.61	2.41	1.31	0.83	6.49	18.51	0.49	0.35	b.d.	1.96	0.04	<10	b.d	b.d	b.d	b.d	b.d	b.d	b.d	b.d	YG	Lump	HIMT
GL 128	66.96	2.26	0.79	0.77	6.67	18.41	0.77	0.11	b.d.	1.01	0.09	470	b.d	b.d	b.d	b.d	b.d	b.d	b.d	b.d	BG	Lump	HIMT
GL 10	66.47	2.30	1.05	0.94	6.26	17.92	1.18	0.30	b.d.	1.55	0.07	250	b.d	b.d	b.d	b.d	b.d	b.d	b.d	b.d	YG	Lump	HIMT
GL 400**	69.33	2.22	0.86	0.54	6.54	17.01	0.67	0.09	b.d.	0.27	0.15	3200	b.d	b.d	b.d	b.d	b.d	b.d	b.d	b.d	BG	Waste/cullet?	Sb-Mn recycled
GL 139	66.91	2.32	1.09	0.94	6.43	17.83	0.61	0.22	b.d.	1.46	0.11	240	b.d	b.d	b.d	b.d	b.d	b.d	b.d	b.d	LG	Thread	HIMT
GL 88	66.87	2.22	0.88	0.87	6.41	18.44	0.54	0.17	b.d.	1.40	0.05	80	b.d	b.d	b.d	b.d	b.d	b.d	b.d	b.d	YG	Lid moile	HIMT
GL 108	67.00	2.31	1.06	0.97	6.31	17.64	0.64	0.32	b.d.	1.59	0.12	180	b.d	b.d	b.d	b.d	b.d	b.d	b.d	b.d	YG	melting pot fragment	HIMT
GL 7	65.95	2.75	1.08	1.04	8.03	17.17	0.80	0.27	b.d.	1.56	0.04	70	b.d	b.d	b.d	b.d	b.d	b.d	b.d	b.d	YG	melting pot fragment	HIMT
GL 111	66.52	2.23	0.89	0.88	6.54	18.42	0.84	0.24	b.d.	1.33	0.11	150	b.d	b.d	b.d	b.d	b.d	b.d	b.d	b.d	YG	Moile	HIMT
GL 33	65.58	2.49	1.79	1.01	5.47	18.33	0.41	0.61	b.d.	2.21	0.10	<10	b.d	b.d	b.d	b.d	b.d	b.d	b.d	b.d	YG	Moile	HIMT
GL 244	66.52	2.26	0.93	0.85	6.43	18.64	0.58	0.23	b.d.	1.40	0.08	150	b.d	b.d	b.d	b.d	b.d	b.d	b.d	b.d	LG	Moile	HIMT

Appendix 1. Compositions of the samples analysed. SiO_2 (silica) was not analysed by ICPS as it was lost in dissolution. Key: Identification (cyl= cylindrical, waste = unidentified melted mass, chip – broken fragment (not part of vessel), roundel = rounded 'button' associated with glass melting/blowing). Sb_2O_5* (reported as elemental Sb in ppm for St Algars; independently analysed by ICP-MS, reported to nearest 10ppm).

DENKMALPFLEGE IM SAARLAND 11 - RÖMISCHE GLASÖFEN | *ROMAN GLASS FURNACES*

VILLA BORG

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